NX-Hivac USER'S MANUAL

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Preface

The Scanning Probe Microscope (SPM) is not only leading the list of equipment pioneering the nano scale world, it is also the most fundamental technology. Subsequent to the first generation optical microscope, and the second generation electron microscope, the SPM has every right to be recognized as a “third generation” microscope since it enables users to experience and have a glimpse of the nano scale world. In addition, it has significant advantages compared with manual microscopes which passively observe samples. The SPM is like a miniature robot, fabricating specific structures by manipulating atoms on the sample surface and using a probe tip to take measurements of those structures.

The SPM originated with the invention of the Scanning Tunneling microscope (STM). The STM uses a tunneling current between a probe tip and a sample in a vacuum state to measure surface topography. As a result, it is limited ~~in~~ that it can only measure conductor or a semiconductor sample. Once the Atomic Force Microscope (AFM) was developed, however, a whole new range of measurement capabilities became possible. Now, it is not only capable to measure non-conductors in air, but also capable to measure the physical, chemical, mechanical, electrical, and magnetic properties of a sample’s surface, and even measure live cells in solution.

The SPM is indeed the key toward the world of nano technology that has yet to flourish. Also, it is an essential equipment for various researches in the field of basic sciences – physics, chemistry, and biology - and in applied industry - mechanical and electrical engineering.

The importance of the SPM attests to grow greater and greater in the future.

Safety Precautions of System

This preview section describes some safety requirements and procedures related to the general operating of the NX-Hivac in detail. This section should be thoroughly understood before operating the NX-Hivac for your safety.

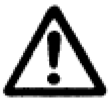
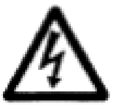
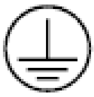
CAUTION!

If the user operates the NX-Hivac in a manner not specified in this User's Manual, serious damage to the instrument may result.

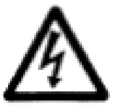
1. Hazard Labels

On the NX-Hivac system, there are hazard labels on the position for hazard possibilities. Caution must be taken for the each hazard label warning.

Table. Hazard label List

Symbol	Description
│	**“ON” (power)** To indicate connection to the mains, at least for main switches or their positions, and all those cases where safety is involved.
○	**“OFF” (power)** To indicate disconnection from the mains, at least for main switches or their positions, and all those cases where safety is involved.
	**“Caution, Risk of Danger”** This symbol denotes conditions or activities that could cause damage to the equipment.
	**“Caution, Risk of Electric Shock”** This symbol denotes conditions or activities that could cause electrical shock or burns.
	“**Protective Earth(Ground)”** This symbol denotes a need for protective grounding of equipment.

1-1. Electrical Hazard Label



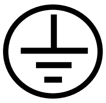
The Electrical Hazard label notifies the area that might cause electrical damage to the system of to the personnel. Care must be taken.

The Electrical Hazard label is attached to the areas listed below.

- **AFM Controller**
- **NX-Hivac Controller**

- **AFM Head**
- **XY scanner**
- **Computer**
- **Monitor**

1-2. Protective Ground label



The protective ground label indicates that this equipment needs to be electrically grounded.

2. Operating Safety

2-1. Definition of safety symbols

Table shown below explains the meaning of the safety symbols – **WARNING**, **CAUTION**, **NOTE**.

Table. Safety terms and their meanings

Symbols	Meaning
WARNING!	Alerts Users to potential danger. Consequences and countermeasures are described. If users fail to follow the procedures described in this manual, serious injury or instrument damage may occur. Such damage will NOT be covered by warranty.
CAUTION!	Calls attention to possible damage to the system that may result if users do not follow the procedures described in this manual.
NOTE!	Draws attention to a general procedure that is to be followed.

Please understand these safety terms thoroughly, and follow the associated instructions. It is important that you read all safety terms very carefully. **WARNING**s, **CAUTION**s, and **NOTE**s include information that, when followed, ensure the operating safety of your NX system.

2-2. General Operating Safety

The following are most of the **WARNING**s, **CAUTION**s, and **NOTE**s necessary to operate the NX-Hivac safely.

WARNING!

The NX-Hivac should be grounded before its components are connected to electric power. The main power plug needs to be connected to a three-prong outlet which includes a protective earth ground contact.

WARNING!

Before the power is turned on, the power selections for the individual components need to be inspected. The voltage selector switch is located on the rear panel of the NX-Hivac Control Electronics, and it can be set to the following voltages: 100 V, 120 V, 230 V, or 240 V.

WARNING!

Do not open the NX-Hivac Control Electronics or the AFM head. Doing so may result in serious electrical shock, as high voltages and electrostatic sensitive components are used in the NX-Hivac Control Electronics and the AFM head.

WARNING!

Be cautious when loading large modules such as EC Cell or ULC onto the NX sample chuck. They may collide with the motorized XY stage when it is moved through a large range, and the modules and/or NX system may be damaged.

CAUTION!

Check regularly to ensure that the NX-Hivac’s cables are free from damage and that all connections are secure. If any damaged cables or faulty connections are found, contact your local Park Systems service representative. Never try to operate the equipment under these conditions.

CAUTION!

All parts in the NX-Hivac system should be handled with extreme care. If not handled properly, these parts can be easily damaged as they are made of fragile electromagnetic equipment.

CAUTION!

An EMI filter must be installed to maintain operating safety and meet EMC (Electromagnetic Compatibility Compliance).

CAUTION!

The AFM head should always be handled with care. When removed from the AFM, the AFM head needs to be carefully placed on a flat surface. This will protect the scanner, the cantilever, and the beam alignment knobs. Never allow anything to impact the AFM head. When separated from the main frame, it is safe to keep the head in its storage box.

CAUTION!

Before the AFM head is mounted or unmounted from the Z stage, the on/off switch for the AFM beam must be turned off. Otherwise, the AFM beam diode in the AFM head may be damaged.

CAUTION!

When the AFM head is mounted or unmounted from the Z stage, ensure that the AFM head does not sustain any damage, and that it is properly grounded. The AFM head is extremely sensitive to electrostatic discharge.

CAUTION!

To meet the EMC guidlines, the Acoustice Enclosure should be closed while making measurements with the NX-Hivac.

3. Compliance

3-1. FCC

FCC Label(Part 15 sec.15.19)

Contents

CHAPTER 1. INTRODUCTION TO NX-HIVAC......................................1

1-1. Scanning Probe Microscope......................................1
1-2. Atomic Force Microscope......................................1
1-3. Park Systems AFM......................................5

CHAPTER 2. COMPONENTS OF NX-HIVAC......................................11

2-1. NX-Hivac Main System......................................12
2-2. AFM Control Electronics......................................21
2-3. The Park NX-Hivac Controller......................................27
2-4. Computer & Monitor......................................27
2-5. Acoustic and Vibration Isolation System......................................27
2-6. Specifications......................................30

CHAPTER 3. INSTALLATION......................................32

3-1. Environment......................................32
3-2. Component List......................................36
3-3. Uncrate......................................37
3-4. System Setup......................................38
3-6. System Relocation......................................46

CHAPTER 4. CANTILEVER SELECTION......................................47

4-1. Cantilever Characteristics......................................47
4-2. Cantilever Selection......................................49
4-3. Cantilever Mounting......................................50
4-4. Cantilever DB......................................57
4-5. Cantilever Storage......................................60
4-6. SLD Detector Chip Carrier......................................61

CHAPTER 5. OPERATION PROCEDURE......................................63

5-1. Basic Procedure......................................63
5-2. Sample Loading......................................79
5-3. Operating Concept......................................82
5-4. Maintenance......................................87

CHAPTER 6. AFM IN CONTACT MODE......................................97

6-1. Principle of Contact Mode AFM 97
6-2. Contact mode setup 98
6-3. Cantilever Selection....99
6-4. Measurement Procedure 100

CHAPTER 7. LATERAL FORCE MICROSCOPY (LFM)....101

7-1. Principle of Lateral Force Microscopy (LFM)....101
7-2. Conversion to LFM 104
7-3. Cantilever Selection....104
7-4. Measurement Procedure 104

CHAPTER 8. AFM IN NON-CONTACT MODE 105

8-1. Principle of Non-contact Mode AFM 105
8-2. Non-contact mode setup....108
8-3. Resonant Frequency setup 109
8-4. Cantilever selection 110
8-5. Measurement Procedure 111

CHAPTER 9. TAPPING MODE....113

9-1. Principle of Tapping mode 113
9-2. Conversion to Tapping mode 115
9-3. Resonant Frequency setup 116
9-4. Cantilever Selection....117
9-5. Measurement Procedure 117

CHAPTER 10. APPROACH SPECTROSCOPY 118

10-1. Spectroscopy Parameters View 125
10-2. Spectroscopy Positions View....133
10-3. Data View....136
10-4. Spectroscopy Data List View 138
10-5. FD Spectroscopy 139
10-6. IV Spectroscopy....142
10-7. Indenter 144
10-8. AD Spectroscopy 148
10-9. TA Spectroscopy....150
10-10. General Procedure for Spectroscopy measurement....153

CHAPTER 11. Q CONTROL MODE 187

11-1. Principle of Q Control Mode 187
11-2. Q Control User Interface 191
11-3. Q Control Procedure 193

CHAPTER 12. MAGNETIC FORCE MICROSCOPY (MFM) **195**

12-1. Principle of Magnetic Force Microscopy 195
12-2. Components 198
12-3. Setup. 198
12-4. Operation 201
12-5. Practice 205
12-6. Advanced Application 206

CHAPTER 13. FORCE MODULATION MICROSCOPY (FMM) **211**

13-1. Principle of Force Modulation Microscopy 211
13-2. Operation 213

CHAPTER 14. ELECTROSTATIC FORCE MICROSCOPY (EFM) **218**

14-1. Principle of Electrostatic Force Microscopy 219
14-2. Setup 228
14-3. Software UI 230
14-4. Operation 235
14-5. Practice 244
14-6. Advanced Application 251

INDEX **258**

Figure contents

Figure 1-1. Diagram of Conventional AFM’s Scanning 2

Figure 1-2. Nonlinearity and Hysteresis (a), and Cross Coupling (b) Observed in Piezoelectric Tube Scanners 4

Figure 1-3. Z Scanner Separated from X-Y scanner... 5

Figure 1-4. Background Flatness Images from a Conventional AFM (a) and Park Systems AFM (b) 6

Figure 1-5. Beam path related to the cantilever’s movement 7

Figure 1-6. Captured Optical Microscope Image 7

Figure 1-7. Lock Head 8

Figure 1-8. SmartScan™ - Data Acquisition Program... 9

Figure 1-9. XEI - Image Processing Program.. 9

Figure 2-1. NX-Hivac System 11

Figure 2-2. NX-Hivac Scanning Probe Microcope 12

Figure 2-3. Standard Head 13

Figure 2-4. Structure of NX-Hivac Head 14

Figure 2-5. Attach Probehand 14

Figure 2-6. Z scanner Assembly 15

Figure 2-7. Removing NX-Hivac Head 16

Figure 2-8. Beam Detection.. 17

Figure 2-9. Beam & PSPD Alignment Knobs... 18

Figure 2-10. XY scanner... 19

Figure 2-11. Optical Microscope of NX-Hivac.. 21

Figure 2-12. Control Electronics (Rear View) 21

Figure 2-13. Standard Scanning 24

Figure 2-14. Change Power.. 25

Figure 2-15. AVIS isolation unit and performance data 28

Figure 2-16. AVIS Controller (left: front, right: rear).. 29

Figure 3-1. Vibration Criteria Graph 34

Figure 3-2. NX-Hivac System dimension and recommended clearance (Top view) 35

Figure 3-3. Acoustic Enclosure Bottom 38

Figure 3-4. NX-Hivac main system placed on an AVIS 39

Figure 3-5. NX-Hivac System setup.. 39

Figure 3-6. NX-Hivac Main System Cables..40
Figure 3-7. Cabling NX-Hivac Main System...41
Figure 3-8. Cabling NX-Hivac control electronics...41
Figure 3-9. Cabling the Park NX-Hivac controller 42
Figure 3-10. System rear view 43
Figure 3-11. Components Setup..44
Figure 3-12. Part Config window 45
Figure 3-13. Reset the motorized Stages...46
Figure 4-1. Cantilever Chip 47
Figure 4-2. SEM image of silicon cantilever...48
Figure 4-3. Tip Convolution 50
Figure 4-4. Glue Type Chip Carrier..50
Figure 4-5. Loading Cantilever Chip on Glue Type Chip Carrier.........................51
Figure 4-6. Cantilever Chip Positioned on Glue Type Chip Carrier 51
Figure 4-7. Correct Mounting of Cantilever Chip..52
Figure 4-8. Structure of Clip Type Chip Carrier 53
Figure 4-9. Cantilever Exchanger..54
Figure 4-10. Placing Clip Type Chip Carrier on Cantilever Exchanger................54
Figure 4-11. Adjust Clip Position..55
Figure 4-12. Mount Cantilever Chip...55
Figure 4-13. Correct Mounting of Cantilever Chip..56
Figure 4-14. Probe Hand before (left) and after (right) Chip Carrier is attached......56
Figure 4-15. Create Cantilever DB 57
Figure 4-16. Input Cantilever Specification 58
Figure 4-17. VERTICAL Sensitivity Calibration 60
Figure 4-18. (Left) Beam position when using SLD detector Chip Carrier, (Right) Beam position when using Standard Chip Carrier...61
Figure 4.19. (Left) Standard Probehand, (Right) with the SLD detector chip carrier attached. 61
Figure 4-20. SLD beam on the Detector Chip Carrier 62
Figure 5-1. The Park NX-Hivac Manager™user interface of the Park NX-Hivac system..64
Figure 5-2. UI of the Valve condition..64
Figure 5-3. UI of the Control Panel..64
Figure5-4. The SmartScan™user interface of the Park NX-Hivac system 66
Figure 5-2. Removing NX-Hivac Head...68

Figure 5-3. Load Cantilever onto Probehand.. 69
Figure 5-4. Part Selection Dialog 69
Figure 5-5. Focus On Cantilever.. 71
Figure 5-6. Focus On Cantilever.. 72
Figure 6-7. Focus on Sample/Cantilever Positon 75
Figure 5-8. Channel Config.. 76
Figure 5-9. Proper Gain (top); Noise from Excessive Gain (bottom) 78
Figure 5-10. Magnetic Sample Holder.. 80
Figure 5-11. Instant Adhesive 81
Figure 5-12. Tape 81
Figure 5-13 Air between Sample and Tape... 81
Figure 5-14. XY Servo scan is ON 82
Figure 5-15. Scanner’s observable area 83
Figure 5-16. Standrad Scanning 84
Figure 5-17. Data Export 86
Figure 5-18. The maintenance mode workspace.. 88
Figure 5-19. Z Scanner calibration setup 89
Figure 5-20. XY scanner calibration setup 91
Figure 5-21. XY scanner calibration example... 91
Figure 5-22. Cantilever calibration setup.. 94
Figure 5-23. Sweep Result workspace... 96
Figure 5-24. Horizontal Axis button with Driving Channel selected 96
Figure 6-1. Relation between the force and the distance between atoms 98
Figure 6-2. SEM image of the shorter cantilevers (A, B, C) from a chip of the PPP-CONTSCR series.. 99
Figure 6-3. Silicon chip of the NSC36 series has 3 rectangular cantilevers.......... 100
Figure 7-1. Quad-cell PSPD 101
Figure 7-2. AFM and LFM signal... 102
Figure 7-3. Setup for LFM mode 104
Figure 8-1. Concept diagram of contact mode and non-contact mode 106
Figure 8-2. Resonant frequency 107
Figure 8-3. (a) Resonant frequency shift (b) Amplitude vs Z-feedback................. 108
Figure 8-4. Resonant Frequency setup in Non-Contact Mode 109
Figure 8-5. SEM image of ULTRASHARP silicon cantilever (the PPP-NCHR series) 111
Figure 8-6. Silicon chip of the NCHR series has 1 rectangular cantilever............. 111

Figure 9-1. Resonant frequency 113
Figure 9-2. (a) Resonant frequency shift (b) Amplitude vs. Z-feedback 114
Figure 9-3. Conversion to Tapping mode 116
Figure 9-4. Resonant frequency setup in Tapping mode 117
Figure 10-1. Spectroscopy Control workspace 118
Figure 10-2. Vision View and expanded Vision View 119
Figure 10-3. Monitor View 120
Figure 10-4. Quad-cell PSPD 122
Figure 10-5. Z scanner bar 123
Figure 10-6. Channels tab 124
Figure 10-7. Spectroscopy control workspace 124
Figure 10-8. Spectroscopy parameter View 125
Figure 10-9. Spectroscopy Options dialog 127
Figure 10-10. Spectroscopy calibration menu 129
Figure 10-11. Cantilever Sensitivity Calibration window 130
Figure 10-12. Cantilever Spring Constant Calibration window 131
Figure 10-13. Force Slope Calibration window 132
Figure 10-14. NCM Amplitude Calibration window 132
Figure 10-15. Spectroscopy Positions 133
Figure 10-16. Moving a spectroscopy point. Left: original position and movement direction; right: final position after move. 134
Figure 10-17. Moving all spectroscopy points. Left: original position and movement direction; right: final position after move. 135
Figure 10-18. Point grid setup and grid box 135
Figure 10-19. Point List setup (Left) and Point Grid setup (Right) 136
Figure 10-20. Data View Axis menu 137
Figure 10-21. Cursor pop-up box 137
Figure 10-22. Single cursor example 137
Figure 10-23. Copy menu pop-up box 137
Figure 10-24. Spectroscopy data axis 139
Figure 10-25. FD spectroscopy parameters 139
Figure 10-26. IV Spectroscopy parameters 142
Figure 10-27. Indenter control window 144
Figure 10-28. Scanner movement during indentation 146
Figure 10-29. Load/Unload ratio control 146
Figure 10-30. Scanner direction 147

Figure 10-31. AD spectroscopy control window 148
Figure 10-32. Thermal analysis spectroscopy control window 150
Figure 10-33. SThM Reference Calibration 152
Figure 10-34. Z Servo Config 152
Figure 10-35. Turn OFF the Line Scan 153
Figure 10-36. Select Cantilever 154
Figure 10-37. Select Contact mode 154
Figure 10-38. Select Spectroscopy mode 155
Figure 10-39. Set the parameters for FD Spectroscopy Options 155
Figure 10-40. Clicking the FD Start button 156
Figure 10-41. Add points to a list 156
Figure 10-42. How to use map 157
Figure 10-43. Set the Parameters in the FD spectroscopy 157
Figure 10-44. Acquire FD spectroscopy data 158
Figure 10-45. Open the Calibration features 159
Figure 10-46. Cantilever Sensitivity Calibration 159
Figure 10-47. Spring Constant Calibration 159
Figure 10-48. Turn OFF the Line Scan 160
Figure 10-49. Select Cantilever 161
Figure 10-50. Select CP-AFM mode 161
Figure 10-51. Adjust the Current Amplifier parameters 162
Figure 10-52. Clicking Spectroscopy button with setting to IV Convertor gain 163
Figure 10-53. Set the parameters for IV Spectroscopy Options 164
Figure 10-54. Clicking the IV Start button 164
Figure 10-55. Add points to a list 165
Figure 10-56. How to use map 165
Figure 10-57. Set the Parameters in the IV spectroscopy 166
Figure 10-58. Acquire IV spectroscopy data 166
Figure 10-59. Turn OFF the Line Scan 167
Figure 10-60. Select Cantilever 168
Figure 10-61. Select Contact mode 168
Figure 10-62. Clicking Spectroscopy button 169
Figure 10-63. Set the parameters for Indentation Spectroscopy Options 170
Figure 10-64. Clicking the Indentation Start button 170
Figure 10-65. Add points to a list 171
Figure 10-66. How to use map 171

Figure 10-67. Set the Parameters in the Indentation spectroscopy 172
Figure 10-68. Acquire Indentation spectroscopy data 172
Figure 10-69. Turn OFF the Line Scan 173
Figure 10-70. Select Cantilever 174
Figure 10-71. Select NCM mode 174
Figure 10-72. Clicking Spectroscopy button.. 175
Figure 10-73. Set the parameters for AD Spectroscopy Options 176
Figure 10-74. Clicking the AD Start button 176
Figure 10-75. Add points to a list 177
Figure 10-76. How to use map 177
Figure 10-77. Set the Parameters in the AD spectroscopy.................................. 178
Figure 10-78. Acquire AD spectroscopy data 178
Figure 10-79. Turn OFF the Line Scan 179
Figure 10-80. Select Cantilever 180
Figure 10-81. Select SThM mode.. 180
Figure 10-82. Adjust the Variable resistor 181
Figure 10-83. Clicking Spectroscopy button.. 181
Figure 10-84. Set the parameters for TA Spectroscopy Options 182
Figure 10-85. Clicking the TA Start button... 182
Figure 10-86. Add points to a list 183
Figure 10-87. How to use map 183
Figure 10-88. Set the Parameters in the TA spectroscopy.................................. 184
Figure 10-89. Acquire TA spectroscopy data... 184
Figure 10-90. A-B vs Probe Current 185
Figure 10-91. SThM Error vs Probe Current 185
Figure 10-92. SThM reference calibration... 186
Figure 10-93. A-B vs SThM Temperature.. 186
Figure 11-1. Schematic diagram of Non Contact Mode 188
Figure 11-2. Phase shift between driving signal and output signal........................ 188
Figure 11-3. Phase change 188
Figure 11-4. Output signal after phase shift 189
Figure 11-5. Schematic diagram in Non Contact Mode with Q Control 189
Figure 11-6. Modulation Amplitude Change according to gain (Left: Before Initial Calibration, Right: After Initial Calibration) 190
Figure 11-7. Frequency Sweep Window with Q Control 191
Figure 11-8. Q Control using Q amplify test field(Left: -0.05, Right: 0.05) 192

Figure 11-9. Modulation Amplitude Change according to gain (Left: Before Initial Calibration, Right: After Initial Calibration) 192
Figure 11-10. Deactivate Q Control 193
Figure 12-1. Process of the SPM imaging 196
Figure 12-2. Scanning process in MFM mode 197
Figure 12-3 Obtained signals in MFM mode 197
Figure 12-4. Required Components 198
Figure 12-5. Magnetizing the MFM tip 199
Figure 12-6. Exchanging the Sample Holder 200
Figure 12-7. Sample Loading 200
Figure 12-8. Selecting the Head Mode and cantilever type 201
Figure 12-9. Select the NCM Sweep 202
Figure 12-10. Scan Control window of MFM mode 202
Figure 12-11. Selecting the Input Signal 203
Figure 12-12. Selecting the monitoring signal in trace control window 203
Figure 12-13. Surface Height and Magnetic domain of the standard sample (20μm x 20 μm scan size) 205
Figure 12-14. PPP-MFMR NCM Frequency Sweep data 206
Figure 12-15. Example of MFM signal interference in Height image 207
Figure 12-16. Sample from Figure2, improved scan result 207
Figure 12-17. Example of Height signal interference in MFM image 208
Figure 12-18. Sample from Figure4, improved scan result 208
Figure 12-19. Sample with weak magnetic force 209
Figure 13-1. Oscillating deflection of the cantilever 212
Figure 13-2. FMM Amplitude and FMM Phase Signal 213
Figure 13-3. Changing the Head mode and select the cantilever 214
Figure 13-4. Select the Channel Config 214
Figure 13-5. Adjust to Set point 215
Figure 13-6. Adjust to Drive 215
Figure 13-7. NCM Frequency sweep 216
Figure 13-8. The trace control windows 217
Figure 14-1. Process of the EFM imaging 219
Figure 14-2. Diagram of 1) EFM, 2) EFM-DC (PFM) 221
Figure 14-3. (a) Surface height, (b) Surface charge image of TGS single crystal by EFM-DC, (c) Surface height, (d) Surface charge image by conventional EFM 222
Figure 14-4. (Left)Surface Height, (Right)Surface Potential 228

Figure 14-5. Sample Preparation..229
Figure 14-6. Cantilever Preparation..229
Figure 14-7. Scan Control Window (Left: EFM, Center: EFM-DC, Right: PFM) 230
Figure 14-8. Tip Bias Servo...230
Figure 14-9. Tip Bias..231
Figure 14-10. Lock-in Window...232
Figure 14-11. Lock-in Setup in EFM 235
Figure 14-12. Head Mode Setup 236
Figure 14-13. Lock-in Setup in EFM-DC..237
Figure 14-14. Head Mode Setup 237
Figure 14-18. Trace mode..241
Figure 14-19. Centering the Trace Curve 242
Figure 14-20. Tip Bias Servo...242
Figure 14-21. Use Phase Only in Tip Bias Servo 243
Figure 14-22. EFM Test Sample...244
Figure 14-23. Expected results of the test sample 245
Figure 14-24. Actual Height and EFM image of the test sample..........................246
Figure 14-25. EFM-DC Test Sample..247
Figure 14-26. PFM Image of Test Sample 248
Figure 14-27. PFM Image of Test Sample domain switching..............................248
Figure 14-28. HOPG 249
Figure 14-29. Expected results of the test sample 250
Figure 14-30. Z Height line profiles according to Drive voltage; Drive voltage = a) 5V, b) 1V 252
Figure 14-39. Line profiles of SKPM Potential Images 256
Figure 14-40-a. Tip bias servo gain=0.1 257
Figure 14-40-b. Tip bias servo gain=0.05 257
Figure 14-40-c Tip bias servo gain=0.01..257

Chapter 1. Introduction to NX-Hivac

1-1. Scanning Probe Microscope

The Scanning Probe Microscope (SPM) proved a prevailing concept wrong, that an atom is too small to be observed with even the best microscope. Now, it has every right to be identified as the third generation microscope, with optical and electron microscopes being the first and second generations respectively. Whereas the maximum magnifying power of an optical microscope is several thousands and that of a scanning electron microscope (SEM) is tens of thousands, an SPM has the magnifying power of tens of millions, enough to observe individual atoms. Even though a transmission electron microscope (TEM) has the lateral resolution high enough to image at the atomic level, its vertical resolution is much weaker at observing individual atoms. On the other hand, the vertical resolution of SPM is even better than its horizontal resolution, making it possible to measure on the scale of fractions of the diameter of an atom (0.01nm).

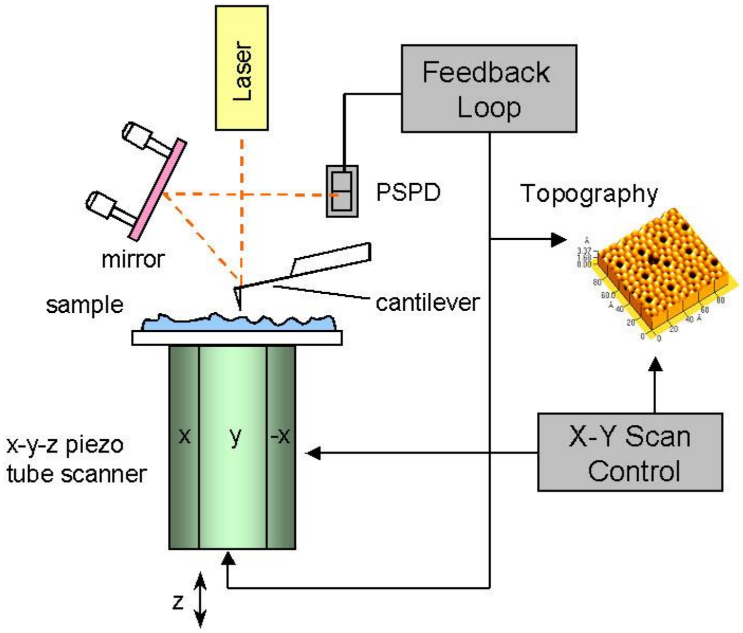
The SPM, with its exceptional resolution, not only makes it possible to understand the various nano scale worlds which heretofore were not completely revealed, but also brings the unbelievable into reality. It provides such capabilities as allowing a user to change the position of individual atoms or to write letters by transforming the surface of a material at the atomic level.

1-2. Atomic Force Microscope

Among SPMs, the first to be invented was the Scanning Tunneling Microscope (STM). The STM measures the tunneling current between a sharp, conducting tip and a conducting sample. The STM can image the sample’s topography and also measure the electrical properties of the sample by the “tunneling current” between them.

The STM technique, however, has a major disadvantage in that it cannot measure non-conducting material. This problem has been solved by the invention of the Atomic Force Microscope (AFM) which may be used to measure almost any sample, regar dless of its electrical properties. As a result, the AFM has greatly extended the SPM's applicability to all branches of scientific research.

Figure 1-1. Diagram of Conventional AFM's Scanning



Instead of a conducting needle, the AFM uses a micro-machined cantilever with a sharp tip to measure a sample's surface. See "Chapter 4. Cantilever Selection" for more information on the cantilever. Depending on the distance between the atoms at the tip of the cantilever and those at the sample's surface, there exists either an attractive or repulsive force/interaction that may be utilized to measure the sample surface. See the "AFM in Contact Mode" and AFM in "Non-Contact Mode" chapters for a further discussion on utilizing the atomic forces.

Figure 1-1 displays the basic configuration for most AFMs. This scanning AFM is typically used to measure a wide variety of samples, which have relatively small roughness. The force between the atoms at the sample's surface and those at the cantilever's tip can be detected by monitoring how much the cantilever deflects. This deflection of the cantilever can be quantified by the measurement of a beam that is reflected off the backside of the cantilever and onto the Position Sensitive Photo Detector (PSPD).

The tube-shaped scanner located under the sample moves a sample in the horizontal direction (X-Y) and in the vertical direction (Z). It repetitively scans the sample line by line, while the PSPD signal is used to establish a feedback loop which controls the vertical movement of the scanner as the cantilever moves across the sample surfa ce.

The AFM can easily take a measurement of conductive, non-conductive, and even some liquid samples without delicate sample preparation. This is a significant advantage over the extensive preparation techniques required for TEM or SEM.

Despite its many advantages, the AFM does have some drawbacks as well.

1. In general, the scanners used in AFMs are piezoelectric ceramic tubes (Figure 1-1). Due to the non-linearity and hysteresis of piezoelectric materials, this may result in measurement errors as shown in Figure 1-2.
2. The geometrical and structural restraints imposed by the tube type scanner results in cross coupling of the individual scan axes. Thus, independent movement in the x, y, and z directions is impossible.
3. Since the tip has a finite size, it is very difficult and sometimes impossible to measure a narrow, deep indentation or a steep slope. Often, even though such a measurement may be possible, the convolution effect due to the shape of the tip and the sample profile may result in measurement errors.
4. Since the tip has to mechanically follow a sample surface, the measurement speed of an AFM is much slower than that of an optical microscope or an electron microscope.

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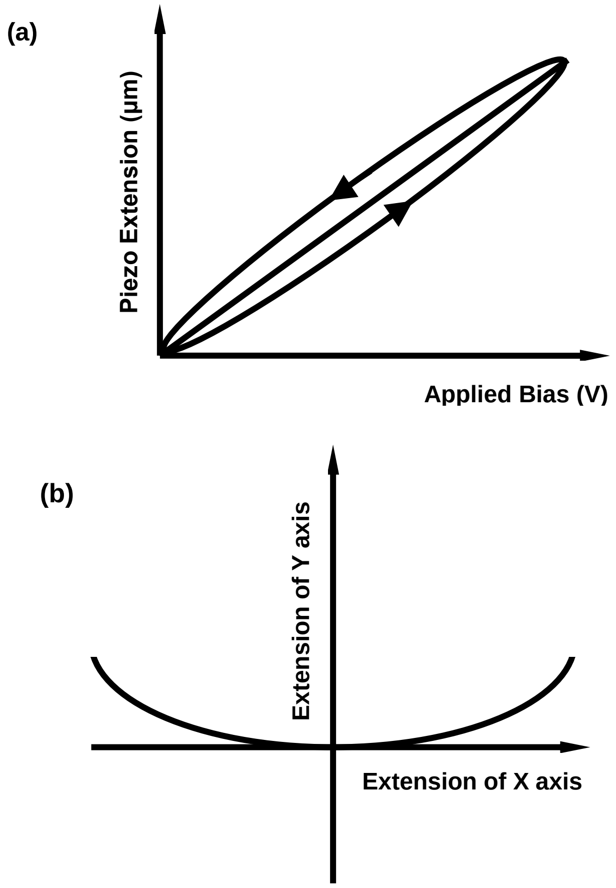
The most inconvenient aspect of using the AFM is its slow speed. As mentioned above, since the image is obtained by the tip's mechanically following a sample's surface, it is much slower than other microscopes that use electrons or light. The main factors slowing the speed of the AFM are the Z scanner's response rate and the respons e rate of the circuit which detects changes in the cantilever’s resonant frequency. The resonant frequency of the typical tube scanner is several hundred Hz. In order to accurately measure a sample area with 256×256 pixels (data points), it is necessary to scan at a rate of about one line per second. Thus, it takes approximately 4 minutes to acquire an image.

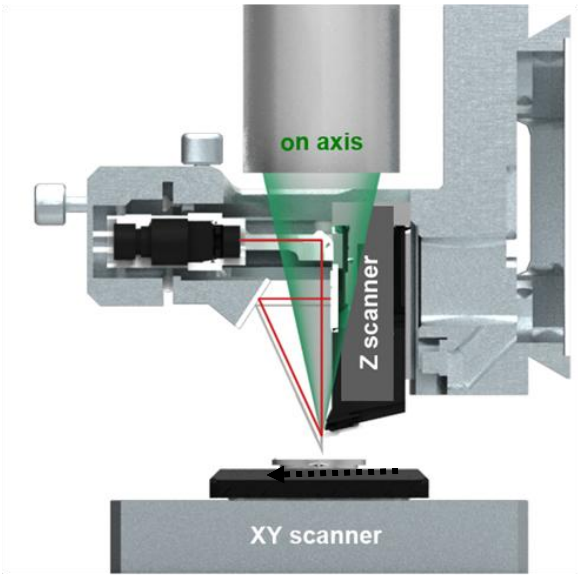
For most cases, the second and third problems listed above can be minimized by software calibration. This is a reasonably simple and inexpensive procedure that involves imaging a standard sample, (usually a grid structure with a known pitch) in order to create a calibration file that will be used to control the scanner’s movements when unknown samples are imaged. Correction using software, however, still depends heavily on the scan speed and scan direction, and such a correction becomes accurate only when the center of the scan range used to measure an unknown sample coincides exactly with the center of the scanning range that was used to image the standard sample and to create the calibration file.

Figure 1-2. Nonlinearity and Hysteresis (a), and Cross Coupling (b) Observed in Piezoelectric Tube Scanners



1-3. Park Systems AFM

Figure 1-3. Z Scanner Separated from X-Y scanner

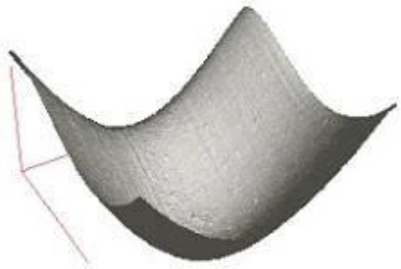


Since the conventional tube type scanner cannot move in one direction independently from other directions, movement in one direction will always simultaneously affect the scanner’s movement in other directions. This cross talk and non-linearity caused by the scanner’s three axes being non-orthogonal to another has a more pronounced effect in the case of measuring larger areas or flat samples. This intrinsic problem can be eliminated completely, however, by physical separation of the Z scanner from the X-Y scanner (see Figure 1-3). .

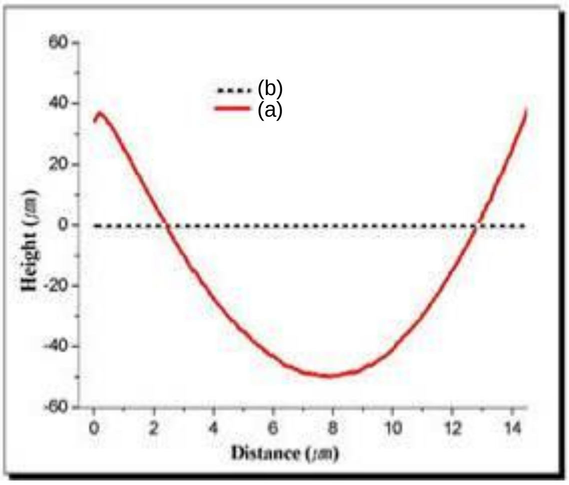
The breakthrough that eliminated these cumbersome problems came when the Park Systems SPMs introduced a new concept of separating the Z scanner from the X-Y scanner. The NX system is designed so that the X-Y scanner scans a sample in two-dimensional space, while the Z scanner moves the tip only in the z direction. Figure 1-3 shows a diagram of the NX system, in which the Z scanner separated from the X-Y scanner. The symmetrical flexure scanner used in the NX system moves only in the X-Y plane, and has superb orthogonality. This scanner’s design also makes it possible to place much larger samples on the sample stage than could normally be accommodated for by a piezoelectric tube type scanner. Furthermore, since the flexure scanner only moves in the X-Y direction, it can be scanned at much higher rates (10~50 Hz) than would be possible with a standard AFM. Because the stacked piezoelectric actu ator used for the Z scanner has a very fast response speed, at least 5 kHz, it is able to respond to topographic changes on the sample surface more than 10 times faster than is possible with a conventional tube type scanner.

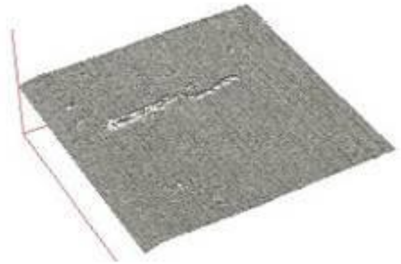
Having the X-Y scanner separated from the Z scanner in the uniquely designed NX system not only increases the data collecting speed by at least 10 times compared to a conventional tube type scanner, but also isolates the vertical and horizontal scan axes, completely eliminating cross coupling, resulting in a very accurate measurement. Moreover, this independent scanning system improves the error due to the inherent non-linearity of the scanner itself. Figure 1-4 compares the background image of a conventional tube scanner compared to that of the new NX scan system.

Figure 1-4. Background Flatness Images from a Conventional AFM (a) and Park Systems AFM (b)



(a) Conventional AFM





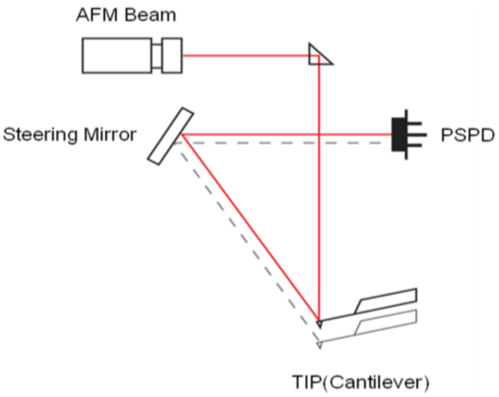
(b) Park Systems AFM

Figure 1-5 shows a diagram that explains the cantilever movement detection mechanism used in the NX system. This SLD Beam & PSPD configuration, which permits the accurate acquisition of stable images at high measurement speeds, satisfies the following two important imaging conditions:

First, the PSPD should be able to measure only the deflection of the cantilever without interference from the Z scanner.

Second, to improve the response rate in the Z direction, the weight of the Z scanner must be minimized.

Figure 1-5. Beam path related to the cantilever’s movement



The cantilever and the PSPD move together with the Z scanner while the SLD beam, a steering mirror and a fixed mirror are fixed relative to the scanner frame. The SLD beam, positioned in front of the Z scanner, is aimed at a fixed mirror that is situated above the cantilever. The mirror reflects the beam downward and onto the back surface of the cantilever. The SLD beam will always hit the same spot on the cantilever’s surface since the Z scanner only moves vertically. Therefore, once the SLD beam is aligned, there is no need to realign the SLD beam, even after the Z scanner has been moved up and down to change samples. The steering mirror, located at the front of the Z scanner assembly, adjusts the reflection angle of the SLD beam that is reflected off the cantilever’s surface. The steering mirror reflects the SLD beam to the PSPD. Another feature of this alignment design is that as a result of placing the PSPD onto the scanner frame, it allows a change of the Z scanner position without having to realign the PSPD. Therefore, only the deflection of the cantilever will be detected, independent of the Z scanner movement.

Since there is nothing obstructing the view above the cantilever in the structure, the optical microscope is located on the same axis as the SLD beam that is reflected at the fixed mirror.

Figure 1-6. Captured Optical Microscope Image

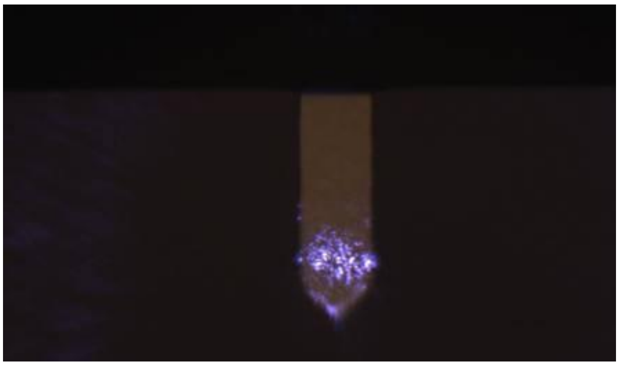
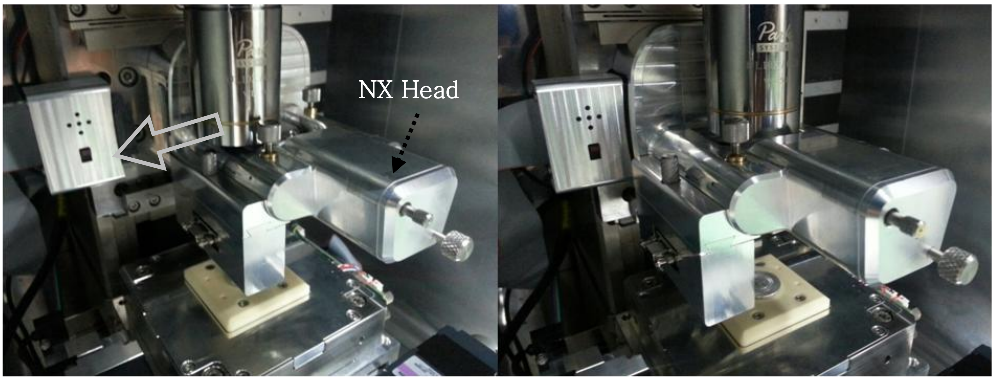


Figure 1-6 shows the cantilever with the SLD beam focused on it, as it is displayed on the vision software. Since the CCD camera is aligned directly with the cantilever with nothing blocking its view, it is very convenient to focus on or to observe the sample while moving the camera up and down. This view also provides superb quality for an optical microscope.

The Park NX-Hivac system's power and ease-of-use are evident throughout the system's design. For example, the SLD beam used in the Park NX-Hivac system's head is low coherence, and it enables accurate imaging of highly reflective surfaces and precise measurement for approach spectroscopy. An additional advantage of the SLD head is its compatibility with experiments that utilize light in the visible region of the spectrum. The unique head design of the crosstalk elimination allows wide-open side access to a sample and the tip.

In addition, the head is easily inserted by sliding it along a dovetail rail and automatically locking into its pre-aligned position with a convenient turn of two thumb locks. There are no additional knobs, springs or cables to adjust as is common with other designs.

Figure 1-7. Lock Head



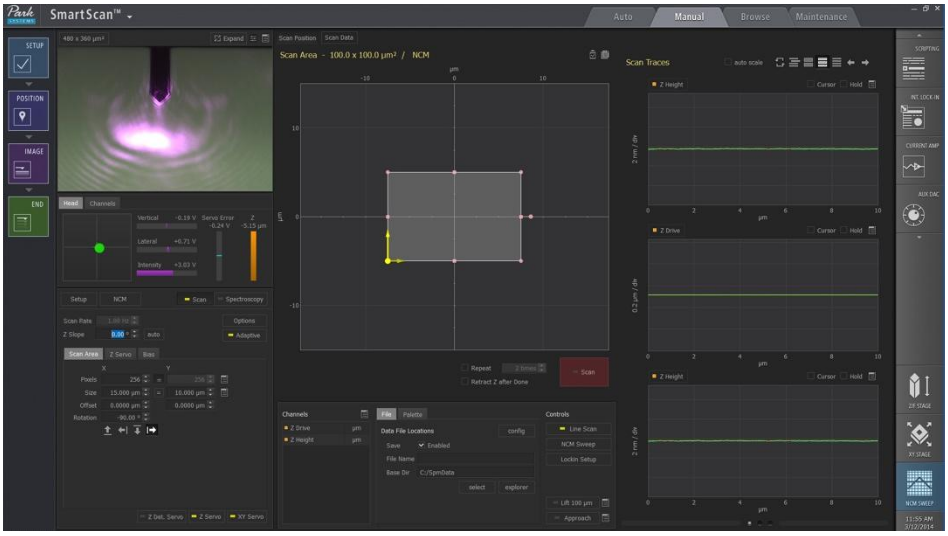
The NX system not only achieved a structural design change that yielded exemplary SPM efficiency, but also brought many improvements to the electronic controller a nd to the supporting software.

The AFM control unit has a fast, powerful Digital Signal Processor (DSP), high speed ADC/DACs and offers built-in support for Digital lock-in and digital Q control functions without the need for additional instruments .

The NX Control Electronics are designed to enable the scanner, the core unit of the AFM, to provide efficient, accurate and fast control, and to facilitate the acquisition of a stable image even beyond a scan speed of 10Hz. In addition, the controller contains input/output terminals that provide a simple means for users to design advanced experiments that extend far beyond and are much more complicated than obtaining basic images.

Furthermore, the up to date computer is equipped with the most recent high-power Intel Core i5-3570 and Windows 10 system. Two 23” LCD monitor displays crystal clear images using a DVI (Digital Video Interface). All necessary software, including SmartScan™, the Data Acquisition program, and XEI, the Image Processing program, is installed on the computer. Figure 1-8 shows the SmartScan™ program’s clean and easy-to-use interface, complete with safety functions and various measurement capabilities that are required to perform advanced applications. Figure 1-9 shows the XEI program that is used to convert acquired data into an image and to perform various analyses that meet the user’s requirements.

Figure 1-8. SmartScan™ - Data Acquisition Program



Scan Area - 100.0 x 100.0 µm² / NCM

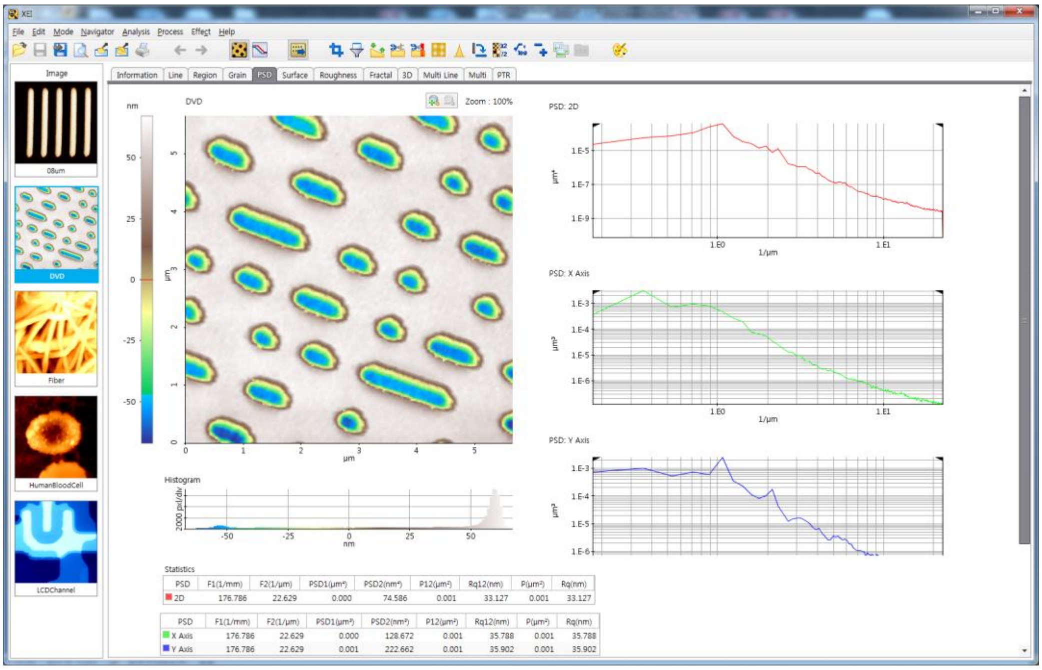
Vertical -0.19 V
Lateral +0.71 V
Intensity +3.03 V
Servo Error -0.24 V
Z -5.15 µm

Scan Rate 1.00 Hz
Z Slope 0.00 °

Pixels X 256 Y 256
Size X 15.000 µm Y 10.000 µm
Offset X 0.0000 µm Y 0.0000 µm
Rotation -90.00 °

Save ✓ Enabled
File Name
Base Dir C:/SpmData

Figure 1-9. XEI - Image Processing Program



Statistics

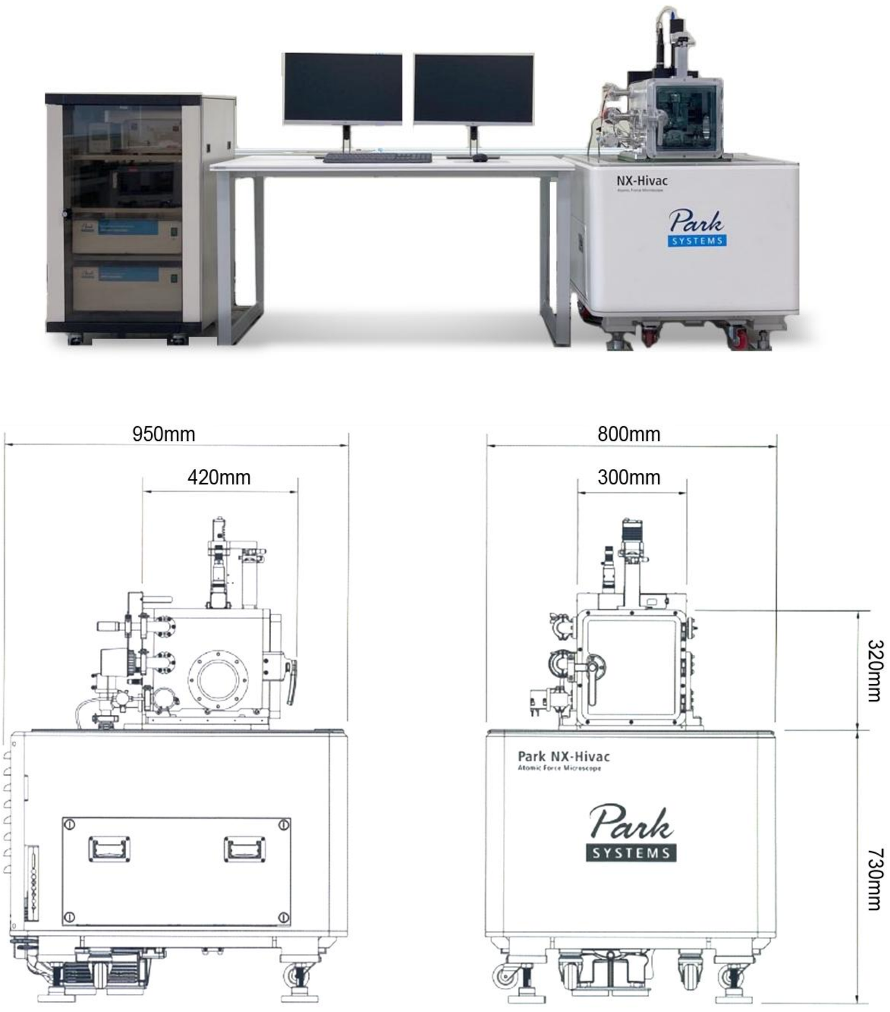
PSD	F1(1/mm)	F2(1/µm)	PSD1(μm^4)	PSD2(nm^4)	P12(μm^2)	Rq12(nm)	P(μm^2)	Rq(nm)
🟥 2D	176.786	22.629	0.000	74.586	0.001	33.127	0.001	33.127

PSD	F1(1/mm)	F2(1/µm)	PSD1(μm^3)	PSD2(nm^3)	P12(μm^2)	Rq12(nm)	P(μm^2)	Rq(nm)
🟩 X Axis	176.786	22.629	0.000	128.672	0.001	35.788	0.001	35.788
🟦 Y Axis	176.786	22.629	0.001	222.662	0.001	35.902	0.001	35.902

Chapter 2. Components of NX-Hivac

The Park NX-Hivac AFM system consists of a number of primary components: the Park NX-Hivac main system, control electronics, dry pump, turbo pump, NX-Hivac controller, computer, and monitors.

Figure 2-1. NX-Hivac System

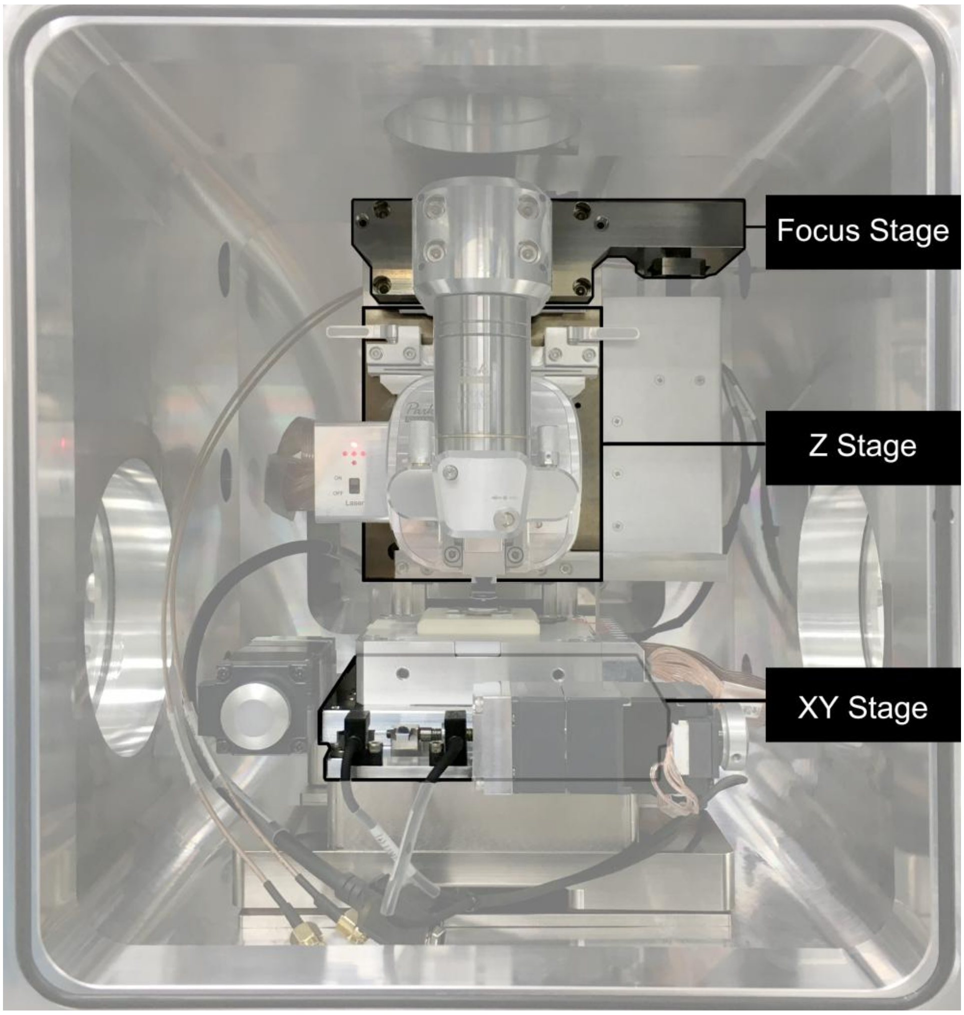


The Park NX-Hivac main system is where actual measurements are made. The Park NX-Hivac control electronics control the movement of the main system according to commands from the computer. All necessary software, including SmartScan(the data acquisition program), XEI(the image-processing program), Park Hivac Manager(NX-Hivac auto vacuum control), and the vision program, are installed on the computer.

2-1. NX-Hivac Main System

The Park NX-Hivac AFM system is much easier to operate than a conventional AFM, and measurements can be made much more quickly and accurately. The Park NX-Hivac main system is composed of a vacuum chamber, which includes AFM core parts, plus a dry pump and turbo pump. These components as shown in Figure 2-2. The following explains each component in detail.

Figure 2-2. NX-Hivac Scanning Probe Microcope



2-1-1. Z Stage

The Z stage head assembly controls the coarse vertical positioning of the Z scanner with a stepper motor, and is used to approach the cantilever near the sample. The max working range of the Z stage is 25mm (max speed 0.8mm/s, resolution 80nm). The Z stage is software controlled.

- **NX-Hivac Head**

The Park NX-Hivac head is the component that actually interacts with the sample and takes measurements. The Park NX-Hivac system includes the standard head and PSPD auto-alignment motor. Along-travel head is optionally available. See below for specifications. Please use the appropriate head for your measurement..

Figure 2-3. Standard Head

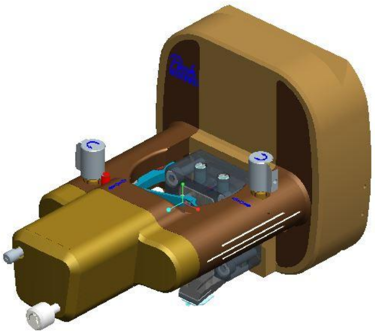


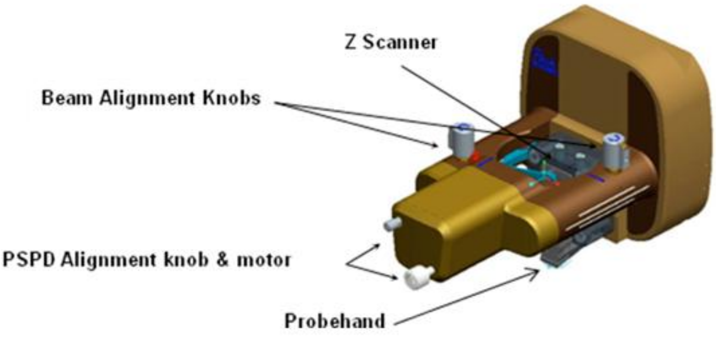
Table 2-1. Specifications of NX-Hivac Head

Items	Standard Head
Compatible Objective Lens	UL10x
Z Scanner Stroke	> 15 ㎛

The NX-Hivac head is a core component of the Park Systems AFM and performs the following functions:

- Cantilever Mount
- Cantilever Modulation
- Beam Detection
- Movement in Z axis

Figure 2-4. Structure of NX-Hivac Head



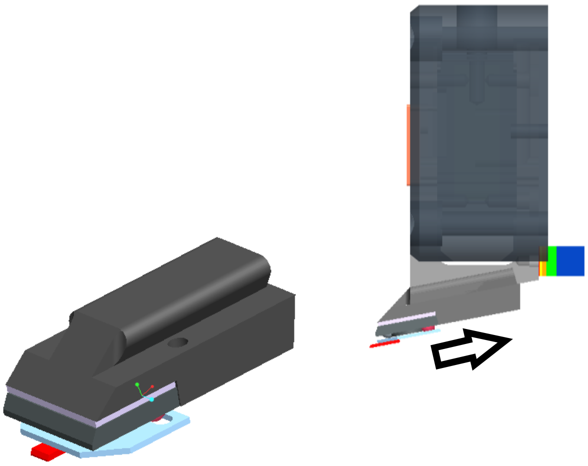
WARNING!

Do not disassemble the NX-Hivac head on your own. Park Systems will not be responsible for any personal, physical damage or degraded performance that may result from unauthorized disassembly.

Probe hand

The probe hand is the part of the AFM head which holds the cantilever. The design of the probe hand depends on the head mode (operating mode) of the AFM. This means that the appropriate probe hand must be selected by the user according to their application. The standard probe hand provided with the NX-Hivac system (Figure 2-5) has a bimorph for vibrating the cantilever in non-contact mode, and can apply an electrical tip bias. It is usable for contact, non-contact, force modulation, lateral force mode, Tapping mode, approach spectroscopy mode, nano indentation mode, lithography mode, electrostatic force mode, among others.

Figure 2-5. Attach Probehand



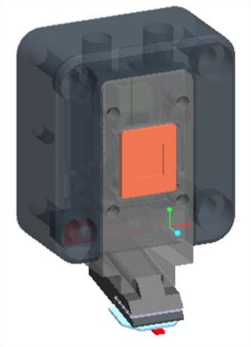
NX-Hivac Z scanner

The Z scanner consists of stacked piezoelectric material, which moves in response to applied voltage. The cantilever is attached to the Z scanner through the probe hand. This enables the tip to maintain constant feedback conditions (force or distance) as it is moved over a sample surface. The measurable dimensions are limited by the Z scanner range. The Z scanner on the standard head can move up to 15 μm and the Long Travel Head's Z scanner can move up to 38μm.

WARNING!

Never disassemble the Z scanner on your own. Park Systems will not be responsible for any personal, physical damage or degraded performance that may result from unauthorized disassembly.

Figure 2-6. Z scanner Assembly



The NX-Hivac's Z scanner is separated from the X-Y scanner. This independence provides the user with several operational advantages.

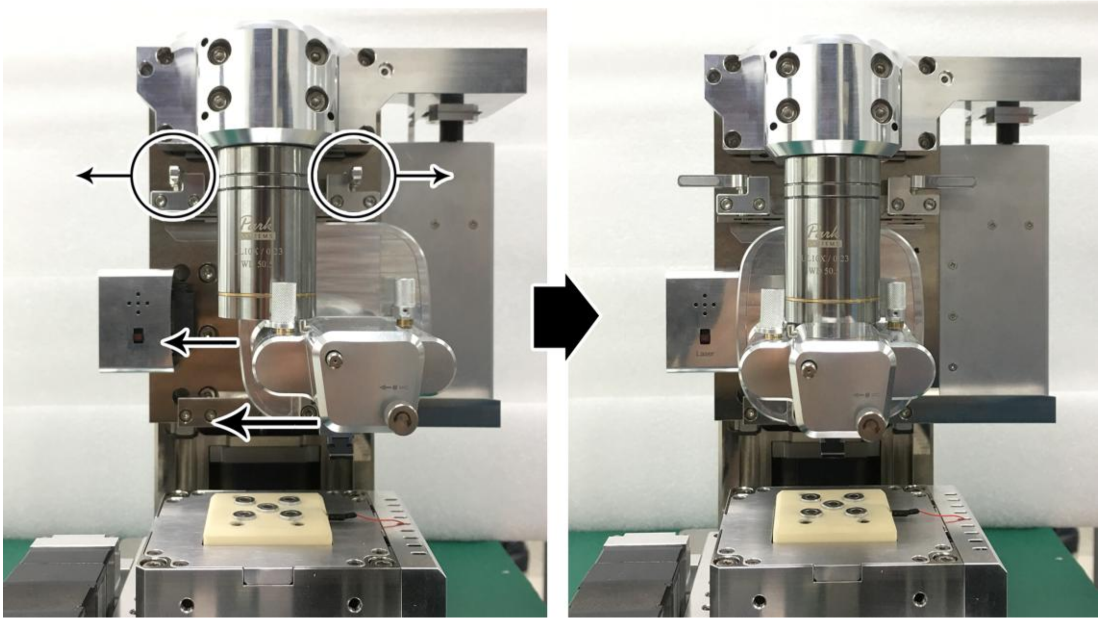
1. The separated Z scanner is lighter. This allows for quicker response times, enabling the tip to follow the topography of a sample surface more quickly, ultimately leading to quicker measurements without sacrificing accuracy or precision. The faster response time also protects the tip, resulting in the ability to acquire clear images for an extended period of time.

2. Since the tip wears out eventually, it is necessary to replace it after some amount of use. The NX-Hivac's Kinematic Mount makes tip exchanges routine and easy.

3. Most AFMs detect the probe's movement to measure topographic data by collecting a beam signal on a position-sensitive photo detector(PSPD) after it is reflected from the back side of a cantilever. To align the beam, conventional AFMs use additional positioning equipment, an operation which is often difficult and cumbersome. However, beam alignment becomes very easy and convenient with the Park NX-Hivac system. Manageable control knobs on the Park NX-Hivac head can be adjusted manually with the help of the control software(SmartScan and the vision program), making location and movement of the beam easy and accurate.

4. It's easy to remove the NX-Hivac head from the main frame. Simply unlock the dovetail thumb locks and slide the Park NX-Hivac head off the dovetail rail. Remounting the head is as easy as removing it.

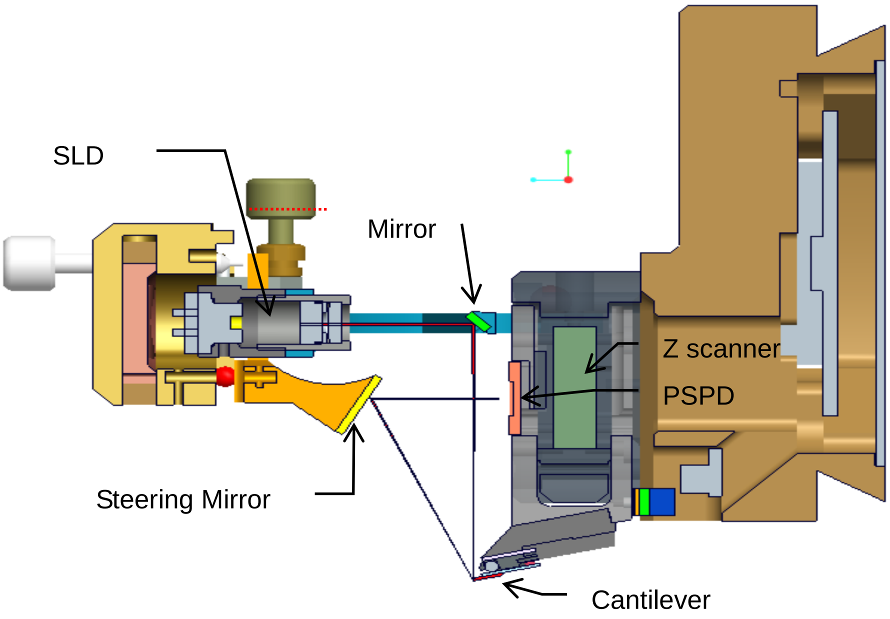
Figure 2-7. Removing NX-Hivac Head



AFM Beam Detection Array

AFMs collect a beam signal after it is reflected from the back side of a cantilever in order to detect the probe's movement. The NX-Hivac uses an SLD beam with a wavelength of 830nm.

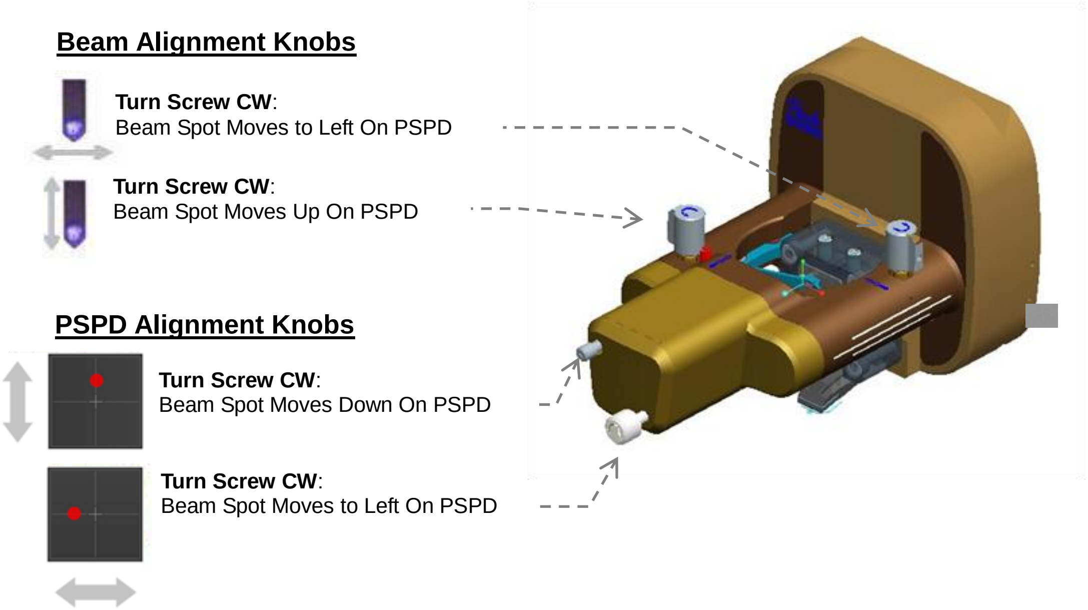
Figure 2-8. Beam Detection



The cantilever and the PSPD move together with the Z scanner. The SLD beam, a steering mirror, and a fixed mirror are fixed relative to the scanner frame. The SLD beam, positioned in front of the Z scanner, is aimed at a fixed mirror situated above the cantilever. The mirror reflects the SLD beam downward and onto the back surface of the cantilever. The SLD beam will always hit the same spot on the cantilever's surface since the Z scanner only moves vertically. The steering mirror, located at the front of the Z scanner assembly, adjusts the reflection angle of the SLD beam that is reflected off the cantilever's surface. The steering mirror reflects the SLD beam to the PSPD. The beam alignment knobs, which are located on the head, control the fixed mirror angle and make it possible for the beam to align onto the cantilever's surface, as shown in Figures2-8 and 29.

The PSPD alignment knobs in front of the head control the steering mirror angle to adjust the reflected beam to go to the PSPD, as shown in Figures2-8 and2-9. .

Figure 2-9. Beam & PSPD Alignment Knobs


Beam Alignment Knobs
Turn Screw CW:
Beam Spot Moves to Left On PSPD
Turn Screw CW:
Beam Spot Moves Up On PSPD
PSPD Alignment Knobs
Turn Screw CW:
Beam Spot Moves Down On PSPD
Turn Screw CW:
Beam Spot Moves to Left On PSPD

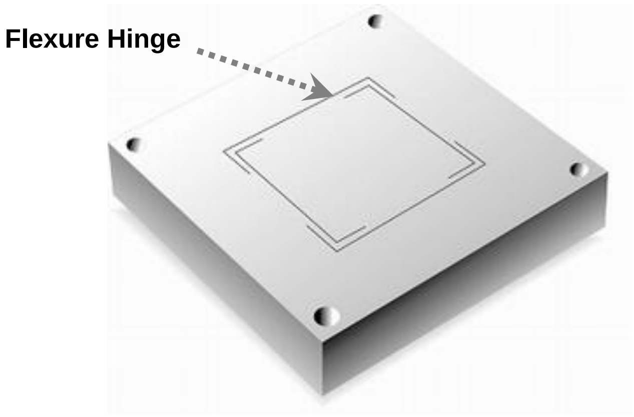
2-1-2. XY Stage

The XY scanner is affixed to the XY stage. By adjusting the stepper motor via software control, the XY stage can be used to horizontally position the sample. The Park NX-Hivac system's XY stage has a maximum range of 24mm in both X and Y axes, with a resolution of 5㎛.

- **NX-Hivac X-Y scanner**

The NX-Hivac X-Y scanner that moves the sample in the XY plane is a Body Guided Flexure scanner. The XY scanner is fabricated from a solid aluminum block. The desired area is cut out from inside the aluminum block, and the lines indicated in Figure 2-10 are fabricated with a special technique called 'Wire Electric Discharge Machining' resulting in a flexure hinge structure.

Figure 2-10. XY scanner



WARNING!

Never disassemble the XY scanner on your own. Park Systems will not be responsible for any personal, physical damage or reduced performance resulting from unauthorized disassembly.

An XY scanner with a flexure hinge structure has the advantage of highly orthogonal two-dimensional movement with minimal out-of-plane motion. Due to the Parallel Kinematics design, the XY scanner has low inertia and axis-independent performance. Hysteresis-correcting Servo Scan (described in Chapter 7) is accomplished by means of an optical sensor in the flexure scanner.

There are two XY scanner sizes that may be used with the NX-Hivac: 50 µm × 50 µm, or 100 µm × 100 µm, or 10 µm x 10 µm depending on the desired maximum measurement range.

- **Sample Chuck**

The sample is loaded on a sample chuck that is fixed on the X-Y scanner. A magnetic holder allows samples prepared on metal plates to be easily loaded onto the scanner. There are five magnetic holders on the sample chuck. Voltage biases from -10V to 10V can be applied to a sample in electrical contact with a metal plate by way of each magnetic sample holder. Samples up to 110mmx110mm on edge, 20mm in thickness, and 500g in weight can be loaded onto the sample chuck.

2-1-3. Focus Stage

The optical microscope is affixed to the focus stage. By adjusting the stepper motor via software, the focus stage can be used to vertically position the optical microscope so as to observe the cantilever/sample. The Park NX-Hivac system's focus stage has a maximum range of 15mm.

■ NX-Hivac Optical Microscope

The Optical microscope is used when positioning the SLD beam onto the cantilever, and for locating regions of interest on the sample surface for measurement. Since the optical microscope's axis is parallel with the Z scanner's, it is possible to have a direct on-axis view of the cantilever in conjunction with the sample area that will be scanned.

All of the components of the optical microscope - the objective lens, the frame, and CCD camera - are rigidly fixed on a single body. Since the entire assembly moves together for focusing and panning, the axis lining the sample and the CCD camera are always fixed, and a high quality optical view is preserved.

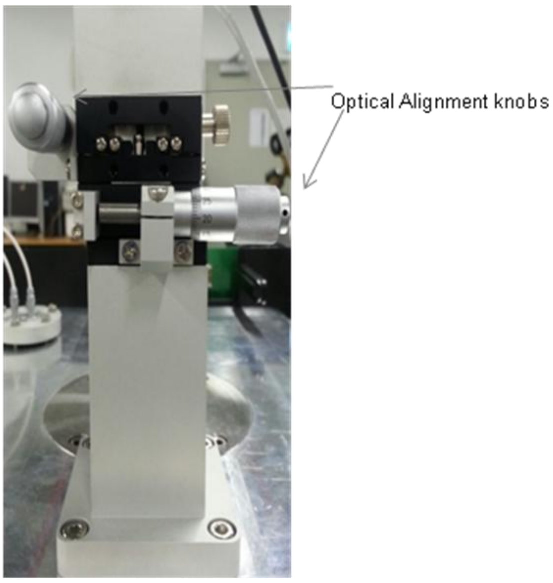
The NX-Hivac provides two options for the objective lens' choice- 10X and 20X. Please refer to the table below for details.

Table 2-4. Specification of Objective Lens

EL20**X** (Enhanced long working distance objective lens)	UL10**X** (Ultra long working distance objective lens)
NA 0.42	NA 0.21
WD 20mm	WD 50 mm
Compatible for Long Travel Head	Compatible for Standard Head, Long Travel Head

The 10X objective lens yields about 500 times magnification and the optional 20X objective lens yields about 1000 times magnification.

Figure 2-11. Optical Microscope of NX-Hivac



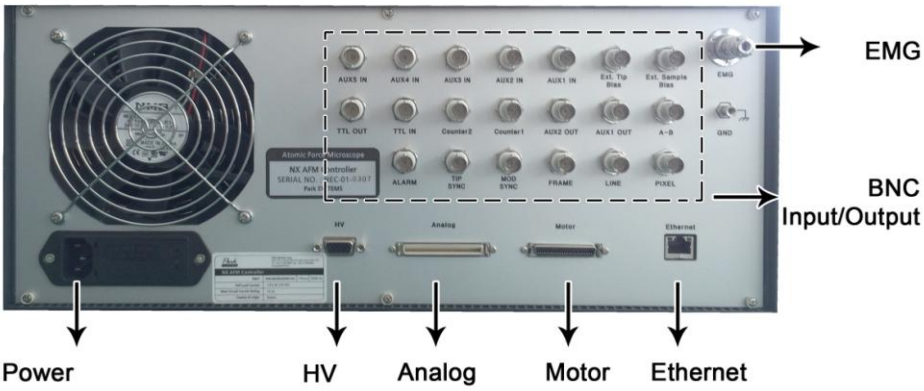
2-1-4. Pump Parts

To create the necessary high-vacuum condition, the Park NX-Hivac system includes a dry pump and turbo pump. The dry pump first creates a low-vacuum condition inside the chamber (~0.15 torr). Once a low-vacuum level has been achieved, the turbo pump takes over, until the vacuum reaches ~10^-5 torr. To prevent damage to the pumps due to overheating, each line includes a safety valve.

2-2. AFM Control Electronics

The NX- Hivac main system is divided into three components, the NX- Hivac main system, the Control Electronics, and the computer. The Control Electronics serves as a mediator between the main system and the computer.

Figure 2-12. Control Electronics (Rear View)



In order to maintain fast, effective communication between the computer and the NX-Hivac main system, an Ethernet connection is used. The DSP contained in the NX-Hivac Control Electronics is the 9600MMACS.

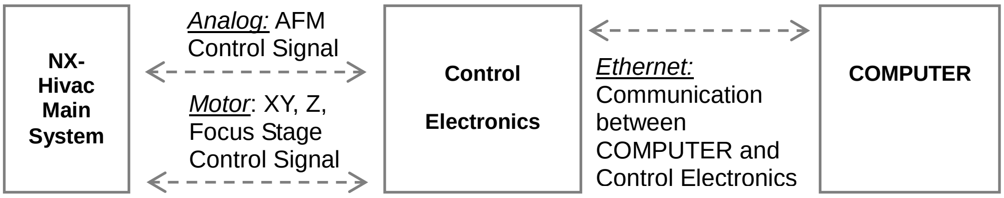

NX-Hivac Main System
Analog: AFM Control Signal
Motor: XY, Z, Focus Stage Control Signal
Control Electronics
Ethernet: Communication between COMPUTER and Control Electronics
COMPUTER

Table 2-5. Connector Information

Connector Label	Type	Connection to	Purpose/ specification
Analog	1.27 mm pitch, 68 pin	Frame COMPUTERB	Analog signal I/O (+/-15V , PSPD, Detector, Piezo drive signal, Tip bias , Sample bias, Modulation) for AFM operation.
Motor	1.27 mm pitch, 50 pin	Frame COMPUTERB	Digital signal I/O (+5V, Z motor, Focus motor, Limit sensor, SPI) for XY, Z , Focus Stage control.
Ethernet	RJ45 Cat.5e	COMPUTER	Connect Electronics with COMPUTER for controlling NX 10 system by COMPUTER.
EMG	Circular 4pin		Power for XY, Z and focus stage motor. Motor can be stopped by disconnecting it in an urgent status. This function is disabled for research system.
HV	2.54 mm pitch 15 pin	Frame COMPUTERB	High Voltage Signal for Scanners

NX Control Electronics supports access of important input and output (I/O) signals such as VERTICAL and Tip bias to external instruments via BNC connections. These signals are detailed in Table 2-6.

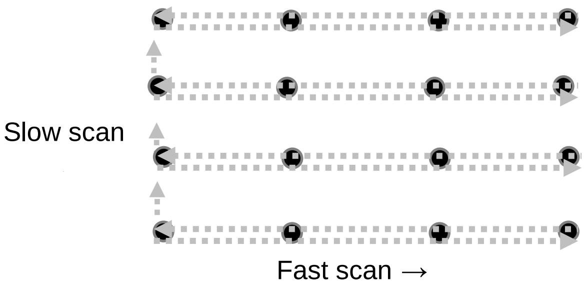
Table 2-6. BNC Input/Output Signals

Connector Label	Purpose	Specification
AUX 5 IN	Inputs connector for user-supplied signals. External signals are introduced through these connectors can be viewed alongside SPM parameters, each being assigned to a channel selectable from the “Input Config” menu. These auxiliary signals can also be captured as an image in XEP or SmartScan for analysis. The three signal paths are identical and independent.	BW 20 kHz, +/- 10V
AUX 4 IN		
AUX 3 IN		
AUX 2 IN		
AUX 1 IN		BW 5 MHz, 50 Ω input impedance. +/- 5V
AUX 1 OUT		BW 5 MHz, 50 Ω input impedance. +/- 2V
AUX 2 OUT		BW 20 kHz, +/- 10V
Ext. Tip Bias	Input connector used when the experimenter wants to apply bias from the external source to the sample.	Input voltage range: -10V to ~ +10V If experimenter wants to apply higher bias to the sample, user can use ‘External High Voltage toolkit’ Full Power Bandwidth: <100kHz
Ext. Sample Bias		
TTL OUT	Reserved	
TTL IN		
Counter 1	Input connector when the experimenter wants to count the signal from detector.	LVTTL input compliant Minimum pulse width: 10 ns Max counting value: 2^32 Time constant: 1 ms ~ 1 sec. (To be determined)
Counter 2		
A-B		Output range: -5V ~ +5 V Small Signal Bandwidth: 5 MHz Impedance: 50 Ω
Alarm	Reserved	
Tip SYNC	Tip bias (sample bias, Z scanner modulation) frequency output.	LVTTL compliant.
MOD SYNC	Frequency output of NCM modulation	
FRAME	Indicates if the images are acquired	
LINE	Indicates the direction of scanner movement	
PIXEL	Indicates scanner status	

- **Image Sync.**

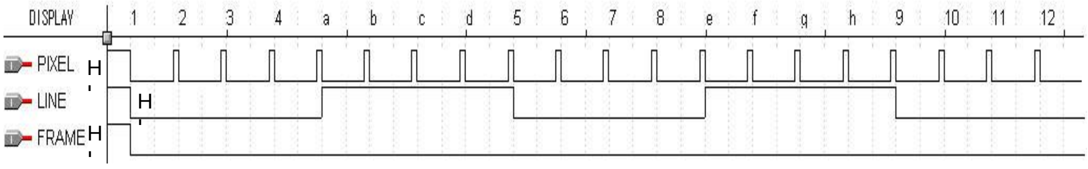
The Park NX-Hivac system provides image sync outputs(frame, line, and pixel)for your experiment. For example, with a4x4 pixel image, the sync signal for pixel, line, and frame on the measured image would be as shown in Figure 2-13. The numbers are the forward(left-to-right scan) image and alphabetical characters are the backward image(right-to-left scan).

Figure 2-13. Standard Scanning



13 p	14 o	15 n	16 m
9 l	10 k	11 j	12 i
5 h	6 g	7 f	8 e
1 d	2 c	3 b	4 a

<Display>



(H: High Status, L: Low Status)

Table 2-7 explains the meaning of each sync signal.

Table 2-7. Image Sync Signals

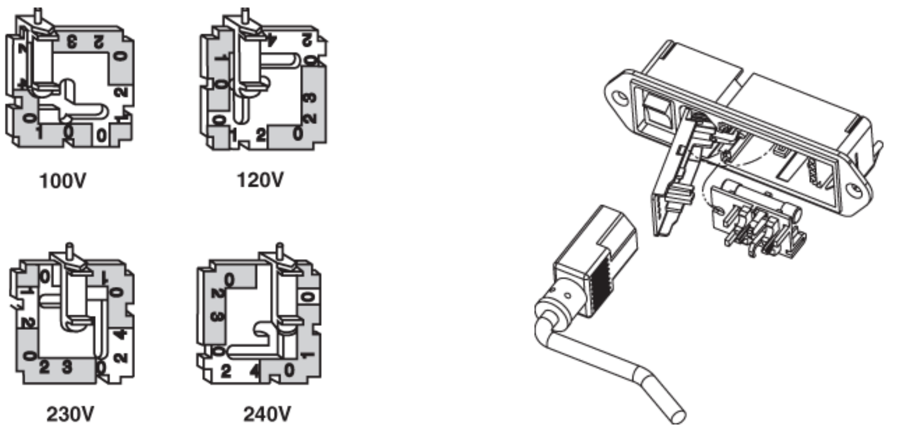
Name	Purpose	Low	High
FRAME	Indicates if the images is acquired	Acquiring the image	No activity
LINE	Indicates the direction of the scanner movement	Trace (or forward) direction	Retrace (or backward) direction
PIXEL	Indicates if the scanner status	Acquiring the pixel data (hence the scanner is stationary)	Moving to the next point

2-2-1. Power/Fuse Change

- **Power**

The power to the NX-Hivac Control Electronics is not free voltage. The procedure for changing the input power voltage follows below:

Figure 2-14. Change Power


100V 120V 230V 240V

1. Remove power cord.
2. Pry door open at socket.
3. Lift and swing door into socket.
4. Lift fuse holder out of housing.
5. Install one AG fuse or two metric fuses.
6. Replace fuse holder into housing.
7. Swing and snap door back in place.

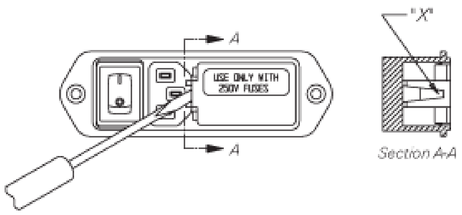
- **Fuse**

[Fuse Specification in: 230V/240V:2A or 100V/120V:4A]

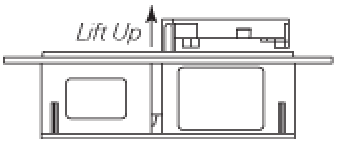
You can change the fuse by following the procedure below:

a) Removing Fuse Holder

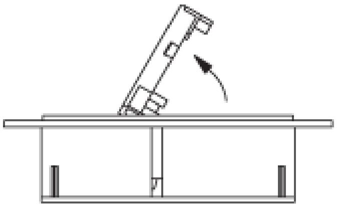
1. Insert a pocket screwdriver at point "X" as shown.



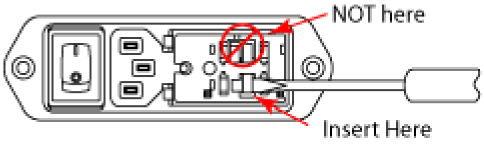
2. Gently lift UP until the entire door lifts up at least 1/4".



3. Once lifted, the door will pivot on its hinges and expose the fuse holder.



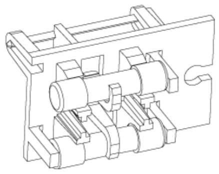
4. When the fuse holder is installed in the single fuse position, apply the screwdriver as shown and gently pry up. Insert screwdriver as shown - do not use fingers to pry the unit loose.



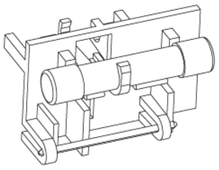
When the fuse holder is installed in the dual fuse configuration, it will release as soon as the door is opened.

b) Changing Fuse

European Fusing Arrangement



North American Fusing Arrangement



Install fuses on one side only. Do not install both AG and Metric fuses at the same time.

2-3. The Park NX-Hivac Controller

The Park NX-Hivac controller distributes power to the vacuum pump and controls valve status.

For the operation of the vacuum pump, the main power input to the Park NX-Hivac controller should be AC100/120V, 50Hz/60Hz, Free voltage with available electric power of 2kVA**.** An IEC plug cord is connected to each output connector so that all of the control electronics can be plugged in. In addition, a PLC controls system facilities such as gauge sensor monitoring and valve operation.

2-4. Computer & Monitor

Programs related to controlling the system - performing measurement and image processing are installed in the computer. They are SmartScan™, XEI and the Vision program. SmartScan™ is for system operation, data acquisition and communication between control electronics and computer. XEI is for image processing and analysis. The Vision program is to observe the cantilever/sample/beam/etc for system operation. See the software manual for further description of the software.

The computer has some additional components installed for the NX-Hivac System.

2-5. Acoustic and Vibration Isolation System

AFMs are instruments that are very sensitive to vibrations. Both vibrations from the floor and acoustic noise of the surroundings have adverse effects on AFM measurements. It is recommended that the NX-Hivac system is placed in an Acoustic Enclosure to block acoustic noise from the surrounding environment, and supported by an Active Vibration Isolation System to block floor vibrations.

2-5-1. Acoustic Enclosure

The Acoustic Enclosure (AE) shields the AFM from acoustic and electromagnetic noise.

- **Standard Acoustic Enclosure:**

Designed exclusively for the NX series system, the integrated acoustic enclosure and granite table isolate the NX system from external acoustic and light noise for an improved performance. The walls of the acoustic enclosure are 40 mm thick, consisting of a 1.5mm stainless steel board, filled with soundproof material. The inner surfaces are covered with ESD coated micro fibers, which won’t emit particulates. Acoustic en closure reduces typically over 10 dB of acoustic noise level, varying with frequency. The Acoustic Enclosure also blocks EMI noise, and is specially coated to prevent electrostatic discharge.

-Dimensions: 700 × 800 × 1,300 mm (outer)

-Mass: 300 kg

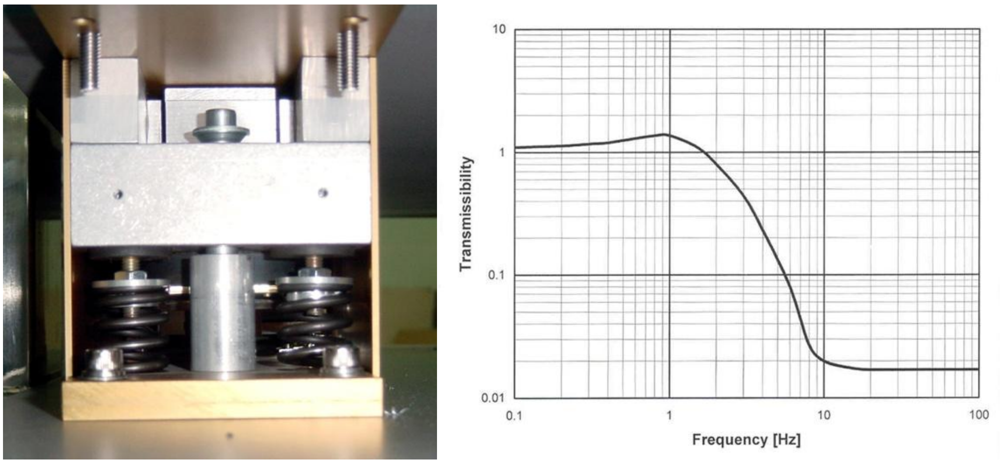
2-5-2. AVIS

- **AVIS**

AVIS, part of the vibration isolation system, blocks vibrations from the floor. The NX-Wafer system uses the AVI 350Sactive vibration isolation system from Hertz. Four isolation units in the AVI 350S, plus two additional isolation units below the system, support the AFM main system and block the effect of vibrations originating from the floor. Each isolation unit uses inertial feedback via electromagnetic transducers to provide not only isolation from building vibrations, but also isolation from vibration sources placed on the system itself, such as force applied by the operator's hand.

AVI 350S provides active isolation of vibrations with frequencies ranging from 2Hz to 200Hz and passive isolation beyond 200Hz. The isolation unit and its transmissibility are shown in Figure 2-15.

Figure 2-15. AVIS isolation unit and performance data



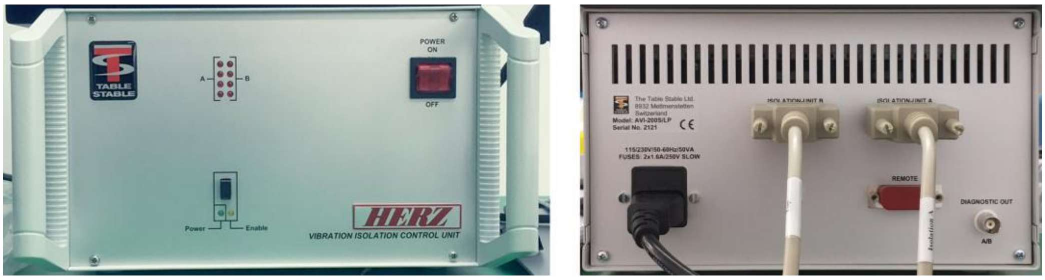
WARNING!

The AVI 350S system can be damaged by shock. Please consult Park Systems when moving the system.

- **AVIS Controller**

AVIS is a part of the vibration isolation system that blocks the effect of floor vibration to the AFM. Four isolation units in the AVIS support the AFM on the bottom stage, and two additional isolation units below the system actuate to cancel out floor vibration.
The AVIS controller provides the power for driving the vibration isolation system and controls the isolation units. Typical power consumption of the AVIS is less than 10W, but it can rise to 50W in extreme environments.

Figure 2-16. AVIS Controller (left: front, right: rear)



On the front panel of the AVIS controller, as shown in the Figure 2-16, there are 16 LEDs arranged in two groups of eight. These LEDs show the status of the system. Each 8-LED group shows the status of the associated isolation units supporting the AFM. When an LED is lighted, it means that there is external vibration and the AVIS is working to cancel it.
Also on the front panel, as shown in the Figure 2-16, there is a yellow isolation indicator LED indicating the isolation condition. Normally when the AFM is isolated from floor vibration, this LED is on. This LED blinks when there is severe external vibration and the AFM is no longer isolated from external vibration.

2-6. Specifications

Classification	Specification
Voltage	230V 50/60Hz, 1Phase
Power	- AFM Controller Power: 150W - Vibration isolation control unit Power: 20W - NX-Hivac Controller(Full load) Power: 350W - TIC Controller Power: 200W
Pneumatic	0.7MPa
N_2 Gas	0.4MPa
Acoustic Noise	<65dB
Dimension	800mm × 950mm × 1330mm
Weight	450 Kg
Recommended Temperature	10 °C ~ 40 °C
Recommended Humidity	30 % ~ 80 % (Not condensing)

NX-Hivac Head	Super luminescent diode (standard): 830nm with low coherency
Optics	Direct on-axis vision of sample surface and cantilever Focus range: 15mm, motorized and software controlled Magnification: 780× (optional 1000×) Field of view: 480μm × 360μm(for 10x obj. lens) CCD: 5Mpixel Objective lens: 10x(0.21NA), 20x(0.42NA) (Optional)
Stage	XY stage travel: 22mm × 22mm, motorized precision movement Z stage travel: 25mm, motorized movement Sample size: 50mm × 50mm, 20mm thickness Sample weight: up to 500g

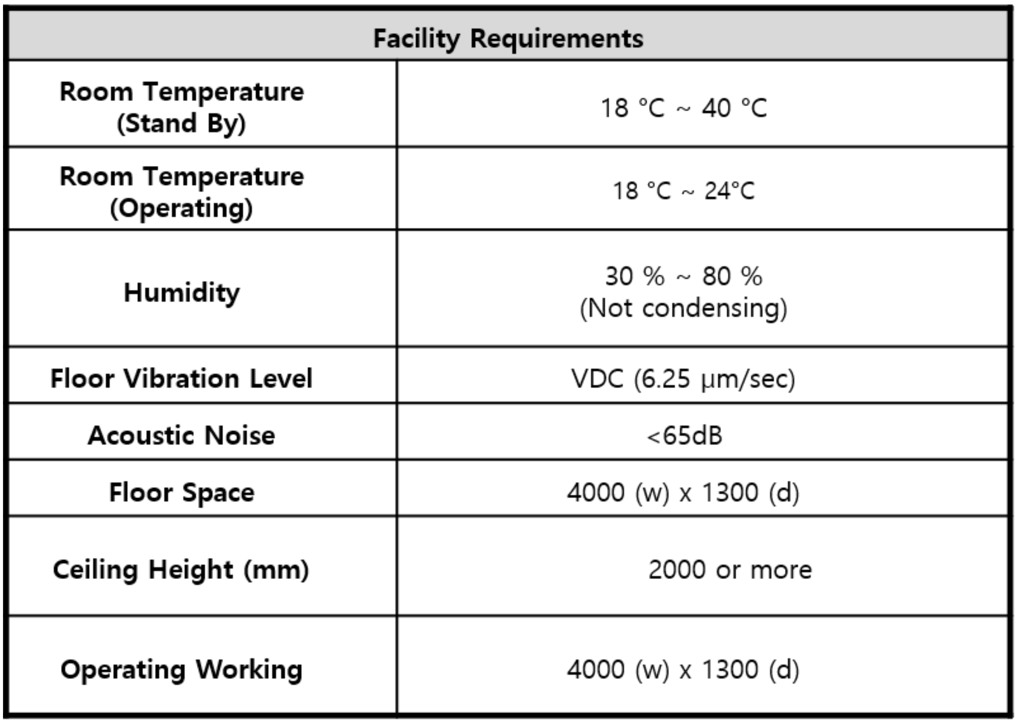
Scanner	Decoupled XY and Z scanner Single module flexure XY scanner with closed-loop control Scan range of XY scanner: 50μm (optional 100μm) Scan range of Z scanner: 15μm (optional 38μm)
Pump	-Dry pump- Ultimate Vacuum: 0.022 torr Dimensions: 265mm x 302mm x 432mm (W x D xH) Moter power 1-ph: 260W -Turbo pump- Max Pressure: 5.0X10^-8 Dimension: 203mm x 203mm x 200mm (W x D xH) Max power: 160W
Software	-SmartScan- Dedicated system control and data acquisition software Adjusting feedback gain, set point in real time Step-and-scan function for programmable imaging -XEI- AFM data analysis software Vacuum pump and valve control software Software control of vacuum sequence
Electronics (AFM Controller)	Main control: DSP(9600MMACS), 100Mbps TCP/IP ADC: 18 channels 4 high-speed ADC channels (50MSPS) 24-bit ADCs for X, Y, and Z scanner position sensor DAC: 12 channels 2 high-speed DAC channels (50MSPS) 20-bit DACs for X, Y, and Z scanner positioning Programmable A-B and LFM gain control Integrated light-source control 2 channel32-bit counter 3 channel digital lock-in amplifier Digital Qcontrol 20 embedded signal input/output ports 5 TTL outputs: EOF, EOL, EOP, modulation, and AC bias Maximum 16 data channels Maximum data size: 4096 × 4096 pixels Power: 200W
Vacuum controller	Angel & Gate Valve Control by PLC Dry Pump Power Supply Power: 700W (Full load)
Edward TIC Controller	Pump Control Turbo Pump Power Supply Power: 200W (Full load)

Chapter 3. Installation

The installation procedure and environmental specifications for the NX-Hivac play a significant role in the safe operation of the system. Since the durability, safety and overall performance of the NX-Hivac depend on the environment and proper installation, close attention to the following installation environment and procedures recommended in this chapter are necessary.

3-1. Environment

Table 3-1. NX-Hivac Requirement



Facility Requirements	
Room Temperature (Stand By)	18 °C ~ 40 °C
Room Temperature (Operating)	18 °C ~ 24°C
Humidity	30 % ~ 80 % (Not condensing)
Floor Vibration Level	VDC (6.25 μm/sec)
Acoustic Noise	<65dB
Floor Space	4000 (w) x 1300 (d)
Ceiling Height (mm)	2000 or more
Operating Working	4000 (w) x 1300 (d)

■ Temperature and Humidity

We recommend installing your Park NX-Hivac system in a clean, well-ventilated, low-humidity environment. For temperatures up to 30 °C, the maximum acceptable relative humidity is 80%.Maximum acceptable relative humidity, decreases linearly to 50% at 40 °C.

■ Vibration and Noise

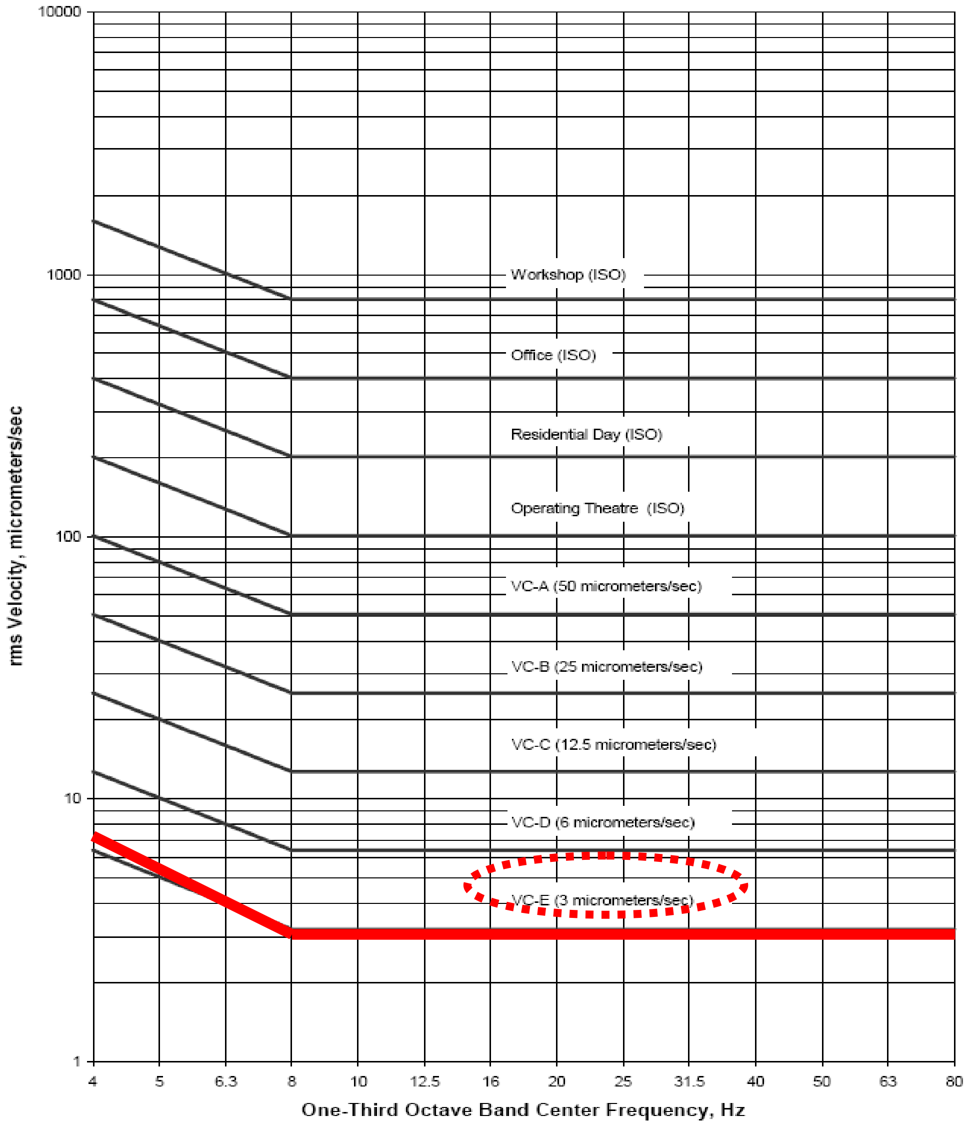
The Park NX-Hivac system must be installed on a level, hard surface. Since the AFM is very sensitive to vibration, a fixed-position active vibration isolation table is used. In addition, installing the AFM inside an acoustically shielded, ground level, or basement room is recommended to reduce inner and/or outer vibration. Installing the device near a wall or pillar inside the building can further reduce vibration and is recommended.

While measurements of samples of any physical size can be affected by vibration, measuring nano scale samples requires particular care. Even small vibrations from the floor can be significant at this scale. To minimize the effect of floor vibrations even further, ensure that cables are not taut, which can transmit vibrations. Note also that connecting the controller’s cable to the computer in a parallel circuit can damage the controller’s electronics.

The results measured by the AFM can also be influenced by acoustic noise and/or light. Therefore, the AFM must be installed away from fans and other sources of noise, such as air conditioning and heating systems. Though the unit requires adequate airflow for proper operation, avoid installing it near ventilation ducts and windows. Once a suitable location is chosen, use the acoustic enclosure and active vibration isolation system to keep vibration and noise to a minimum.

Please refer to Figure 3-1 for more information on recommended vibration levels. Note that the Park NX-Hivac system should be installed in an environment that meets or exceeds the criteria established by the line labeled “VC-E” in Figure 3.1.

Figure 3-1. Vibration Criteria Graph



■ Electrical Requirements

The Park NX-Hivac system requires an AC power supply with the following specifications:

- Power supply:100/120V or 220/240V, single phase, 15A, 60Hz
- Power consumption: 1.2kW(max)
- Ground resistance: recommended below 30ohms

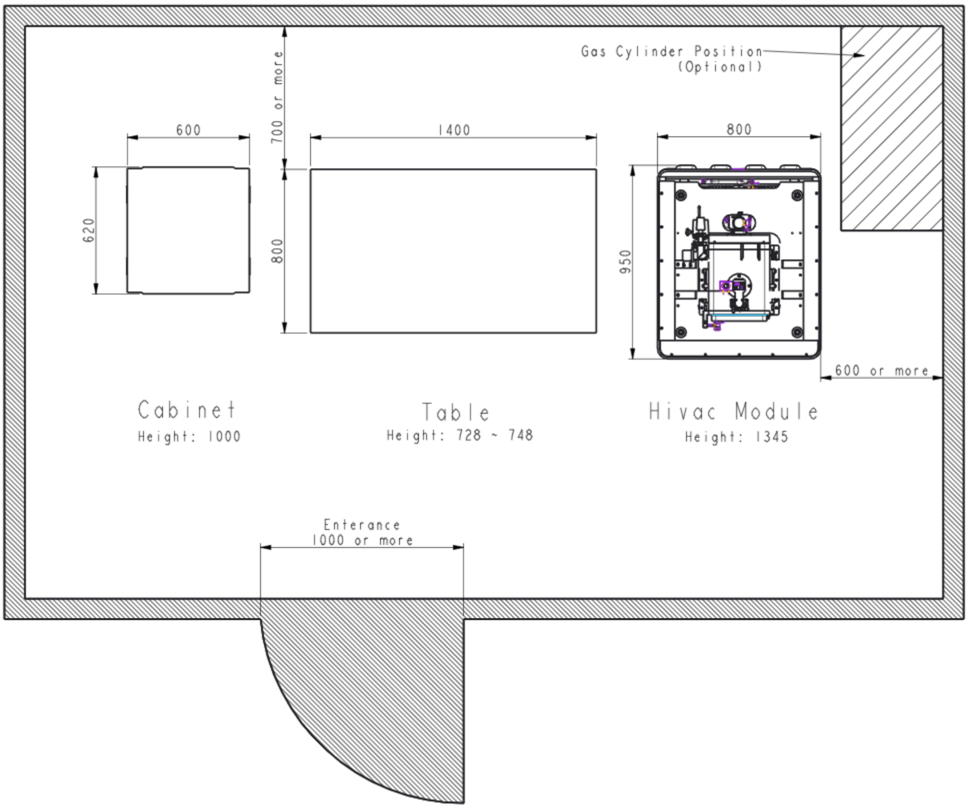
Since the Park NX-Hivac AFM is highly sensitive to power fluctuations, we recommend installing an uninterruptable power supply(UPS). To reduce image noise, connect all power cords to a grounded power source.

■ System Layout

The following table displays system dimensions. The space requirement of the NX-Hivac system installation is shown in Figure 3-2.

Dimensions and Weight	Width (mm)	Depth (mm)	Height (mm)
Vacuum chamber	300	420	320
AFM Controller	450	480	190
Granite Plate and support	800	950	730
NX-Hivac controller	450	450	150
Computer	178	445	448
Monitor	330	585	595

Figure 3-2. NX-Hivac System dimension and recommended clearance (Top view)



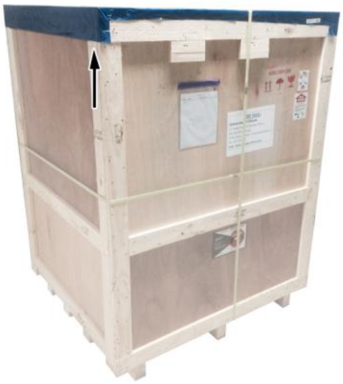
3-2. Component List

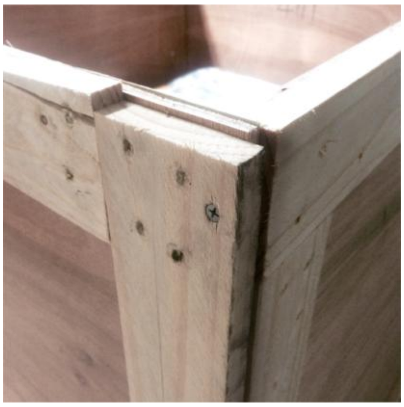
■ NX-Hivac SPM Main System

- NX-Hivac Main System
- NX AFM Controller
- NX-Hivac Controller
- Acoustic Enclosure
- Computer
- LCD Monitors (2ea)
- Accessory Ⅰ
- Accessory Ⅱ
- Tool Box
- Multi Cord
- Dry pump, Turbo pump
- Wooden Box Ⅰ
- Wooden Box Ⅱ
- Vibration Isolation
- Option (SSRM)
- Table & Cabinet

3-3. Uncrate

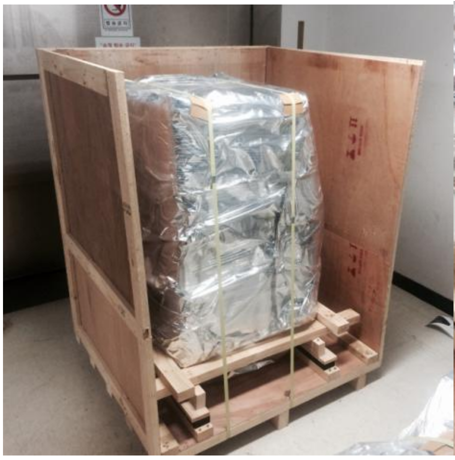
- Use a Phillips screwdriver to peel off the back of a blue vinyl top box and remove the screws that hold the panels in each side.





CAUTION: Two people are required to remove all panels of the crate.
Improper lifting can cause muscle strain or back injury.

- After removing the panel discard cut the banding strap wrapped around the product.



- Remove the vinyl using a knife or scissors.

- Collect as much as possible the forks of the forklift is located on the bottom, then place the product on the floor.

3-4. System Setup

3-4-1. Install Acoustic Enclosure

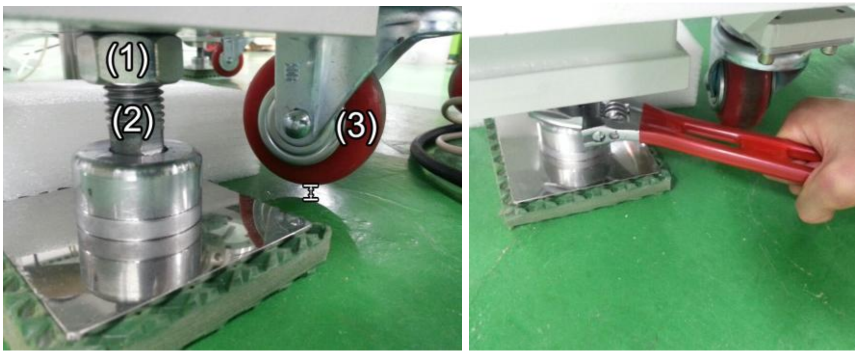
1. Choose a suitable location to install the Park NX-Hivac system. Locate the steel foot and wheel on the bottom four corners of the acoustic enclosure.

2. Using a wrench, adjust each steel foot (1)counter clock wise so that the attached wheel(3) can be raised about 5mm from the floor(refer to Figure 3-3). If the wheel is raised more than pictured, excess image noise could result.

3. Adjust the height of the steel feet mounted to the acoustic enclosure until the stone tabletop is level.

4. Once the stone tabletop is level, fix the height of each steel foot height by fastening the bolt ((2) in Figure 3-3).

Figure 3-3. Acoustic Enclosure Bottom



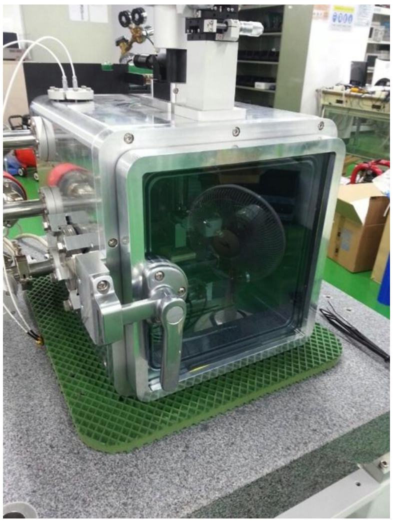
3-4-2. AVIS Setup (Optional)

1. Place the AVIS on the center of the stone tabletop. Install the AVIS according to installation manual provided by manufacturer of each AVIS.

3-5-4. Load the Vacuum Chamber

1. Make sure that the AVIS is locked before carefully placing and centering the Park NX-Hivac main system on top of the AVIS
2. Refer to the manual provided by the manufacturer of each AVIS to lock the AVIS.

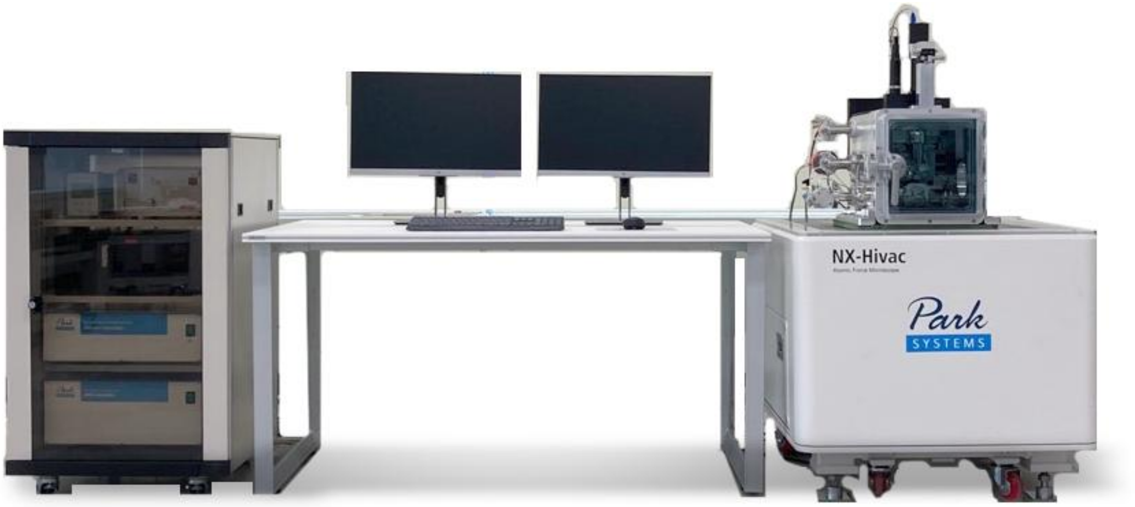
Figure 3-4. NX-Hivac main system placed on an AVIS



3-5-5. Load Control Electronics & Computer/Monitor

1. Load the Park NX-Hivac control electronics and monitors/keyboard/mouse/ computer on a suitable flat surface.

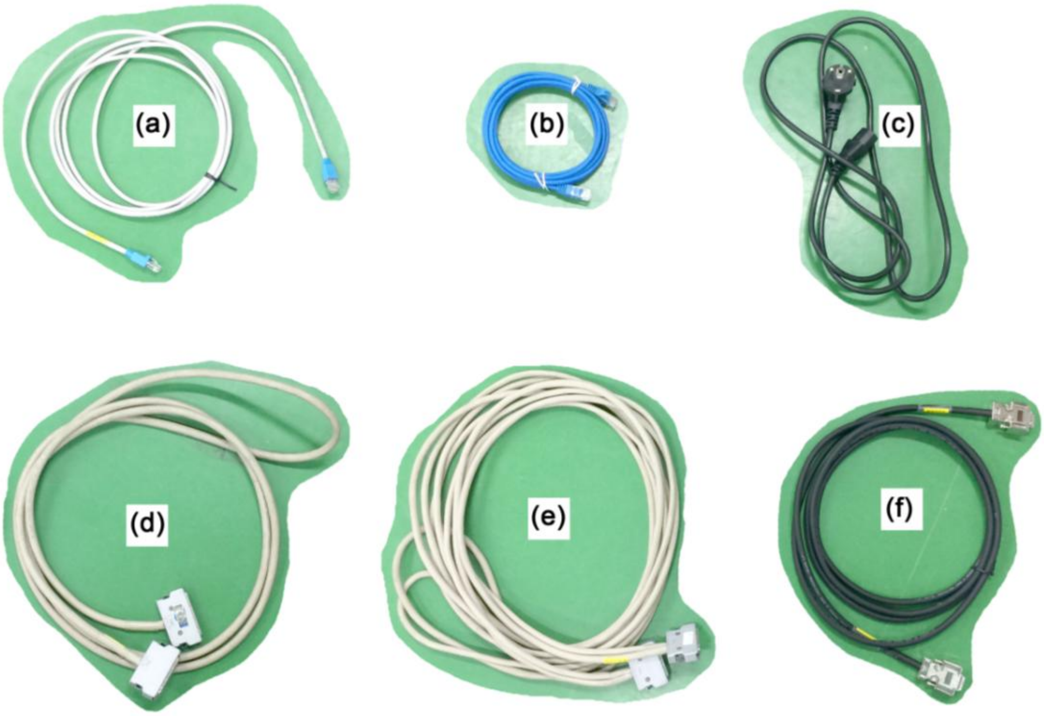
Figure 3-5. NX-Hivac System setup



3-5-6. Cabling

1. Required Cables:
   (a)Camera cable
   (b)Ethernet cable
   (c)Power Cable
   (d)Analog Cable
   (e)Motor cable
   (f)High Voltage cable
   (g)RS232 cable for PLC
   (h)RS232 cable for sensor
   (i)Solenoid valve control cable
   (j)Dry pump control cable
   (k)Turbo pump control cable
   (l)Dry pump power cable
   (m) Ethernet cable for low-vacuum gauge sensor
   (n)Ethernet cable for high-vacuum gauge sensor
   (o) Power cable for NX-Hivac controller

Figure 3-6. NX-Hivac Main System Cables



2. Cabling NX-Hivac main system (Figures 3-7 and 3-8)

① Connect the **Camera cable** between the illuminator connector (1) on the back of the NX-Hivac main system and the LAN port of the computer.

② Connect the **Motor cable** between the 50 pin connector (a) on the back of the NX-Hivac main system and the motor connector (A) on the rear panel of the NX-Hivac control electronics.

③ Connect the **analog cable** between the 68 pin connector (b) on the back of the NX-Hivac main system and the analog connector (B) on the rear panel of the NX-Hivac control electronics.

④ Connect the **High Voltage cable** between the High Voltage connector (c) on the back of the NX-Hivac main system and the Voltage connector (C) on the rear panel of the NX-Hivac control electronics.

⑤ Connect the **Ethernet cable** between the Ethernet connector (2) on the rear panel of NX-Hivac control electronics and the LAN port of the computer.

⑥ Connect the **power cable** (3) on the NX-Hivac control electronics.

Figure 3-7. Cabling NX-Hivac Main System

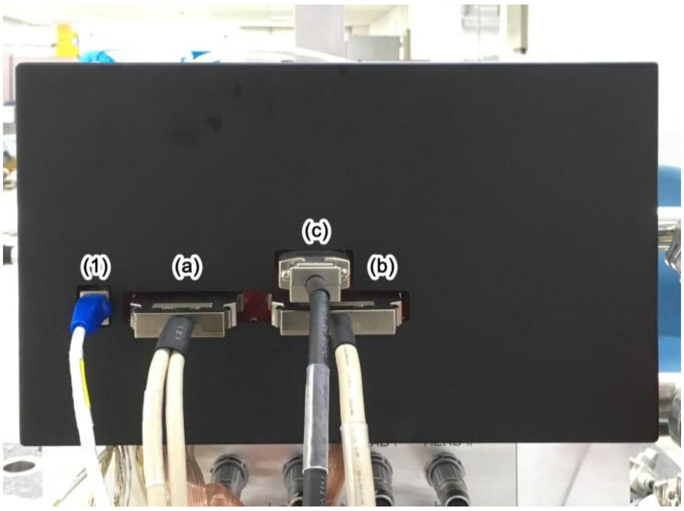
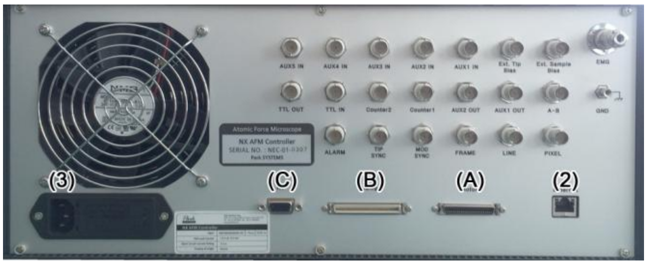


Figure 3-8. Cabling NX-Hivac control electronics



3. Cabling Computer

Please refer to the manual supplied by the computer manufacturer.

4. Connect Park NX-Hivac controller cables

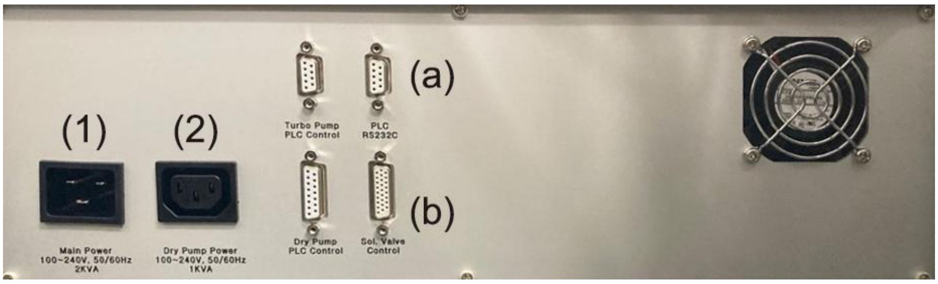
a) Connect the **RS232 PLC cable** between the connector (a) on the back of the Park NX-Hivac controller and the RS232 port of the computer.

b) Connect the **solenoid valve control cable** between the connector (c) on the back of the Park NX-Hivac controller and the pneumatic board on the system.

c) Connect the **power cable**(1) on the Park NX-Hivac controller.

d) Connect the **dry pump power cable** between the connector (2) on the back of the Park NX-Hivac controller and the dry pump power connector.

Figure 3-9. Cabling the Park NX-Hivac controller



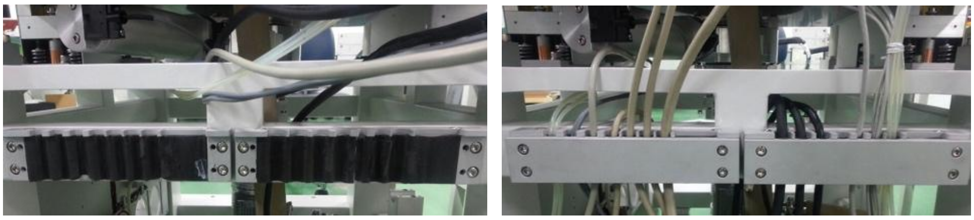
***A Note on Mounting Cables on the Vacuum Chamber**

To reduce the vibration transferred to the system via cables, main body cables should be attached using the cable mount on the back side of the vacuum chamber.

If the cable hanging between the cable mount(in orange rectangle) and main body is too tight, vibration can enter the system. Therefore, when clamping the cable in the cable mount, leave sufficient cable slack between the clamp and the system main body. Do not, however, leave so much cable slack that cables touch the AVIS, which can transmit vibration to the system.

1. Remove the small back cover of the acoustic enclosure by unscrewing four bolts.
2. Remove the cover of the cable mount by unscrewing four bolts.
3. Arrange the cables, then replace the cover and secure it using the screws.
4. In reverse order, attach the large/small back cover of the acoustic enclosure.
5. Connect computer cables

Figure 3-10. System rear view



Please refer to the manual supplied by the computer manufacturer for information on connecting the proper cables to the computer system.

3-5-7. Power On

1. Connect to Power Supply

Connect the Park NX-Hivac control electronics, computer, and monitors to the grounded power supply. Make sure that all switches are turned off to prevent damage to the equipment.

2. Power On

Turn on the power supply of all of the NX-Hivac system components.

NOTE!

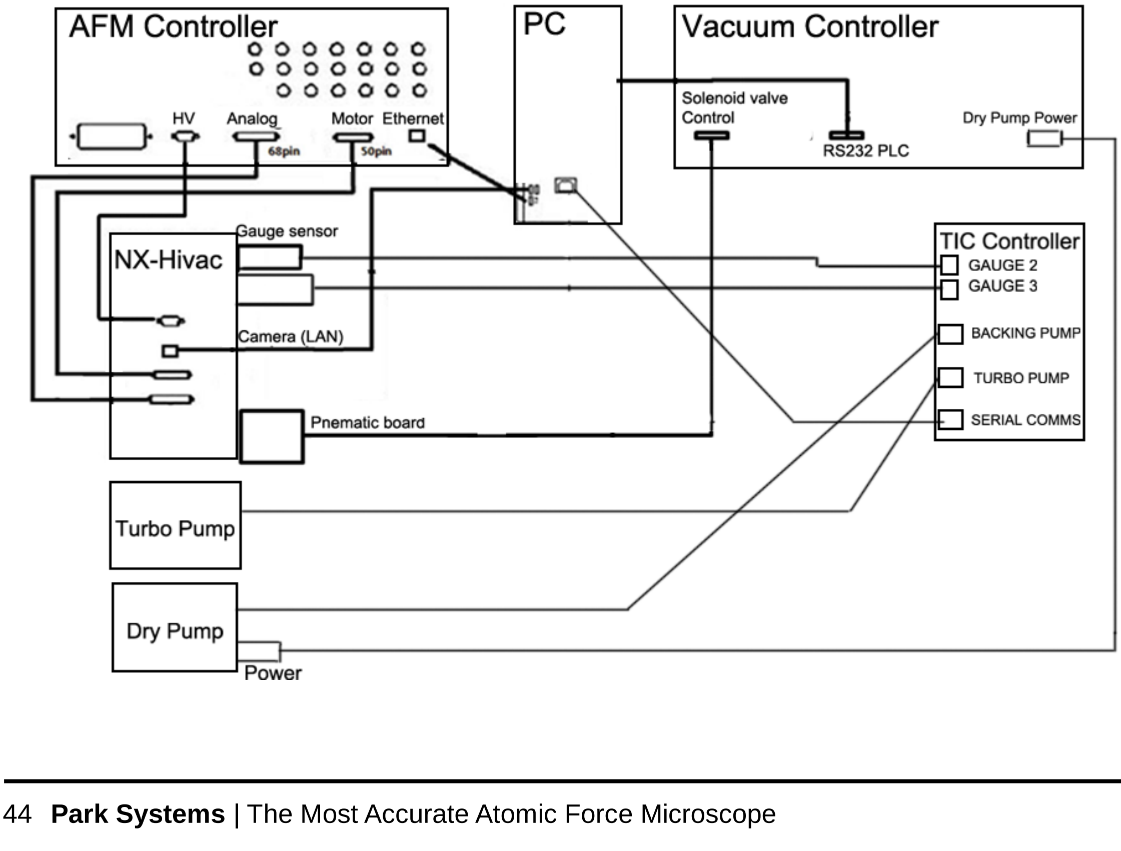
> Power to each component can be switched on in any order, but the Park NX-Hivac control electronics must be turned on before running the SmartScan™ software

3-5-8. Installation Checkup

1. Run SmartScan™ program

Click the SmartScan™ icon on the main window screen or in the folder C:\Park Systems\SmartScan\Bin. The program will start and you can check to ensure that system initialization completes without any error messages. If there is a problem, check whether the power supply is on, and make sure all the components are arranged correctly as shown in Figure 3-11 Components Setup.

Figure 3-11. Components Setup



2. Check Calibration of Scanners

① Load the standard sample on the magnetic sample holder of the XY scanner.

② Take image and check if the dimensions of the standard sample measured from the obtained image correspond to the specification of the standard sample.

3. Zero Scan Test

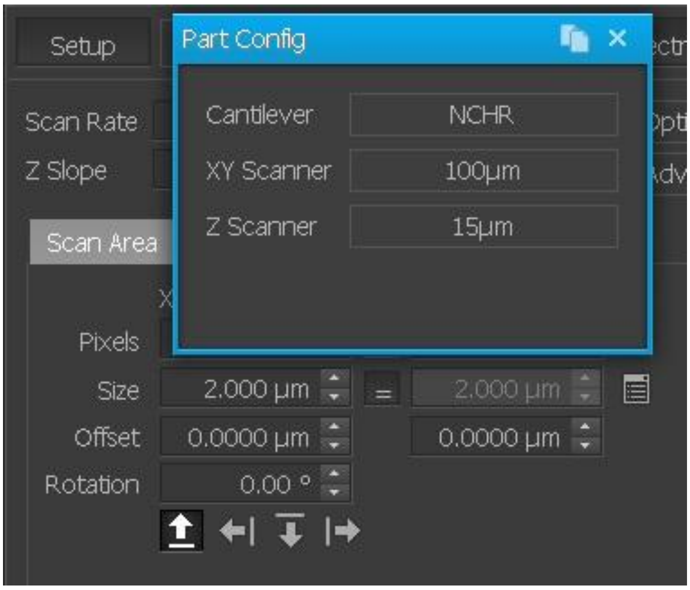
① Load a flat sample, such as bare silicon wafer, to the magnetic sample holder of the XY scanner.

② Mount a Non-contact cantilever (NCHR) to the probe hand.

③ Set the head mode to 'Contact mode' and approach to the sample.

④ Set the XY/Z scanner range to 0.2 at part config.

Figure 3-12. Part Config window



Cantilever NCHR
XY Scanner 100µm
Z Scanner 15µm
Size 2.000 µm = 2.000 µm
Offset 0.0000 µm 0.0000 µm
Rotation 0.00 °

⑤ Set Scan rate to 2 Hz, Gain 0.5, LPF 0, 256×256pixels and take a sample image with Scan Size 0.

⑥ Open the obtained Height image on XEI and flatten using the following conditions.

[1^{st} order 1µm x 1µm fast scan]

[2nd Order line by line in both X and Y direction]

⑦ Check the RMS roughness of the processed image. The RMS roughness should be less than 0.5Å for a properly installed NX-Hivac system equipped with an AVIS.

3-6. System Relocation

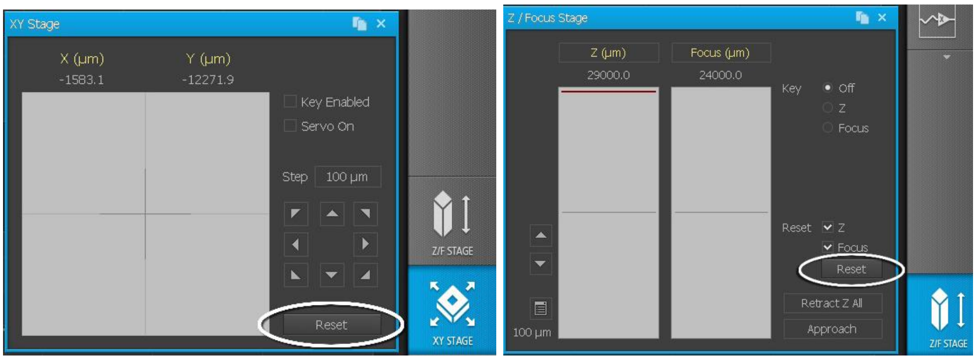
① Check the system (before transferring the system.

WARNING!

If you have an AVIS system, it should be in "Lock" mode in order to protect from outside impacts that may occur during shipping or storage. Please refer to the manual provided by the manufacturer for more detailed information regarding the AVIS system.

② Reset the motorized stages (XY, Z and focus) by selecting the [Reset] & [R.Origin] buttons.

Figure 3-13. Reset the motorized Stages



③ Put the power of NX-Hivac system [Control Electronics, Computer, Monitor] off.

④ Lock the optical microscope by following the Section 3-3-8 in reverse order.

⑤ Lock the AVIT before Turn off the power.

⑥ Disconnect the cables.

⑦ Lift the foot of the acoustic enclosure.

⑧ Relocate the acoustic enclosure to new installation site by pushing it using the wheel on the bottom.

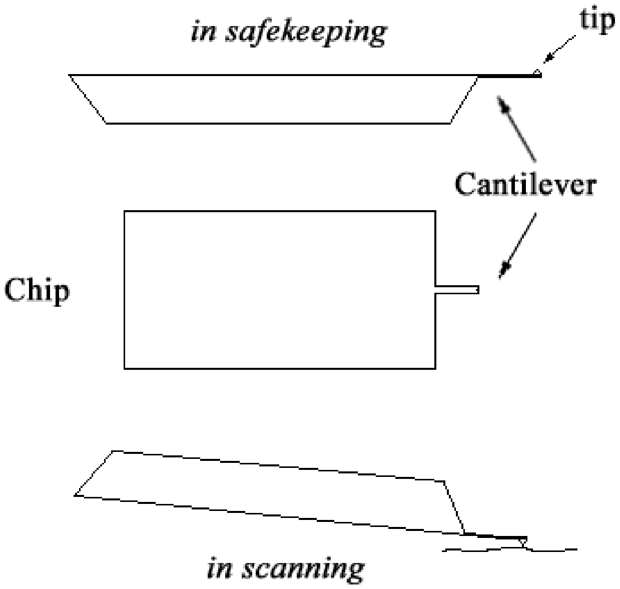
⑨ Set up the NX-Hivac system after finishing the system relocation.

Chapter 4. Cantilever Selection

4-1. Cantilever Characteristics

Generally speaking, the term ‘cantilever’ includes the silicon chip, a cantilever hanging from the chip, and a tip hanging from the end of the cantilever. Figure 4-1 shows the overall view and the names of the parts of the cantilever used in the SPM (Scanning Probe Microscope).

Figure 4-1. Cantilever Chip

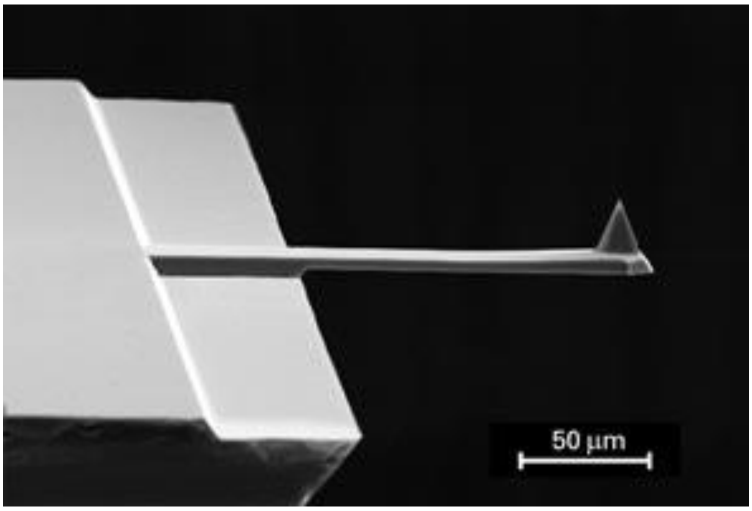


The chip, the cantilever, and the tip are made from Silicon (Si) or Silicon Nitride (Si_3N_4), and are manufactured using macro-machining techniques.

Because a cantilever has very small dimensions - 10㎛ width, 100㎛ length, and several ㎛ thickness - it is very difficult to handle in the process of attaching to the SPM. To make it easier to use, the SPM uses a relatively large chip, the size of several millimeters.

Figure 4-2 is an SEM image of a cantilever manufactured this way.

Figure 4-2. SEM image of silicon cantilever



The cantilever is the part sensing the surface properties (the topographic distribution, the physical solidity, electrical properties, magnetic properties, chemical properties, etc.) by detecting the degree of deflection due to the interaction with the sample surface, and is a determining factor for image resolution.

When viewed from the top, the structures of cantilevers are divided into two groups: those with a rectangular shape and those with a triangular shape. Each design has a different force constant depending on the width, depth, thickness, and composition material. Among different materials, the Silicon Nitride cantilever is stronger than the Silicon cantilever, but it has some disadvantages:

When the thickness is more than 1㎛, contortion may occur.

The curvature at the end of the tip is large – on the order of tens of nanometers.

It has a low aspect ratio.

Compared to this, the Silicon cantilever has a tip curvature of less than 10nm, and is more commonly used. In non-contact mode, which has a high resonant frequency, the rectangular shaped cantilever with a bigger Q-factor, a cantilever with a high force constant, is used more than the V shape. The cantilever provided with the NX-Hivac by default is a silicon, rectangular shaped cantilever for use in both contact and non-contact mode.

In addition, the upper surface of the cantilever (the opposite side of the tip) is coated very thinly with a metal such as gold (Au) or aluminum (Al) to enhance the reflectivity. However, for EFM (Electrostatic Force Microscopy) or MFM (Magnetic Force Microscopy), when the whole cantilever and tip is coated to measure the electric or magnetic prop erties, there is no extra coating on the cantilever.

4-2. Cantilever Selection

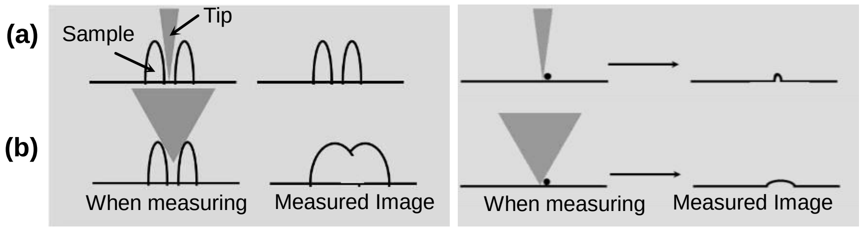
There are several types of cantilevers varying in material, shape, softness (represented by the spring constant), intrinsic frequency, and Q-factor. The choice of a cantilever from among these is primarily determined by the measurement mode.

For contact mode, a “soft” cantilever which has a small spring constant (typically 0.01 N/m ~ 3N/m) is chosen. The softer cantilever has a more sensitive response to the tiny forces between atoms. The probe tip used in contact mode has a thickness of about 1㎛ to achieve a small spring constant. The smaller spring constant results in larger deflections in response to small forces, and thus provides a very fine image of the surface structure.

Cantilevers used for non-contact mode are thicker (~ 4㎛), with a typical spring constant of 40N/m and a high resonant frequency. In Non-Contact Mode, the AFM vibrates a cantilever near its resonant frequency, and measures the force gradient via the amplitude and phase shift due to interaction between the probe and the sample. When an AFM is operating in the atmosphere, if the probe tip is situated on a moist or contaminated layer, it may often stick to the layer due to the surface tension of the tip. This happens more frequently when the spring constant of the cantilever is smaller. Because of the small spring constant, it is difficult to bring it back to the original position. Therefore we need a cantilever with a spring constant which can overcome the surface tension. The sharper the tip, the more stable operation can be expected because the surface area of the tip and the surface tension are reduced.

Selecting the proper cantilever depends partly on the morphology of a sample’s surface. For example, when the tip radius is bigger than the features of a sample, the tip shape will influence the resulting image, as shown in Figure 4-3(b). Therefore, a tip sharper than the smallest sample features should be selected in order to avoid these artifacts. Sharper tips, however, have shorter life times and are more expensive than general-purpose cantilevers. The standard cantilevers have a tip radius of 10nm.

Figure 4-3. Tip Convolution



Measuring a sample twice before and after rotating it relative to the sample stage allows a user to determine if there are any tip-shape artifacts in images. If such artifacts are present, one will see image features with the same orientation in both scans. However, if the original image is a true representation of the sample surface, then every feature within the images will appear rotated along with the sample.

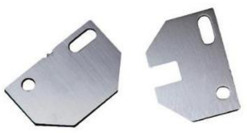
4-3. Cantilever Mounting

Cantilever chips must be mounted on chip carriers before use. Park Systems provides various types of chip carriers for different measurements. Both pre-mounted and unmounted cantilever chips are provided. If your cantilever chip is not mounted onto a chip carrier, you must do so with adhesive using glue type chip carriers or with clip type chip carriers. Once your cantilever chip is on a chip carrier, you can simply attach it to the probehand, where it will be held in place by magnets.

4-3-1. Glue Type Chip Carrier

The cantilever chip is attached onto the marked area on the glue type chip carrier (Figure 4-4) using glue. There are various glue type chip carriers:

Figure 4-4. Glue Type Chip Carrier



- Standard Chip Carrier
- Ceramic Chip Carrier for SThM
- Ceramic Chip Carrier for SCM
- Teflon Coated Chip Carrier for CP-AFM
- Teflon Coated Chip Carrier for EC-Cell

■ Required Components

The following items are required to load un-mounted cantilever chips in general.

- Glue type chip carrier
- Instant adhesive for metal

(Cyanoacrylate (superglue) adhesives provided with NX system are recommended)

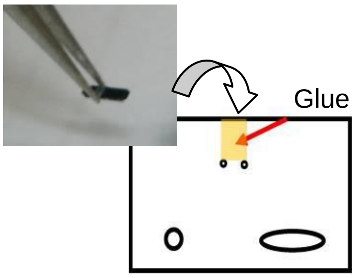
- Un-mounted cantilever chips

■ How to Load Un-mounted Cantilever Chip

① Remove any dust from the chip carrier.

② Pour some glue onto any flat area. Use a small stick, such as a toothpick, to place a dab of the adhesive on the chip carrier. The two small points (or grooved lines) on the chip carrier should be used as guidance for aligning the cantilever chip.

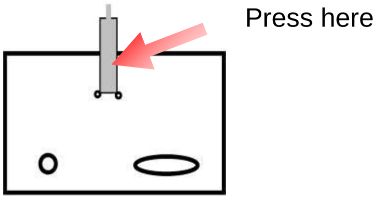
Figure 4-5. Loading Cantilever Chip on Glue Type Chip Carrier



③ Place the cantilever chip on top of the adhesive using forceps and align the edge with the two small points (or grooved lines).

④ Gently press down on the chip for several seconds.

Figure 4-6. Cantilever Chip Positioned on Glue Type Chip Carrier



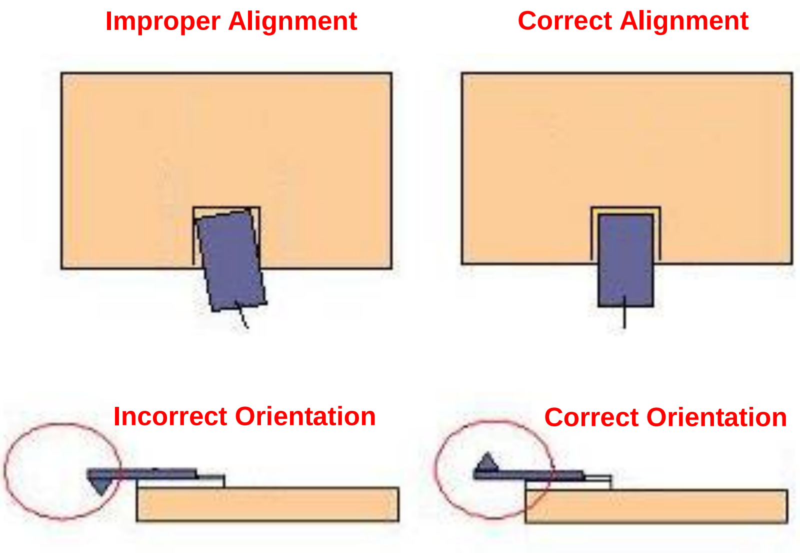
NOTE!

You should allow several hours for the adhesive to completely dry; otherwise, Non-Contact mode images may be affected.

NOTE!

Make sure that the cantilever chip is attached the right way up. If necessary, reattach the cantilever chip.

Figure 4-7. Correct Mounting of Cantilever Chip

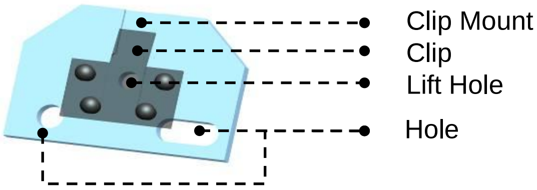


4-3-2. Clip Type Chip Carrier

Using the clip type chip carrier, an unmounted cantilever chip can be easily stabilized without glue. Figure 4-8 shows the structure of the clip type chip carrier.

- Chip Mount: Cantilever chip is placed here. (Size: 1.7mm × 2.55mm, 0.2mm thickness)
- Clip: Holds cantilever chip.
- Lift Hole: Meets with Cantilever Exchanger Pin. Pressing down this hole will open space between the Clip and Chip Mount area for mounting.
- Round Hole & Slot: These two Hole & Slot will be mounted on the probe hand. They will guide Clip Type Chip Carrier to be placed on the probe hand in consistent position.

Figure 4-8. Structure of Clip Type Chip Carrier



The chip type chip carrier is coated with chromium, is designed for various environments such as air, liquid, wiring, and does not need electrically conductive glue to be connected between the cantilever and chip carrier electrically.

■ Required Components

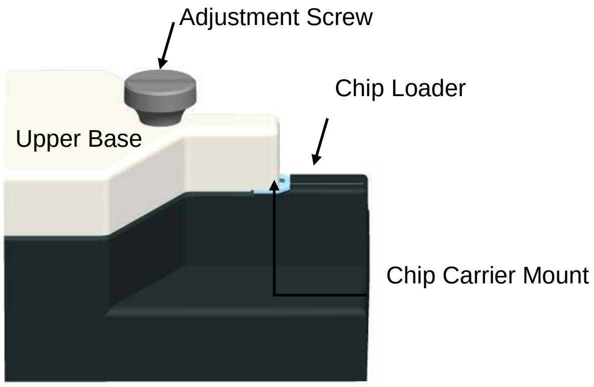
The following items are required to load un-mounted cantilever chip to standard clip type chip carrier.

- Standard Clip Type Chip Carrier
- Cantilever Exchanger
- Un-mounted Cantilever Chips

1. Cantilever Exchanger

There is a round hole, visible when the upper base is uncovered. When you overlay the chip carrier hole above the pin located on the chip carrier mount part of the cantilever exchanger and press the upper base of the cantilever exchanger, then the bottom part of chip carrier will go down and the clip will be opened. Then, the un-mounted cantilever chip can be easily placed.

Figure 4-9. Cantilever Exchanger



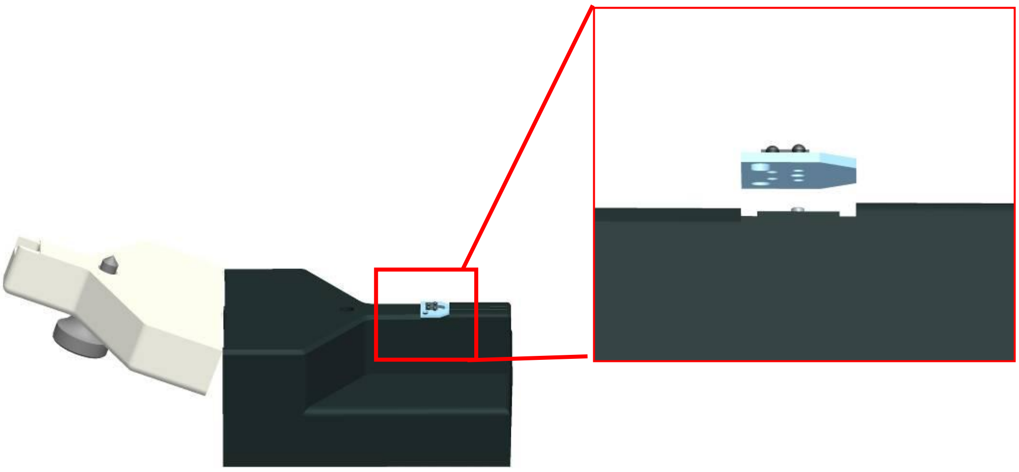
There is an adjustment screw on the upper base of the cantilever exchanger to move the upper base up or down. Turning the screw clockwise moves the upper base down and keeps the clip opened. Turning the screw counter-clockwise moves the upper base up and keeps the clip closed.

■ How to Load Un-mounted Cantilever Chip

① Lift up the upper base of the cantilever exchanger.

② Place the clip type chip carrier on top of chip carrier mount. Make sure that the round hole on the bottom of the chip carrier is overlaid on the chip carrier mount pin.

Figure 4-10. Placing Clip Type Chip Carrier on Cantilever Exchanger

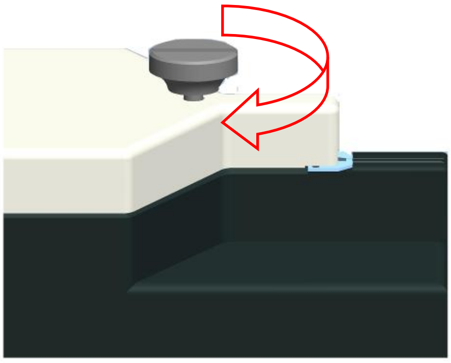


NOTE!

The cantilever may not be mounted correctly if the cantilever chip isn’t sufficiently aligned on the Cantilever Exchanger.

③ Close the upper base of cantilever exchanger and turn the adjustment screw clockwise to open the chip carrier’s clip.

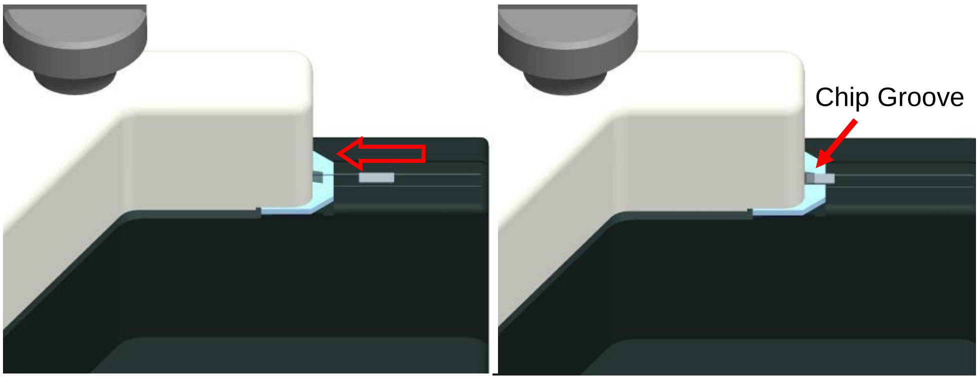
Figure 4-11. Adjust Clip Position



④ Pick an un-mounted cantilever chip using tweezers and place it on chip loading place of the cantilever exchanger.

⑤ Slide the cantilever chip into end of the chip groove on the chip carrier.

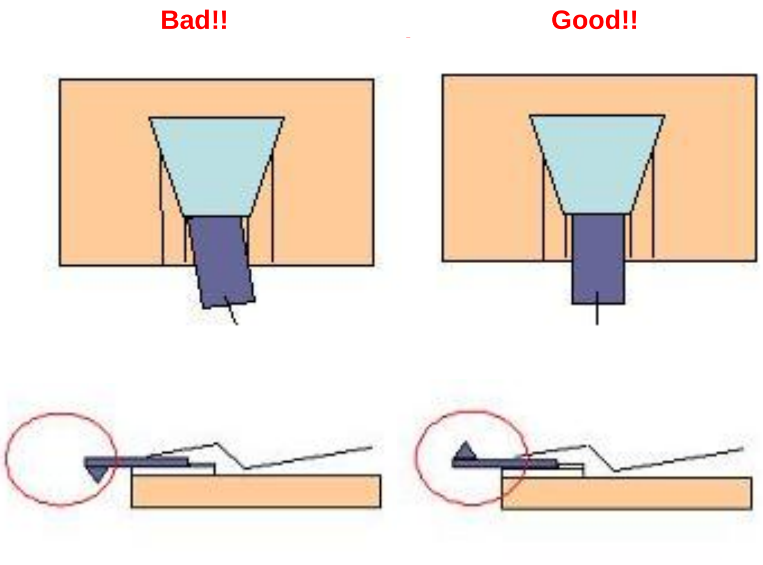
Figure 4-12. Mount Cantilever Chip



NOTE!

Make sure that the cantilever chip is placed the right way up. If necessary, reinsert the cantilever chip.

Figure 4-13. Correct Mounting of Cantilever Chip

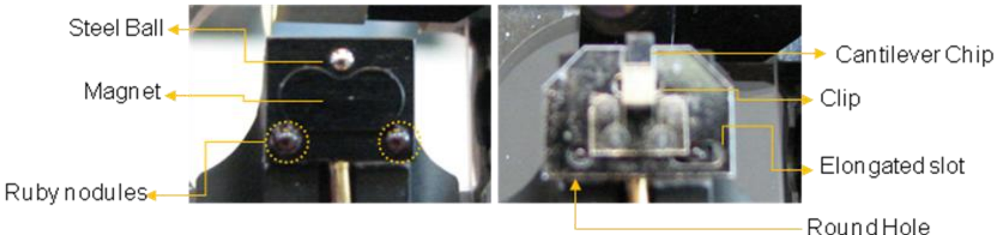


⑥ Turn the adjustment screw of the cantilever exchanger counter-clockwise to lift up the upper base.

4-3-3. Chip Carrier Mount

Mount the chip carrier with a cantilever chip to the probehand.

Figure 4-14. Probe Hand before (left) and after (right) Chip Carrier is attached



There are two holes in a chip carrier; a round hole and an elongated slot. When you overlay the two ruby nodules located on the end of the probe arm with these holes, the cantilever chip will be attached into place by a magnet, and the position of the cantilever will be firmly fixed in one position.

4-4. Cantilever DB

The cantilever DB stores specifications for each cantilever type. The SmartScan™ software comes preloaded with database entries for cantilevers shipped with the system. The user can specify which cantilever is in use in SmartScan™ through the Setup menu: [Line Scan Click>Setup>Cantilever]. If an entry doesn't exist for your cantilever, you can create one with the following steps:

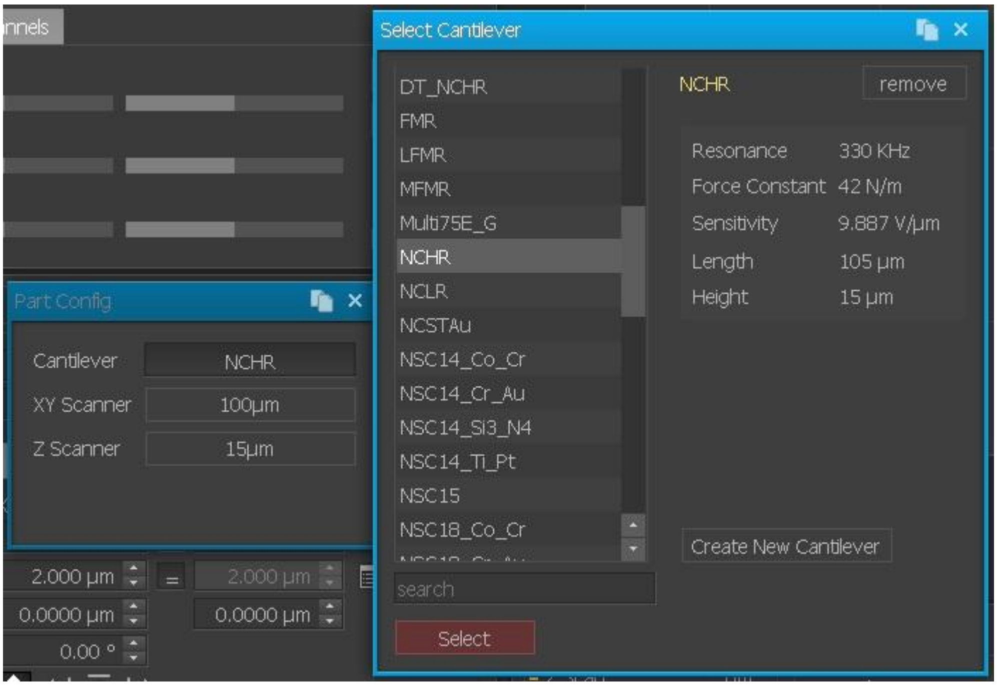
[Step]:

Create Cantilever DB -> Input Cantilever Spec -> Calibrate VERTICAL Sensitivity

4-4-1. Create Cantilever DB

1. Turn off the head.
2. Open the 'SmartScan™ Part Selection' dialog by clicking [Line Scan Click>Setup>Cantilever] on SmartScan™.
3. Clicking the [Advanced] button will display the 'Create Part' panel. In this panel, select 'Part Type' as 'Cantilever'.
4. Write a name for your cantilever in the blank space on the left of the [Create] button, and click the [Create] button. It creates a new cantilever DB using the currently selected cantilever DB and switches to the newly created cantilever DB.

Figure 4-15. Create Cantilever DB



Part Config

Cantilever NCHR

XY Scanner 100μm

Z Scanner 15μm

Select Cantilever

NCHR

Resonance 330 KHz

Force Constant 42 N/m

Sensitivity 9.887 V/μm

Length 105 μm

Height 15 μm

NOTE!

Before you create the cantilever DB, it is recommended to select the cantilever type with a similar force constant since the cantilever DB is created by copying the previous selected one.

4-4-2. Input Cantilever Specification

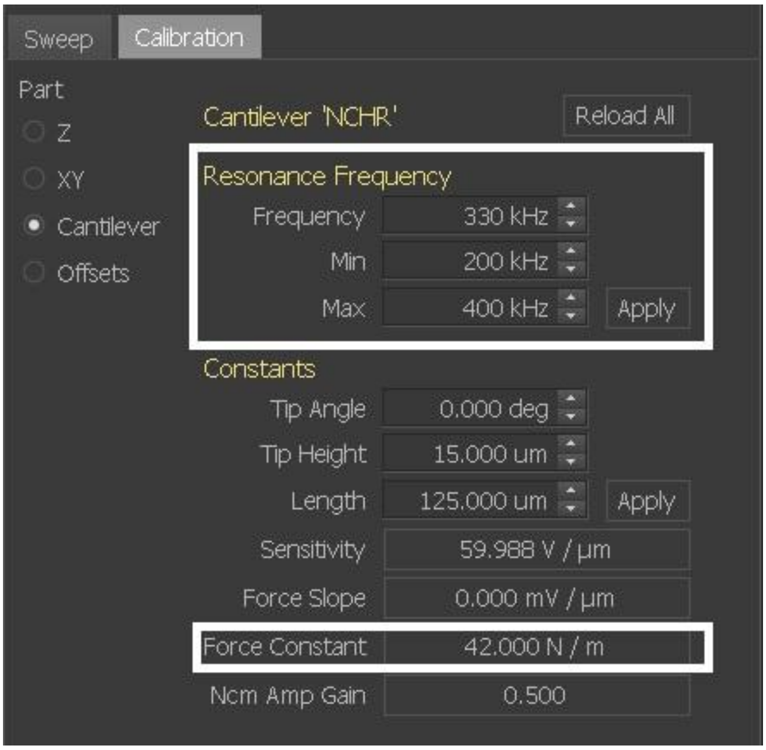
1. Turn on the head and switch to ‘Maintenance’ mode by selecting [Mode>Maintenance Mode].

NOTE!

The default password is set to ‘probe’ .

2. Go to ‘Cantilever Calibration’ by clicking [Mode>Calib Mode>Cantilever].
3. Write the resonance frequency range (Minimum Frequency, Maximum frequency), the typical resonance frequency and the force constant. Refer to the cantilever specification sheet provided by the cantilever manufacturer.
4. Save the input values by clicking the **Apply** button.

Figure 4-16. Input Cantilever Specification



Part
○ Z
○ XY
● Cantilever
○ Offsets

Cantilever 'NCHR'

Resonance Frequency
Frequency 330 kHz
Min 200 kHz
Max 400 kHz

Constants
Tip Angle 0.000 deg
Tip Height 15.000 um
Length 125.000 um
Sensitivity 59.988 V / µm
Force Slope 0.000 mV / µm
Force Constant 42.000 N / m
Ncm Amp Gain 0.500

4-4-3. Calibrate VERTICAL Sensitivity

VERTICAL sensitivity is the calibration factor between the deflection of the cantilever and the movement of the reflected beam on the PSPD. In contact mode, this PSPD position is converted to a distance deflected by the cantilever using the VERTICAL sensitivity calibration. That deflection is then converted to a force in Newtons using the spring constant of the cantilever stored in its DB file.

For Force (V), $F=Sx$

For Force (N), $F=kx$

(F: Force (N or V), k: Force constant (N/m), x: Deflection (m), S: VERTICAL Sensitivity (V/m))

VERTICAL sensitivity is obtained by taking a FD (Force vs. Z scanner displacement) curve. Before this curve can be taken accurately, however, one first needs to calibrate the AFM's Z scanner and the force constant of the cantilever

1. Taking an FD curve (in contact mode) on a bare Si wafer sample with your cantilever.

***FD Curve**

a) Approach your cantilever to the sample.

b) Go to FD spectroscopy by selecting [Mode>Scan Mode>FD Spectroscopy] or the icon.

c) Add a point on the scan image.

d) Set the parameters on FD spectroscopy control window.

e) Perform FD spectroscopy by clicking the [Acquire] button.

f) Zoom in the region that has a linear slope by dragging the mouse after acquiring the FD curve and click the [Apply] button. Then, the Z scanner moving range (Min, Max) is automatically changed to one in the selected region.

g) Perform FD spectroscopy again by clicking the [Acquire] button.

(For more information about FD Mode, Please refer to 10-10-1.)

2. Switch to 'Maintenance' mode by selecting [Mode>Maintenance Mode].

NOTE!

The default password is set to 'probe '.

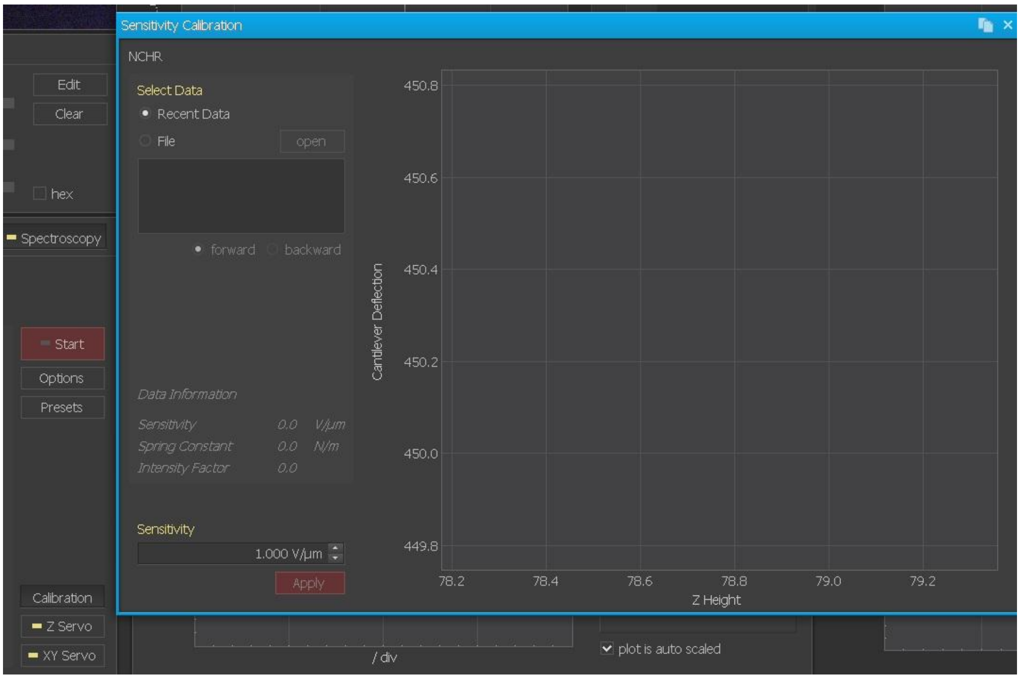
3. Go to 'Cantilever Calibration' by clicking [Mode>Calib Mode>Cantilever] or by cl

icking the icon.

4. Select 'Sensitivity' in the 'Cantilever' tab.
5. Open the curve you obtained in FD spectroscopy. If it was the last FD curve obtained with this system, it should already be open.
6. Select the linear area in this curve by clicking and dragging on the mouse.
7. Click the [Calculate] button to calculate VERTICAL sensitivity value.
8. Click the [Calibrate] button for VERTICAL Sensitivity to apply the value obtained in the previous step. Click the **Apply** button to make the calibration permanent.

Figure 4-17 shows a labeled image of SmartScan™, showing some of the steps for VERTICAL sensitivity calibration.

Figure 4-17. VERTICAL Sensitivity Calibration



Data Information

Sensitivity 0.0 V/µm
Spring Constant 0.0 N/m
Intensity Factor 0.0

Sensitivity 1.000 V/µm

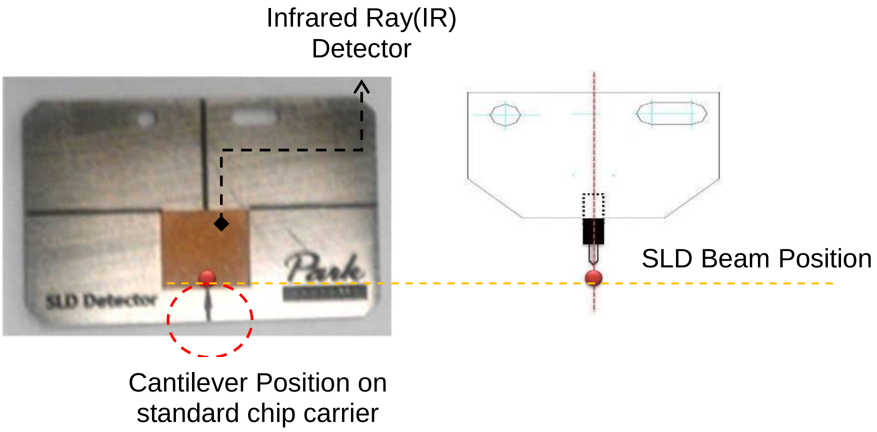
4-5. Cantilever Storage

When cantilevers are kept in ambient conditions with variable temperature and humidity for long periods, their reflected beam intensity can decrease due to oxidation of the cantilever coating material. It is also possible that the end of the tip can become damaged. For these reasons, it is recommended to store cantilevers in a desiccator

4-6. SLD Detector Chip Carrier

When the SLD beam is aligned to the Infrared Ray Detector, it is visible to the naked eye. The beam falls on the same location as the cantilever when using the Standard Chip Carrier, marked by the ↑ arrow in the figure above, so it is easy to position the SLD beam onto the SLD detector.

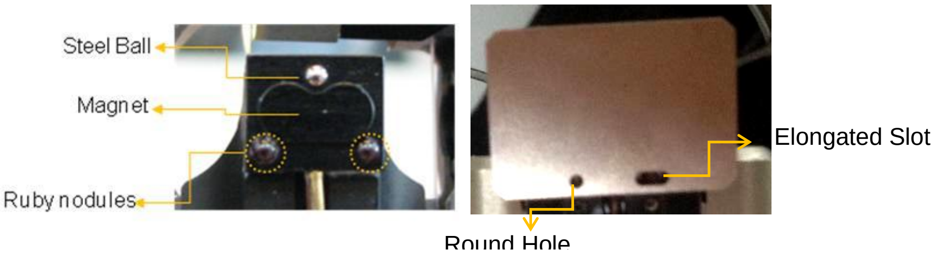
Figure 4-18. (Left) Beam position when using SLD detector Chip Carrier, (Right) Beam position when using Standard Chip Carrier.


Infrared Ray(IR) Detector
SLD Detector
Park
SLD Beam Position
Cantilever Position on standard chip carrier

Attachment

There are two holes in the chip carrier, a round hole and an elongated slot. Overlay the two ruby nodules located on the probehand with these holes. The detector chip carrier will be attached into place by a magnet, and its position will be firmly fixed in this one position.

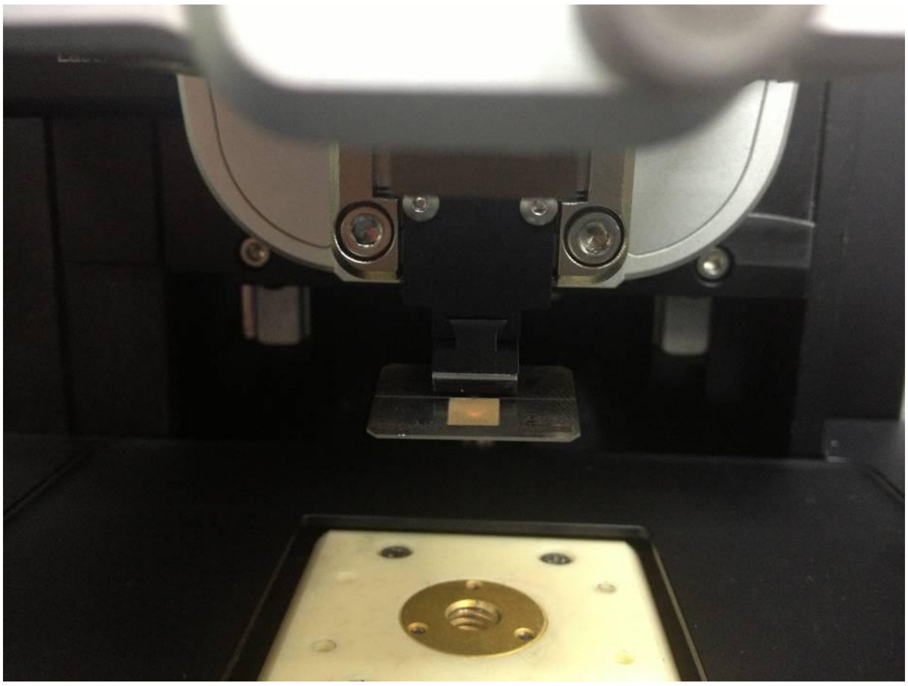
Figure 4.19. (Left) Standard Probehand, (Right) with the SLD detector chip carrier attached.



Usage

1. Attach the detector chip carrier on the probehand (4-19).
2. Position the SLD beam on the location marked ↑ by adjusting the beam alignment knobs until the SLD beam becomes visible (4-20).

Figure 4-20. SLD beam on the Detector Chip Carrier



3. Re-attach the chip carrier and cantilever after removing the detector chip carrier.
4. Move the SLD beam upward or downward while turning the Y beam alignment knob (large knob on the left side of head), since the SLD beam has been located on the cantilever position in X axis but with an offset in Y axis, depending on the cantilever type (Figure 4-18).

Note!

When using the SLD detector Chip Carrier, please turn off the illuminator.

Chapter 5. Operation Procedure

5-1. Basic Procedure

[Step] Following is procedure for Operation measurement:

Powering On ->Loading a Sample ->Removing the Head ->Loading a Cantilever ->Finding the Cantilever->Aligning the Beam on the Cantilever ->Centering the Beam on the PSPD ->Vacuum pumping ->Approaching the Tip to the Sample

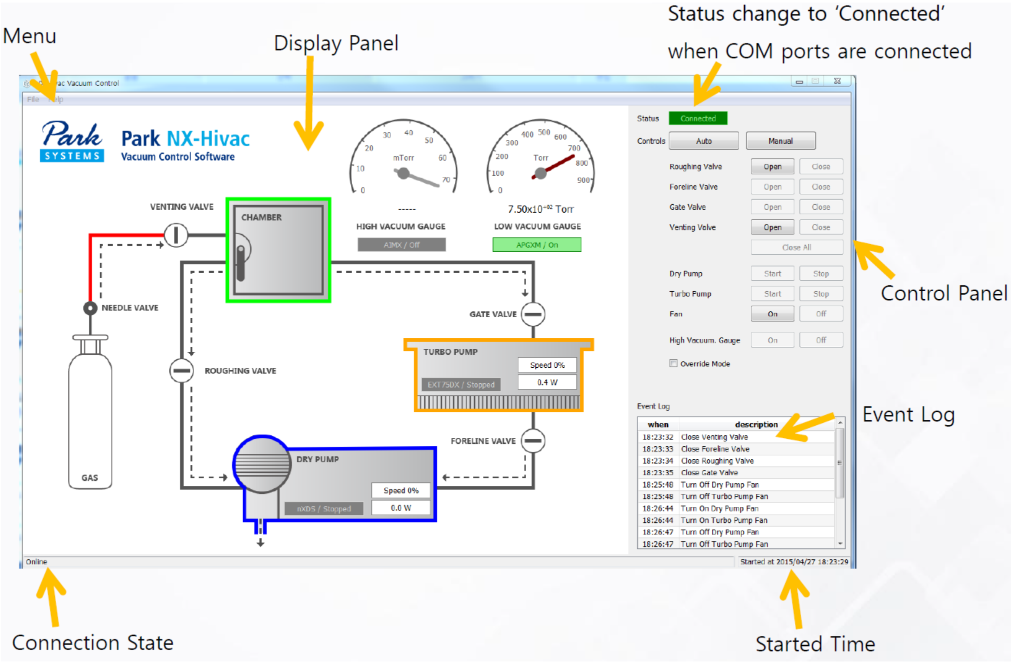
5-1-1. Power On

1. Turn on the components of your NX-Hivac system
   [Computer, Monitors and Control Electronics]

NOTE!

> The Control Electronics must be turned on before the SmartScan™ Program is started; otherwise, you will receive a initialization error message and will need to restart SmartScan™.

2. The NX-Hivac is operated by the SmartScan™ software. When you click the SmartScan™ icon in the desktop or in C:\Park Systems\SmartScan\bin of your computer, you can start SmartScan™, the software program for controlling NX- Hivac.
3. Turn on the NX-Hivac controller
4. Running the NX-Hivac Manager. When 'NX-Hivac Manager' is runned automatically closes all of Valve.

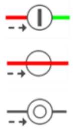


Event Log

when	description
18:23:32	Close Venting Valve
18:23:33	Close Foreline Valve
18:23:34	Close Roughing Valve
18:23:35	Close Gate Valve
18:25:48	Turn Off Dry Pump Fan
18:25:48	Turn Off Turbo Pump Fan
18:26:44	Turn On Dry Pump Fan
18:26:44	Turn On Turbo Pump Fan
18:26:47	Turn Off Dry Pump Fan
18:26:47	Turn Off Turbo Pump Fan

Started at 2015/04/27 18:23:29

Figure 5-1. The Park NX-Hivac Manager™user interface of the Park NX-Hivac system



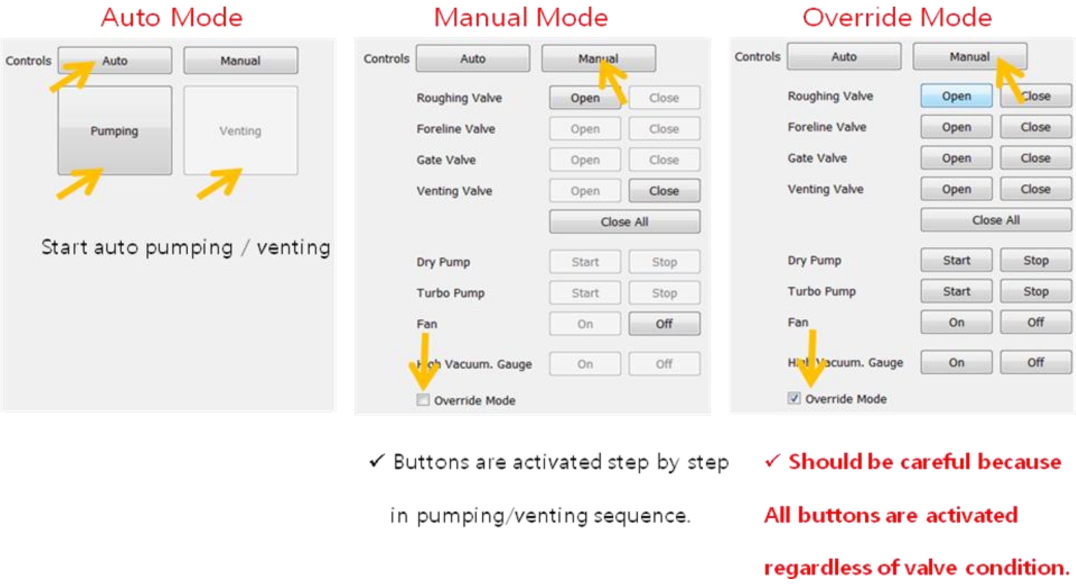
"Closed" (both side of pipeline are displayed as different color)

"open" (both side of pipeline are displayed as same color)

"unknown" (During opening / closing)

Figure 5-2. UI of the Valve condition

5. Auto and Manual mode can be chosen.



Start auto pumping / venting

✓ Buttons are activated step by step in pumping/venting sequence.

✓ Should be careful because All buttons are activated regardless of valve condition.

Figure 5-3. UI of the Control Panel

Warning!

Do not open the foreline valve until turbo pump power has reached 0%!!

6. Proceeds in the following order the Auto Pumping.

   [Controls – Auto – pumping].

Table 5-1. Auto Pumping / Venting process

Auto pumping	Auto venting
1. Displaying messages "Check closed Door" and Receive Confirm to proceed	1. Take Checked before staring for User
2. Turn on Fan	2. Turn off High Vacuum Gauge
3. Turn off High Vacuum Gauge	3. Close Gate Valve + 1.0 Second Standby
4. Close Gate Valve	4. Stop Turbo pump + 1.0 Second Standby (Do not wait until fully stop)
5. Close Venting Valve	5. Close Foreline Valve + 1.0 Second Standby
6. Close Foreline Valve	6. Stop Dry Pump (Standby wait until fully stop)
7. Open Roughing value + 1.0 Second Standby	7. Open Roughing Valve + 1.0 Second Standby
8. If Turbo Pump On, Wait until Off	8. Open Venting Valve + 1.0 Second Standby
9. Open Foreline valve + 0.5 Second Standby	9. Instruction (Needle Valve to open) for user
10. Turn on Dry pump	10. Wait until the Over 7.5 * 10^{+2} Torr of Low Vacuum Gauge
11. Wait until the Under 1.5 * 10^{-1} Torr of Low Vacuum Gauge	11. Complete
12. Turn on Turbo Pump + Wait until the Over 80% Speed	
13. Close Roughing Valve + 2.0 Second Standby	
14. Open Gate Valve	
15. Turn on High Gauge + 1.0 Second StandBy	
16. Complete	

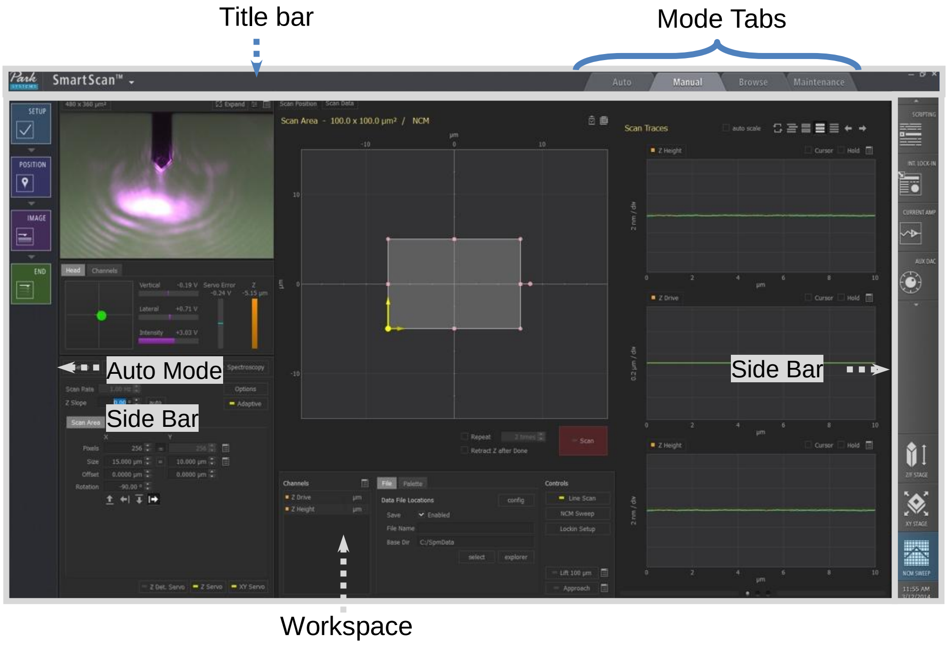


Figure5-4. The SmartScan™user interface of the Park NX-Hivac system

5-1-2. Load Sample

1. Mount sample onto the sample plate using tape or glue. If possible, the best method is to glue the sample on using hard-setting instant adhesives.
2. Load sample on the magnetic sample holder. If the sample is large, unscrew the magnetic sample holder from the XY scanner and place sample directly on the Sample chuck at the XY Scanner.
3. Locate sample underneath the probe hand using the XY stage control. See ‘Motorized Stage Control’ section for more information on stage control.

NOTE!

Before you use the XY stage pad, be sure to lift the tip off the sample by using the Z stage control pad.

WARNING!

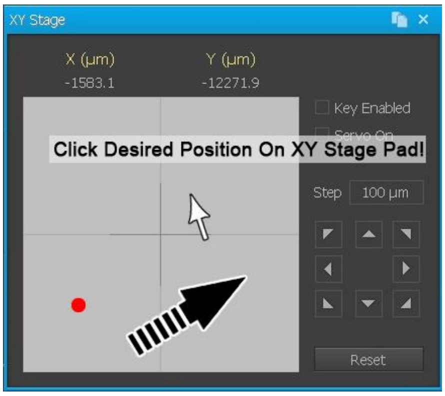
When the Z scanner’s arm and the sample are very close, a rapid movement of the Z scanner may cause the scanner’s arm to collide with the sample. This may result in severe damage to the probe tip, the sample, and/or the scanner itself.

NOTE!

The cantilever depiction in the Z Stage pad is not the center bar. Treating it as the center bar will result in unintended movement of the Z Stage.

**XY Stage Control Window*

For the NX-Hivac, you can see both XY and Z/F stage pads on the screen. If there is no “X-Y stage control window” on your computer screen, you can open this window by clicking the X-Y stage icon .



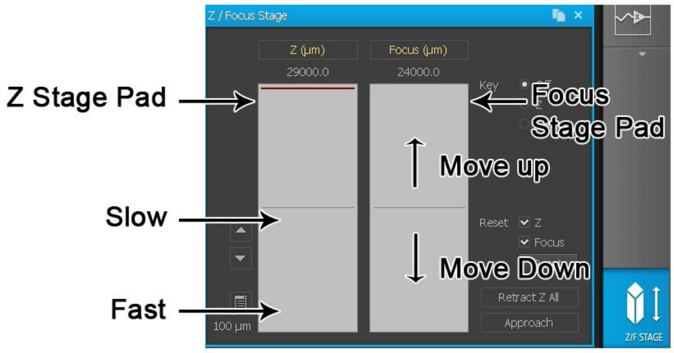
Click Desired Position On XY Stage Pad!

The XY stage pad is used to move the tip around the sample surface before you take an image. The XY stage can be moved in both the x and y directions, which moves the sample relative to the probe tip. The XY stage pad controls both the direction and the speed of the XY stage. Move the cursor with your mouse and click the cursor where you want to get images in the X-Y stage pad, then the X-Y stage will move in the opposite direction so that the NX head move to the defined location. The red point represents the position of the NX head, and you can see its movement by watching this point. This allows for convenient repositioning of the NX head around the sample surface. To increase the speed of movement, click the cursor further from the center cross on the XY stage pad.

**Z stage and Focus stage Control*

The Motor Control window contains the Z Stage and Focus components. These control pads are used to lower or raise the Z Stage and Focus Stage.

Clicking above the center bar will raise that stage, and clicking below the center bar will lower it. The speed depends on how far away from the bar you click. The NX-Hivac Focus stage’s movement is synchronized with that of the Z stage. Therefore clicking Z stage pad will move the Z stage and the Focus stage together. However clicking Focus stage pad will move the focus stage only.



WARNING!

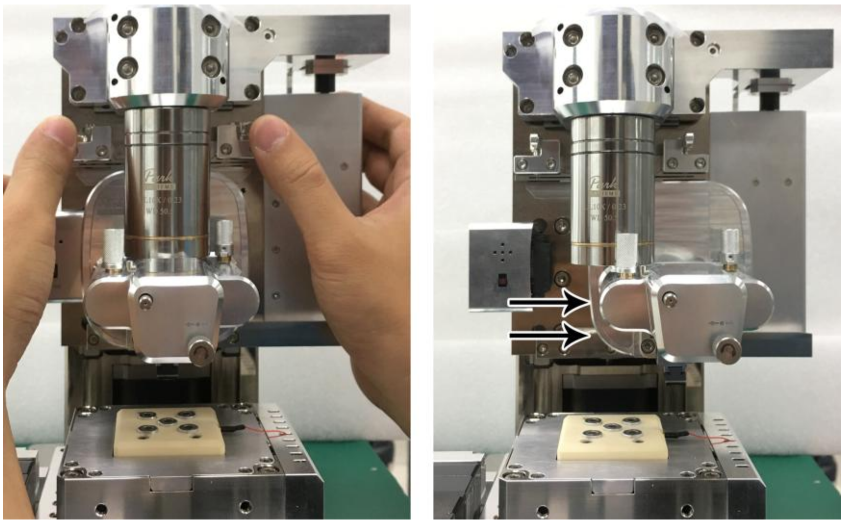
> Be cautious when loading large modules such as EC Cell or ULC onto the NX sample chuck. They may collide with the motorized XY stage when it is moved through a large range, and the module and/or the NX system may be damaged.

5-1-3. Cantilever Mount

Remove Head from the NX-Hivac Main System

1. Confirm that the head has clearance. If it is too close to the sample, raise the Z stage. If the Focus stage is too close to the head, raise the Focus stage.
2. Turn off the AFM beam switch and unlock the dovetail locks on the sides of the head. Disconnect the head from the connector of the NX-Hivac main system. Then, slide the head out to the right.

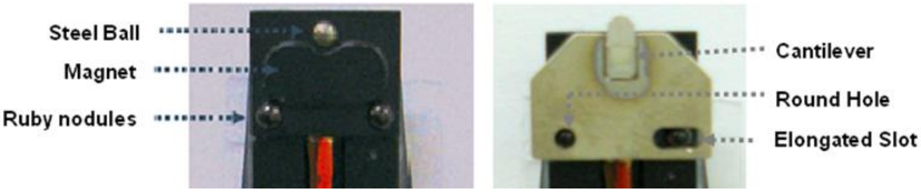
Figure 5-2. Removing NX-Hivac Head



Load Cantilever onto Probehand

1. Mount cantilever onto the probehand on the head. To ensure no damage to the cantilever occurs, it is recommended that the cantilever chip mount is held between your thumb and your index finger. The alignment is simple since two holes on the chip mount should fit directly over the two ruby balls on the magnetic tip holder on the probe hand.

Figure 5-3. Load Cantilever onto Probehand



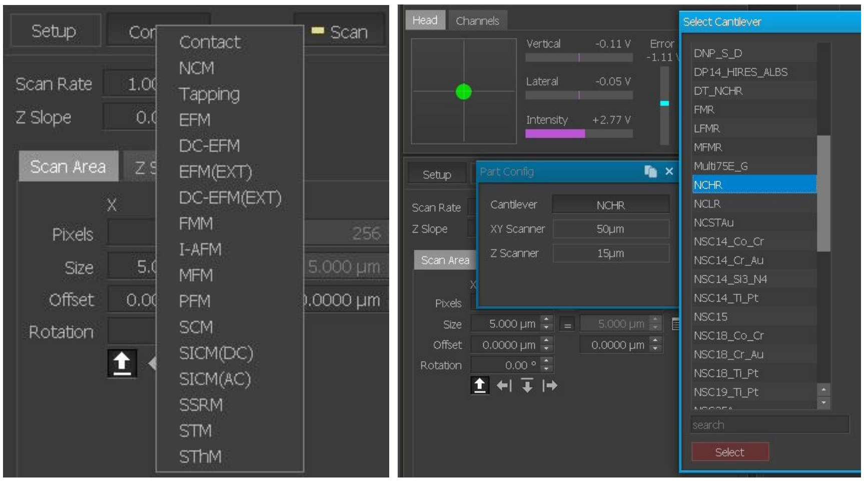
2. The center of the camera on the monitor screen is the approximate position of the last user’s cantilever, and therefore the beam. It is very important to NOT adjust the optical alignment knobs in order to make Section 6-5 much easier.

Attach Head to the NX-Hivac Main System

5-1-4. Select Head Mode/Cantilever

1. Attach the head to the NX-Hivac main system in inverse order of Figure 5-2 Turn off the Line scan by clicking the Head mode box to select Head mode and then clicking the Setup box in the SmartScan™ software.
2. Select the desired Head mode in this SmartScan™ Part Selection dialog. Then, turn on the Line scan.

Figure 5-4. Part Selection Dialog



Vertical -0.11 V
Lateral -0.05 V
Intensity +2.77 V
Error -1.11 V

Cantilever NCHR
XY Scanner 50µm
Z Scanner 15µm

Size 5.000 µm = 5.000 µm
Offset 0.0000 µm 0.0000 µm
Rotation 0.00 °

5-1-5. Find Cantilever

1. Move the focus stage down nearby the head using the focus motor control in the software. As you click upper or lower position from the center bar on the stage pad, the stage will move up or down. If you cannot move the focus stage, please move down the Z stage a little in maintenance mode (Mode->Maintenance mode) and try again.
2. Turn the X and Y optical alignment knobs to find the cantilever on the camera. Pay close attention to how much you turn in order to perform Step 5.
3. The cantilever is on the cantilever chip and the cantilever chip is mounted on the chip carrier. Therefore, you only need to focus on the cantilever.

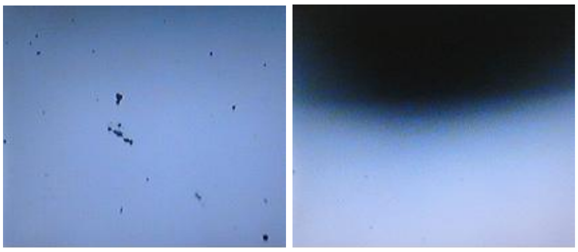
****When you cannot find the cantilever***

a) Move the head towards the sample, using the Z stage motor control in SmartScan™, as close as possible by visually monitoring the cantilever-sample separation. If the head cannot move down after the error message "Laser intensity is too low" appears, change the mode to maintenance mode. [Mode ->Maintenance mode]

WARNING!

Be careful when controlling the Z stage in maintenance mode as the interlock function to protect the system against head crashes is deactivated. Crashing the cantilever into the sample may heavily damage the XY or Z scanners.

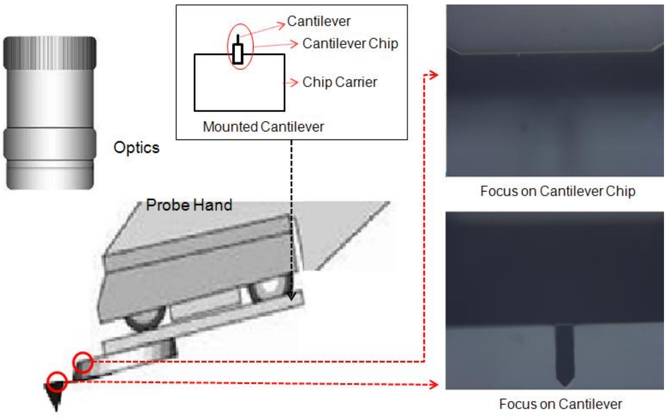
b) Focus on the sample surface using the Focus stage motor control in SmartScan™. Find the cantilever chip shadow by the illuminator, using the X and Y optical alignment knobs.



Left: Sample Surface, Right: Cantilever Shadow on Sample Surface

c) Lift the Focus stage up, and you can see the cantilever chip substrate. Then, move the optical alignment knobs to position the cantilever on the center of the vision program.

Figure 5-5. Focus On Cantilever



5-1-6. Align Beam on Cantilever

The AFM obtains images of the sample surface by detecting the bend of the cantilever using the position of a reflected laser beam since these deflections are too small to detect directly. Align the laser beam on the backside of the cantilever.

Remember how much you turn the X and Y optical alignment knobs to find the cantilever on the camera. Repeat the EXACT translation, but with the beam alignment knobs. Depending on how accurate your movements are, the beam should be near the edge of the cantilever or cantilever chip substrate.

1. Focus on the Cantilever Chip Substrate: It is easier to find the beam by placing it on the edge of the cantilever chip substrate with the Y beam alignment knob since its area is large.

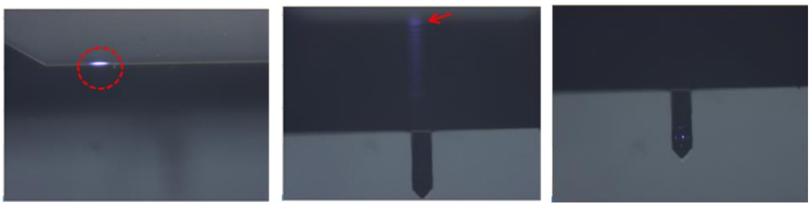
2. Find Beam Spot: While turning the Y beam alignment (large knob on the left side of head) CLOCKWISE, you should see the beam spot move UP on the cantilever. A bright spot (see Figure 5-6) appears when the beam hits the edge of the cantilever chip substrate.

3. Position Beam Spot on Front Half of Cantilever: With the beam spot on the edge of cantilever substrate, turn the X beam alignment knob. You should see the beam spot move along the edge of the cantilever chip substrate.

NOTE!

If you don’t observe ALL of the above, then the spot you see on the cantilever is not the direct laser beam.

Figure 5-6. Focus On Cantilever



When Beam spot cannot be found:

You can easily find the laser using the IR chip carrier.

5-1-7. Align Beam on PSPD

The reflected laser beam from the cantilever travels to the PSPD (position sensitive photo detector) where its position is tracked and this data is then fed into a feedback loop controlling the vertical motion of the Z scanner. This feedback is active at all times when the AFM is powered on. This detection scheme allows cantilever movement smaller than an atomic radius to be measured by the AFM.

Align the reflected laser beam from the cantilever to the PSPD by controlling the PSPD alignment knobs.,

1. Turn Y PSPD alignment knob to maximize INTENSITY.
2. Turn X PSPD alignment knob to maximize INTENSITY.

NOTE!

Align the PSPD to find the maximum INTENSITY signal. The easiest way to do this is to change only one alignment knob at a time (either the X or the Y) until a maximum is found, then move to the other knob and repeat the process. If you adjust both knobs at once, the process will be difficult.

CAUTION!

If the PSPD alignment knob is too tight or loose during adjustment, the Sus ball between the knob and mirror can fall out. The laser beam will not align to the PSPD when the knob is too tight or too loose.

3. Repeat steps 1 and 2 until beam intensity is maximized (2-3V when the backside of cantilever is metal-coated as general) on the PSPD.

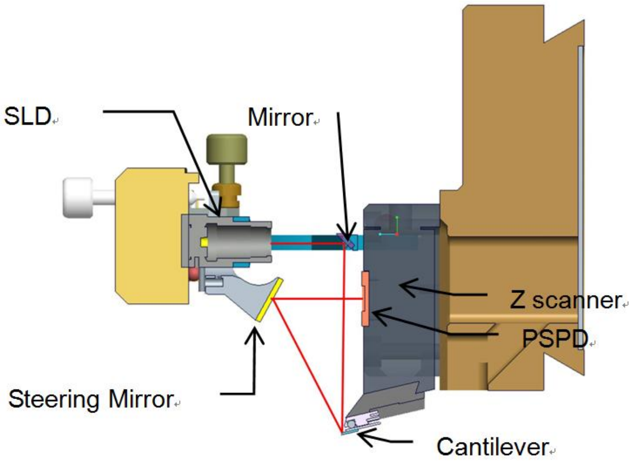
NOTE!

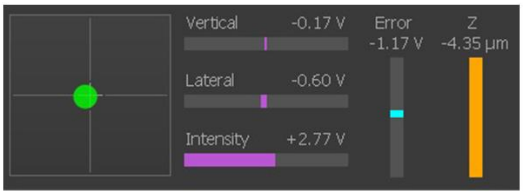
> Sometimes if the backside of the cantilever is rough or coated, INTENSITY can be smaller or bigger. In general, when the cantilever surface is not coated with metal, the INTENSITY value is closer to 1V because of the difference in surface reflectivity.

4. When INTENSITY is maximized, turning the X PSPD alignment knob (small right knob on front of head) CLOCKWISE will move the red spot on the PSPD to the LEFT. Turning the Y PSPD alignment knob (small left knob on front of head) CLOCKWISE will move the red spot on the PSPD UP. By adjusting the knobs, position the beam spot (red spot) on the center of the PSPD in SmartScan™ so that VERTICAL, LATERAL value is smaller than ±0.5V.

****When INTENSITY value on PSPD is too small:***

Even if the VERTICAL value is within the acceptable range, if the INTENSITY value is too small, it may be difficult for the beam to approach the center of the PSPD and for the tip to approach the sample properly. Therefore, a proper INTENSITY value should be obtained before adjusting the VERTICAL. If the INTENSITY is too small, then the beam path depicted in the figure below is not optimized. In this case, by using the IR detector card, check if the beam is located in beam path. After adjusting the direct beam spot on the PSPD, proceed to the PSPD alignment procedure.





Vertical -0.17 V
Lateral -0.60 V
Intensity +2.77 V
Error -1.17 V
Z -4.35 μm

NOTE!

Turning the X or Y PSPD alignment knob can make INTENSITY (beam intensity) suddenly smaller. In this case, stop turning the X or Y PSPD alignment knob and turn it the opposite direction.

5-1-8. Approach Tip to Sample

1. **Set Point Setting**:

a) Contact Mode

- Set Point in Contact Mode: Reference force for Z feedback
  As the cantilever and sample’s surface get closer, the repulsive force between tip and sample grows bigger, the cantilever bends more and PSPD’s VERTICAL value changes. We can calculate force between the sample’s surface and cantilever through changed VERTICAL value. For Z scanner feedback loop, the specific force is chosen, called the ‘Set Point’ in Contact mode.
- Contact Mode uses the repulsive force that actually makes physical contact between the tip and sample’s surface. In other words, applying the Set Point more means that the tip pushes on the sample stronger.

b) Non-contact Mode

- Set Point in Non-contact Mode: Reference amplitude for Z feedback
  The cantilever vibrates after setting the drive frequency and drive amplitude to resonant frequency. As the cantilever and sample’s surface get closer, the attractive force between tip and sample increases and the cantilever’s vibration amplitude will decrease. For the Z scanner feedback loop,
  the specific amplitude is chosen, called the ‘Set Point’ in Non-contact mode.
- Drive amplitude is changed depending on the distance between the tip and sample’s surface. Therefore, the ‘Set Point’ also is the distance between the probe tip and the sample surface.
- <u>Perform frequency sweep (NCM ASetup). Please make sure the selected frequency is within the range of resonant frequency.</u>
  <u>The amplitude of the selected frequency (red cross)-drive amplitude is recommended to be set near 20nm.</u>
- You need to adjust the drive amplitude depending on your sample.
  For example, setting the drive amplitude over 20nm might be more effective when the sample is fragile and/or consists of strong adhesion force.

2. **Check Desired Position on Sample:**

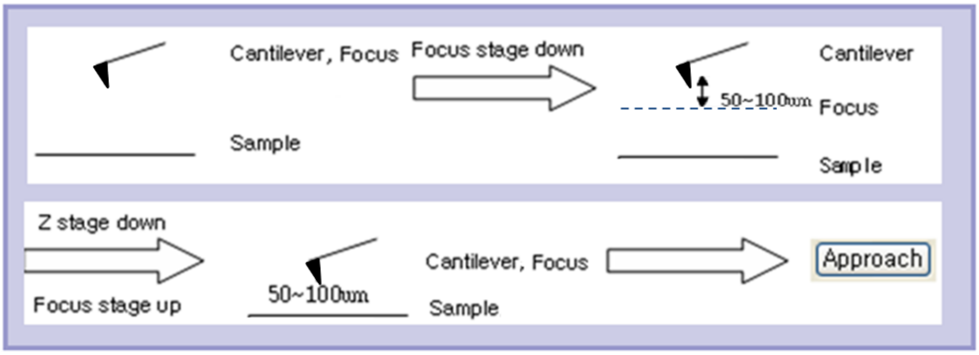
a) Bring tip a few millimeters from the sample.

- Move head towards the sample using the Z-stage motor control in the software. Visually inspect the tip-sample separation. Stop when the tip is a few millimeters from sample.
- Focus on cantilever.

b) Bring tip 50-100 ㎛ from sample.

- After the cantilever is focused, lower the focus stage until the sample is focused in order to check the sample surface.
- Lift the focus stage until the cantilever is focused then and lower the focus stage about 50~100㎛ from the cantilever.
- Move the Z stage slow down until the sample surface comes into focus, and the distance between the cantilever and the sample is approximately 50~100㎛.
- Focus on the cantilever using the focus stage motor control in the software.

Figure 6-7. Focus on Sample/Cantilever Positon

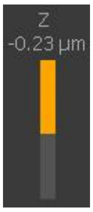


WARNING!

If the cantilever and sample are in focus at the same time, the tip has crashed into the sample. The cantilever and sample should NOT be in focus at the same time.

3. **Approach**

- Click “Approach” (underneath the Z stage motor control). When the light to the right of the motor controls stops blinking, the tip’s approach is complete.
- The upper half of Z scanner bar in the PSPD window will be green if “Approach” is successful. Before approaching, it is recommended to set the scan size to 0 and Z servo gain to 1 in the scan control window.



CAUTION!

Don't perform a frequency sweep after approach.

CAUTION!

Don't move the XY position using XY stage after approach.

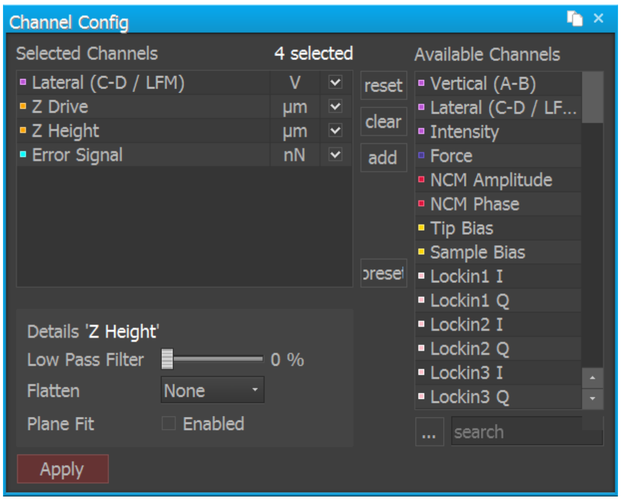
CAUTION!

Don't turn off the beam after approach.

5-1-9. Imaging

1. **Channel Config Setting**
   - Select the desired input signals in Channel Configuration [Setup-> Channel Config].
   - If the desired input signal isn't shown in the main panel of Input Config, Click the [...] button to see hidden signals or use the channel search feature at the bottom right portion of the window. The selected signals in the popup dialog will be displayed on the main panel of Channel Config.

Figure 5-8. Channel Config



Channel Config

Selected Channels 4 selected

Channel	Unit	
Lateral (C-D / LFM)	V	☑
Z Drive	µm	☑
Z Height	µm	☑
Error Signal	nN	☑

Details 'Z Height'
Low Pass Filter 0 %
Flatten None
Plane Fit ☐ Enabled

Available Channels
Vertical (A-B)
Lateral (C-D / LF...
Intensity
Force
NCM Amplitude
NCM Phase
Tip Bias
Sample Bias
Lockin1 I
Lockin1 Q
Lockin2 I
Lockin2 Q
Lockin3 I
Lockin3 Q

- **Z Drive**: Calculated Value from the driving voltage to the Z scanner in the feedback system. Considered as the height information of the sample surface since the Z scanner is in feedback to respond to the sample height.
- **Error Signal**: PSPD(VERTICAL)-SetPoint. The feedback loop works this signal to be 0. During the scan, this signal returns to 0 rapidly in good feedback but slowly in poor feedback. For such reason, through this signal, the feedback status can be confirmed, and it is recommended to monitor the Error Signal during the parameter setting.
- **Height**: Z scanner's actual movement from the sensor directly. Considered the height information of the sample surface since the Z scanner is in feedback to respond to the sample height.
- **NCM Amplitude**: Amplitude of cantilever vibration in NCM. This signal is maintained to be constant in the feedback loop. During the scan, it returns to the reference amplitude rapidly in good feedback but slowly in poor feedback. For such reasons, through this signal, the feedback status can be confirmed. It is recommended to monitor this NCM amplitude during the parameter setting in NCM and TAPPING MODE.
- **NCM Phase**: Phase of cantilever vibration in NCM and TAPPING MODE. This signal is sensitive for elasticity and viscosity of the surface. These properties can be displayed on phase imaging. It is recommended to acquire this signal in NCM.
- **Lateral Force**: value in PSPD containing the cantilever’s twisting
- **Force**: Calculated force from value in PSPD. Refer to Section 4-4-3 for detail information.
- **VERTICAL**: value in PSPD containing cantilever deflection information

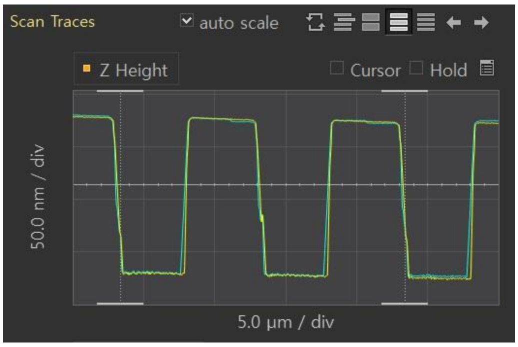
2. **Parameter Setting**
    - Input a value in the Scan Size field found in the Scan Area tab. This will be the size of your image. The XY Scanner will begin moving back and forth using this value. This movement may be visible on the vision program.
    - Select a value in Scan Rate field. Keep in mind that the speed of the tip will be (2 * Scan Size) / (Scan Rate), and that too high speed will result in tip and sample damage. Observe the input signal of Height and Z Drive Channels in Scan Traces Window.

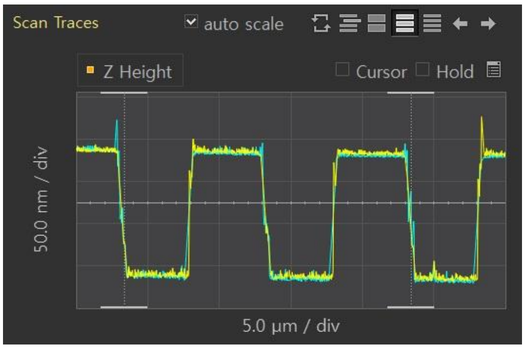
- Adjust the value in Z Gain field found in Z Servo tab until the trace line is stable. If this is difficult, try lowering the Scan Rate.

An abridged list of the parameters in the Scan Control Windows follows.

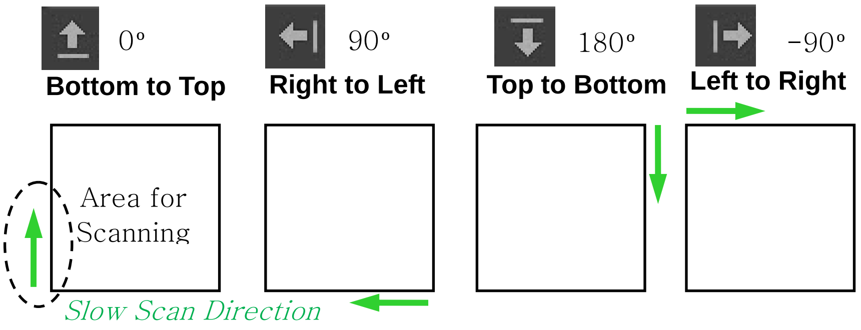
For a complete list, see the SmartScan™ Software Manual.

Figure 5-9. Proper Gain (top); Noise from Excessive Gain (bottom)





- **Repeat**: If selected, the system will activate the text display to the right. Enter a number between 2 and 1000 to repeat the scan the specified number of times.
- **Retract Z after Done:** Checking the Retract Z after Done check box will lift the cantilever away from the sample 100µm using the Z stage control once the image has been acquired.
- **Offset X, Y**: Specifies the center of the scan area in a relative coordinate system with (0,0) being the center of the X-Y scanner.
- **Rotation**: Allows the direction of scanning to be changed within the range of 180˚~＋180˚. Rotation can be set by adjusting the value in rotation field or using the icon buttons below.



- **Z Servo**: Select Z scanner feedback on/off. The Z Servo must be on for most SPM modes.:
- **Z Servo Gain**: Controls the sensitivity of the Z scanner feedback loop. If this value is too high, the Z scanner will oscillate, producing noise in the image or line scan. If it is too small, then the SPM probe will not track the sample surface properly.
- **Set Point**: In **Contact** mode, specifies the force that will be applied by the end of the tip to the sample surface when the system is in feedback. In **Non-Contact** mode, the set point represents the amplitude of tip oscillation.
- **Tip Bias**: Controls the voltage applied to the tip when EFM or C-AFM modes are used.

3. <u>**Acquire Image**</u>
   - Once the trace line is stabilized, click the “Scan” button to start the measurement.
4. <u>**Finish**</u>
   - After the imaging is complete, set the Scan Size to zero in order to avoid damage to the tip and sample and lift the Z stage. Then close the SmartScan™ program and turn off NX-Hivac control electronics.

5-2. Sample Loading

5-2-1. Lift NX-Hivac Head

First, raise the head high enough so that you have no difficulties in loading the sample onto the X-Y scanner.

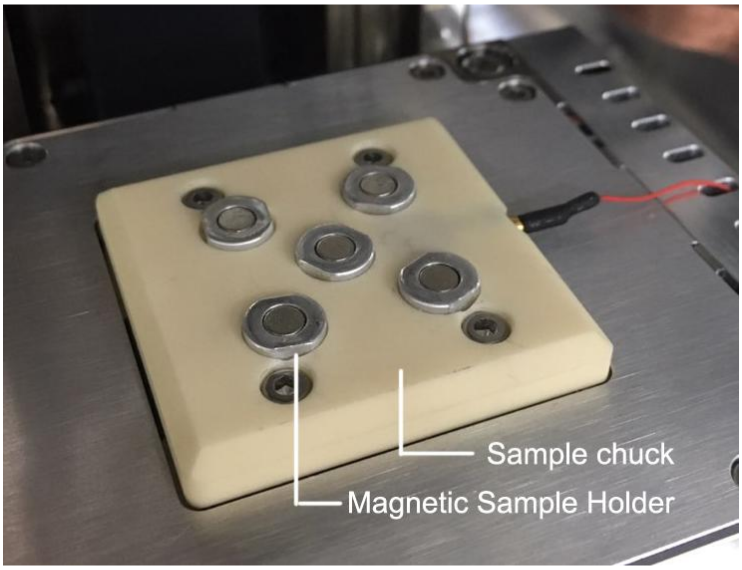
CAUTION!

If the head is not rasied high enough, the sample or the cantilever may be damaged.

5-2-2. Load Sample on XY scanner

Generally, the sample is fixed to a magnetic sample plate prior to imaging using glue or tape. The sample plate is then placed on the magnetic sample holder.

Figure 5-10. Magnetic Sample Holder

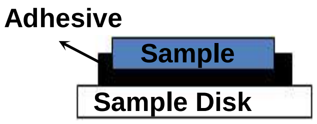


When the sample is larger than a sample plate, remove the sample chuck by turning it counter-clockwise. The sample can then be placed directly on the sample chuck. Resulting images may display drift, as the sample is not securely fixed.

Instant Adhesive

You can fix the sample on a sample disk using an adhesive. Hard-setting adhesives such as cyanoacrylate glues are recommended; otherwise, the sample may move significantly during the imaging procedure. When the sample is glued on a metal sample plate using electro-conductive adhesives, such as silver paste, it will be grounded through the magnetic sample holder but will take a longer time to dry.

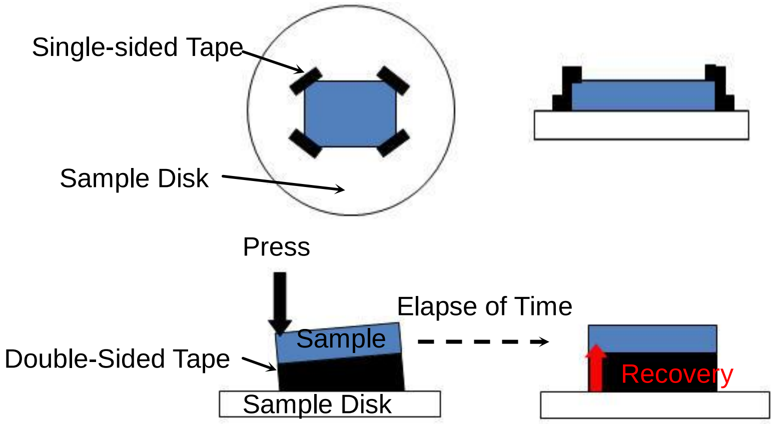
Figure 5-11. Instant Adhesive



Tape

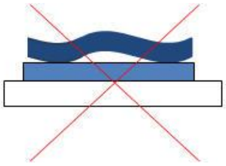
You can fix the sample using adhesive tape. Using tape to fix the sample is convenient but may result in sample drift during imaging. Using a single strip of double-sided tape will reduce drift, but the adhesive layer on any tape will move significantly on a nano scale over time.

Figure 5-12. Tape



When the sample is a film, the user should be especially careful when mounting it because unintended gaps between the tape and sample can allow the film to move during scanning.

Figure 5-13 Air between Sample and Tape



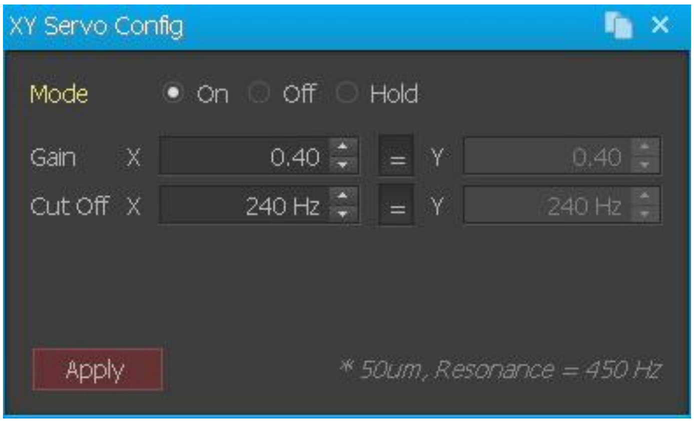
5-3. Operating Concept

5-3-1. Basic Operating Concept

The NX-Hivac scanner is separated into an X-Y scanner and a Z scanner instead of the single piezoelectric tube scanner used in most other SPMs. The X-Y scanner moves the sample in the horizontal direction for the range you want to image. The Z scanner moves the cantilever in the vertical direction to trace the morphology of the sample. These independent movements of the XY direction and the Z direction are combined to make a three-dimensional image.

Two measurement types for XY scanner, ‘Closed Loop’ and ‘Open Loop’, are possible depending on the status of the XY Servo scan. ‘Closed loop’ refers to when the XY Servo scan is “ON” and ‘Open loop’ is when the XY Servo scan is “OFF”.

Figure 5-14. XY Servo scan is ON



Mode ● On ○ Off ○ Hold

Gain X 0.40 = Y 0.40

Cut Off X 240 Hz = Y 240 Hz

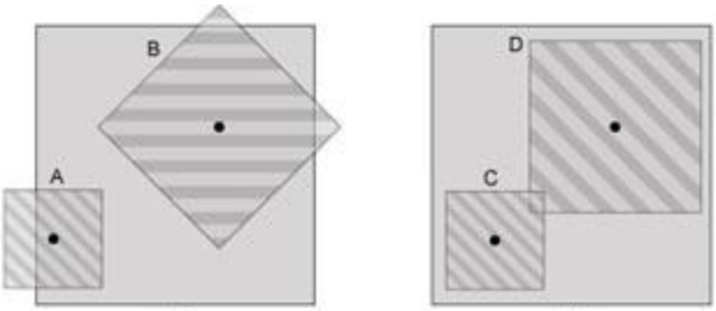
* 50um, Resonance = 450 Hz

In general, piezoelectric materials display nonlinear behavior in response to an applied voltage. Therefore, the scanner, which is made of a piezoelectric material, displays nonlinearity and hysteresis (Refer to Chapter 1). When the scanner’s range of motion increases, nonlinearity and hysteresis can be calibrated by means of hardware corrections.

In the NX-Hivac system, detectors are used to measure the actual movement of XY or Z scanners. This information is compared with the desired movement, and discrepancies are corrected for by modifying the voltage applied to the scanner. This ServoScan system effectively eliminates the nonlinearity of the piezoelectric actuators.

NX-Hivac scanners, both X-Y and Z scanner, have a maximum range of movement. Figure 5-15 depicts the maximum XY scan range as a solid gray-shaded square. The area outside of this square cannot be observed. For example, if the scanner’s maximum range is 50 ㎛, it is not possible to scan both areas ***A*** and ***C*** even though they have the same scan size (15 ㎛). Area ***A*** is impossible to scan because its offset (the black point) extends its range over the maximum range of the scanner. Area ***C***, however, is possible to scan. Also, although ***B*** and ***D*** have the same size and the same offset, it is impossible to scan area ***B*** which extends over the maximum range due to its different angle of rotation. Whenever the user enters an “excessive range” like ***A*** and ***B***, the scan range will be changed automatically to an observable area that falls within the scanner’s maximum allowable range.

Figure 5-15. Scanner’s observable area



(a) (b)

The lateral resolution of an image acquired by AFM is calculated by dividing the scan size by the pixel size. If you measure a 10 μm square image with 256 × 256 pixels, the lateral resolution is 10 ㎛/256 = 39.1 nm. This means the size of one data point in the 10 ㎛ square image is 39.1 nm. Even though you can increase an image’s pixel count to get higher lateral resolution, it will take much longer to acquire an image. Another solution to get higher resolution data is to decrease the scan size. If you measure a 100 nm image with 256 × 256 pixels, you can get a lateral resolution of 3.91 Å per data point. Therefore, when you want to measure fine structure, it is desirable to reduce the scan size.

Also, the scanner’s ability to make an elaborate motion is another factor that influences the lateral resolution. The scanner expands or shrinks in proportion to an applied voltage. Hence, you can manage the scanner’s motion more precisely by dividing the applied voltage into smaller units in the DAC (digital-to-analog converter). The NX-Hivac system uses a 20-bit DAC for controlling scan movement in X and in Y. A 16-bit DAC is used for determining scale so that the scanner’s motion and position can be elaborately controlled. When an applied voltage that can make the scanner move 50㎛ is controlled using a simple 20-bit DAC, the lateral resolution is 50 ㎛ / 2^{20} = 0.19 Å.

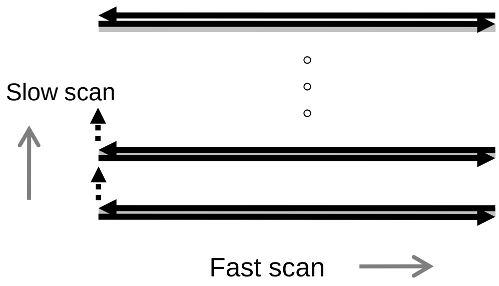
The resolution of the Z scanner can be adjusted by limiting the Z scanner’s motion range. The number entered in the text box labeled Z scanner range can be regarded as a proportionality factor relating Z scanner’s maximum movability. Basically, if the Z scanner Range is 1.0, then the Z scanner in the standard head can move through a 15μm range. However, if the Z scanner Range is 0.5, then the Z scanner’s maximum movable range would be reduced to 7.5μm. This adjustment that effectively reduces the Z-scanner’s maximum rang e results in an increase in vertical resolution. To use the Z scanner Range feature effectively, you should consider two points: the z-scanner’s available maximum range and the vertical resolution. Before adjusting the Z scanner Range, one must first consider the overall height variation of the sample surface. Of course, this height difference should not be greater than the Z scanner’s maximum available range. For example, if a sample has 30㎛ height difference, it cannot be measured if the standard head is used..

■ XY Scan Method

The XY scanner movement is controlled using piezoelectric elements which expand or contract in length in response to an applied voltage. This allows for circuits containing several DACs (digital-to-analog converter) and high-voltage amplifiers to electronically drive the XY scanner in a raster pattern while imaging samples.

That is, the X scanner moves the sample first along a line from left to right and then retraces this line until it is back to its original position. Next, the Y scanner takes a single step along the orthogonal direction and the process repeats. In this way, the XY scanner can get two dimensional data by repeating the process many times. The user can define the amount of data per line and the number of lines to be collected, corresponding to image pixel width and height, respectively AFM data is most commonly collected in square, n x n pixel scans. In this example, the X direction is known as the fast-scan direction and the Y is known as the slow-scan direction. (See Figure 5-16) The fast-scan direction can be selected by software arbitrarily within the XY-plane the slow-scan direction will always be orthogonal.

Figure 5-16. Standrad Scanning



- ➢ The probe moves along a line trace in the fast-scan direction and collects data points.
- ➢ The probe moves back along the same line trace in the opposite direction.
- ➢ The probe steps in the slow-scan direction to the next line trace.
- ➢ The probe scans the next line trace in the fast-scan direction and collects data.

■ Z Scan Method

When the XY scanner is moving in the fast scan direction, the Z scanner is vertically moving to track the sample morphology. The AFM image is created by the digitized Z scanner feedback signal which is collected at every X and Y position corresponding to a pixel a s defined by the user's scan parameters. Point data is acquired and forms a line; this line is a collection of consecutive points throughout the X axis, in form of digitalized data that derives from Z scanner feedback signals. Next, these lines are consecutively acquired along the Y axis, thus creating an AFM image. The brightness of the AFM image indicates sample height information. Park SYSTEMS AFMs have strain gauge sensors on the Z scanner in order to accurately measure sample heights regardless of the non-linear characteristics inherent to all piezoelectric devices.

5-3-2. Image Data Type

Unlike other common file formats, the 'TIFF' files have tags. The 'TIFF' file format includes a header and many tagged fields. The tagged fields can describe dimensional information such as the width and the height of the images so that the software that handles the 'TIFF' file can read these tagged fields and then extract information from them in order to generate images to display in the image viewer. Consequently, the 'TIFF' does not affect the original image file and has superior compressibility as well as no resolution limits. These advantages make the TIFF format ideal for handling larger, capacious files.

The data files produced by conventional SPM instruments are not a common image file format. Thus, to see these acquired images in an Image viewer and the traditional Windows Explorer display, it is necessary to change the file format saved by individual SPM instruments into the image file format by using image processing software.

If the collected data is saved as a common image file format, it may be quite convenient to view the images without any special software conversion process of the information file. However, this is difficult since conventional image file formats include only image data (R, G, B) and cannot save the large amount of sample data which is measured by the NX systems.

Considering these difficulties, the TIFF format is a more flexible means of storing SPM images. Therefore, in the NX system, the image data is saved as a 'TIFF' file format, in which a huge amount of data can be saved in the private-tagged area and the acquired images from this data can be saved in the standard-tagged fields as an image file so that it can be viewed in the common image viewer.

When you see the NX system's acquired data in the common image viewer, you can identify this data as a familiar sample image, and you can process the images without transforming original measurement data.

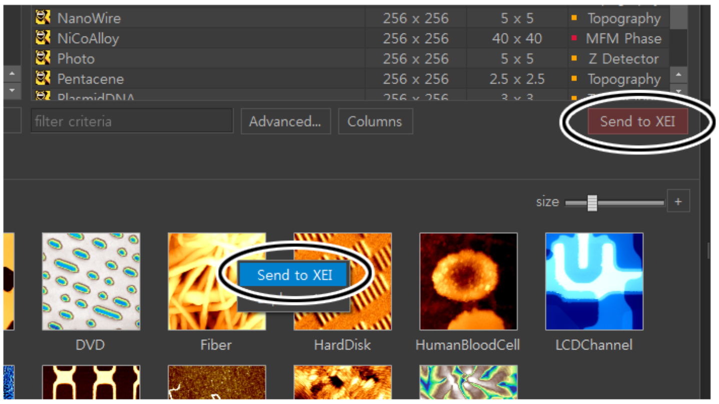
The part changed in the common Image viewer is the information that is saved in the standard-tagged fields of the data file. Therefore, the collected data saved in the private-tagged field will be secure from the transformation of the data in the image viewer, and also this data may be changed or processed in the XEI image processing program.

■ Data Export

Obtained images can be exported to Text or bitmap format to allow analysis by external software. Tiff files can be exported in the form of a text file or an image file (jpg, png, bmp, and emf) from the "Export" command in the context menu of the Image display panel in XEI image processing program. The raw tiff file consists of two parts, the scan data and the image. When the tiff file is exported as a text file, the file will contain basic information about the tiff file and the data array of the scan data. On the other hand, when the tiff file is exported as an image file, the exported image file only includes the image of the tiff file but not the scan data within it; the image will not include any dimensional information.

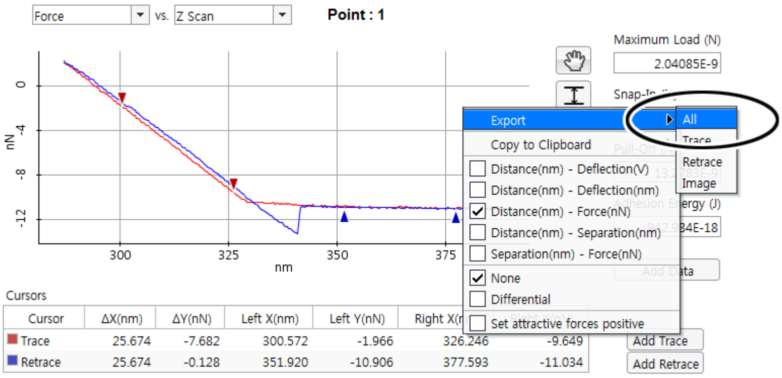
Figure 5-17. Data Export

On SmartScan



NanoWire	256 x 256	5 x 5	Topography
NiCoAlloy	256 x 256	40 x 40	MFM Phase
Photo	256 x 256	5 x 5	Z Detector
Pentacene	256 x 256	2.5 x 2.5	Topography

On XEI



Force vs. Z Scan

Point : 1

Maximum Load (N) 2.04085E-9

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(	Right Y(nN)
🟥 Trace	25.674	-7.682	300.572	-1.966	326.246	-9.649
🟦 Retrace	25.674	-0.128	351.920	-10.906	377.593	-11.034

0
-4
-8
-12
nN
300
325
350
375
nm
Snap-In
Pull-Off
Adhesion Energy (J)
Add Data
Export
All
Trace
Retrace
Image
Copy to Clipboard
☐ Distance(nm) - Deflection(V)
☐ Distance(nm) - Deflection(nm)
☑ Distance(nm) - Force(nN)
☐ Distance(nm) - Separation(nm)
☐ Separation(nm) - Force(nN)
☑ None
☐ Differential
☐ Set attractive forces positive
Add Trace
Add Retrace

5-4. Maintenance

Maintenance procedures are required to maintain accuracy and safety of the SPM. There are two kind of maintenance procedure. One is a daily check and the other is a periodic test which is recommended to be perfomed after operating the SPM for a certain period of time.

Frequency checklist

Table a. Checklist for freqency checkup

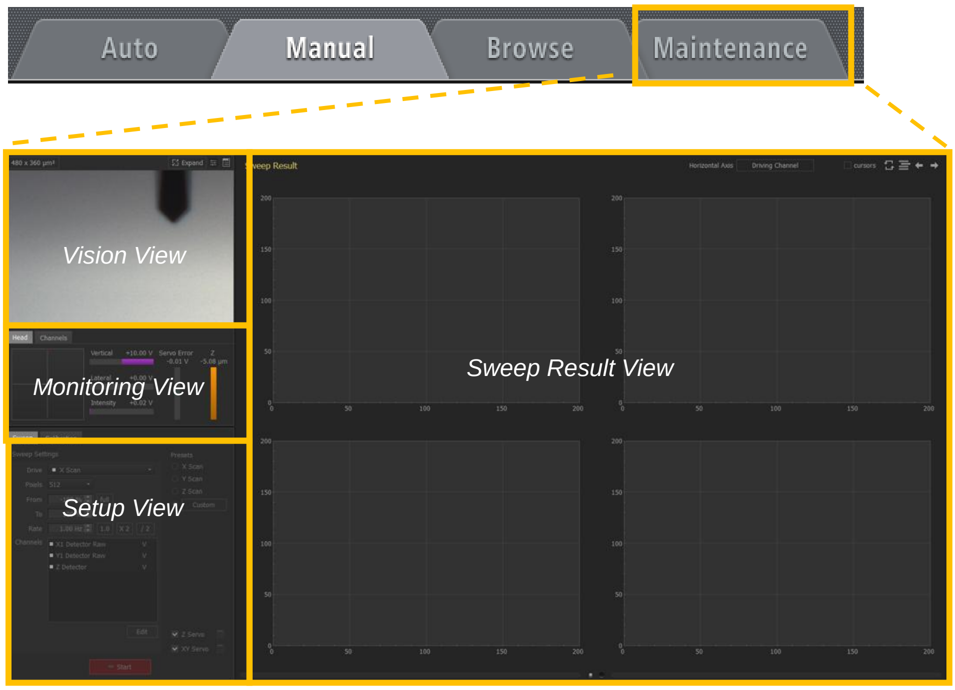
Frequency	Item	Action
1 Day	Noise and Vibration	- Any abnormal noise generated or vibration near AFM main body.
3 Month	Fixation	- Fixation of the bolts
	Clean condition and broken parts	- Clean inside the AE.
	Calibration	- Calibration of XY scanner
6 Month	Cable connection	- Cable connection of all the cables.
	XY, Z, Focus Stage	- Reset all the motorized stages to check the performance of stage motor and limit sensor.
	Calibration	-Calibration of Z scanner
1 year	Any parts	- Check for any broken parts
	Cables	- Check the cabling conditions of the main cables that connects the electronics and SPM

* For height or width analysis, in order to improve the accuracy of the measured data, It recommended to check the scanner (XY or Z) Calibration before measurement.

5-4-1. Calibration

Access the maintenance mode workspace by clicking the **Maintenance** tab or by clicking **SmartScan ▼ -> Maintenance**. Figure i-1 shows the maintenance mode workspace and labels for each view area (Vision View, Monitoring View, Setup View, and Sweep Result View). Each view area is described below.

Figure 5-18. The maintenance mode workspace



Setup View

Setup View displays setup parameters for sweep tests and scanner and cantilever calibration. Setup View is separated into two tabs: the Sweep Setup View and the Calibration Setup View.

Sweep Setup View

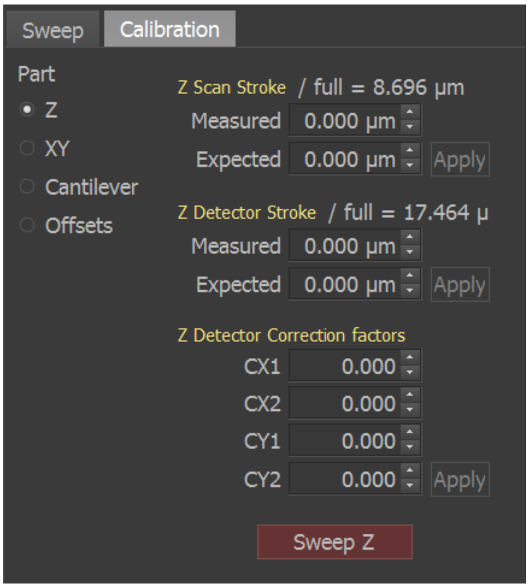
Use the controls here, you can perform a sweep of the desired driving channel and view various resulting signal traces. For more detail, refer to Chapter 12, Sweep Tests.

Calibration Setup View

Various instrument components, including the Z scanner, XY scanner, and cantilever can be calibrated from this tab. The sub-interface for each component can be toggled by clicking the desired radio button.

- **Calibration/Z Scanner**

Figure 5-19. Z Scanner calibration setup



Z Scan Stroke / full = 8.696 µm
Measured 0.000 µm
Expected 0.000 µm

Z Detector Stroke / full = 17.464 µ
Measured 0.000 µm
Expected 0.000 µm

Z Detector Correction factors
CX1 0.000
CX2 0.000
CY1 0.000
CY2 0.000

Z Calibration Parameters	Function
Z Scan Stroke	**Z Scan Stroke** is the Z scanner movement determined by the applied voltage bias to the Z piezo/scanner. The **Measured** value is the height derived from the Z scan calibration image. The **Expected** value is the height value reported for the known sample. After entering the **Measured** and **Expected** values, click **Apply** to adjust the calibration.
Z Detector Stroke	**Z Detector Stroke** is the Z scanner movement determined by the linearized sensor. The **Measured** value is the height derived from the Z height calibration image. The **Expected** value is the height value reported for the known sample. After entering the **Measured** and **Expected** values, click **Apply** to adjust the calibration.
Z Detector Correction Factors	These are factory calibrated nonlinear correction factors.

- **Stroke Calibration**

The Z scanner stroke can be calculated by imaging a grating sample that has a known height. Differences between the known value and the measured value can be adjusted through calibration tables.

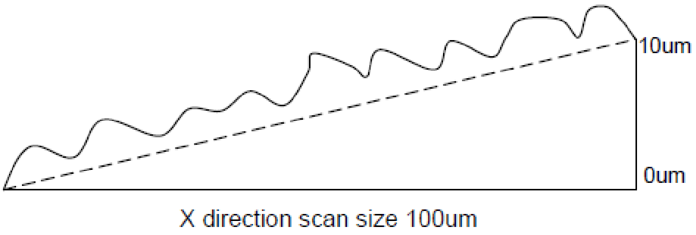
For example, a grating sample of height 3μm×3μm is measured as 120nm. If the known height reported by the manufacturer is 100nm +/- 7nm, the measured value is off by 13-20nm. Calibration of the scanner stroke can correct the measurement discrepancy.

The Z stroke is calculated two ways. The first way to determine the stroke is using the voltage applied to the Z piezo. The second way determines the stroke using a sensor. Each signal must be calibrated separately using different channels.

- **Non-Linear Correction Factors**

The Z scanner calibration provides software correction for non-linear Z scanner movement. For example, if you can see a non-linear image like the one below, you can correct it by calibrating **CX**, **CX2**, **CY**, and **CY2**.

The X direction and Y direction of this surface are expressed as $AX^2+BX+CY^2+DY$, where $AX^2=CX2$, $BX=CX$, $CY^2=CY2$ and $DY=CY$. When you obtain a 1st order slope from the Z height as below, you can enter +0.1 into CX since the equation is $Y=AX^2+BX+C$, where $A=0$, $B=10μm/100μm=0.1$, and $C=0$. Please note that currently the software does not calculate the values of X, Y, X2 and Y2. You will need to calculate these values manually.



To calibrate the Z scanner, image a standard sample with a known step height and enter the measured and known (expected) heights into the calibration setup interface. A summary of the parameters for Z scanner calibration can be found in the table below. For more information about scanner calibration, please refer to the NX User's Manual.

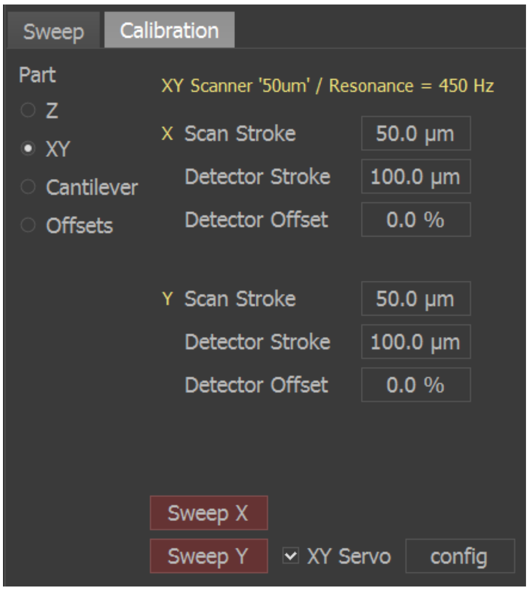
- **Sweep Z**

Clicking this button sweeps the Z scanner in full bias range and displays the result in the Sweep Result panel on the right. With this, you can check the full stroke of the Z drive/detector. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

- **Calibration/XY Scanner**

Figure 11-3-2 below shows the XY scanner calibration setup. XY calibration values include **Scan Stroke**, **Detector Stroke**, and **Detector Offset**. Each can be adjusted independently for the X and Y directions. When calibrating the scanner, the X scan values are used when then XY servo is off (open loop), while the X detector values are used when the XY servo is on (closed loop). Please see the NX manual for more detailed information about XY scanner calibration.

Figure 5-20. XY scanner calibration setup



Part
○ Z
● XY
○ Cantilever
○ Offsets

XY Scanner '50um' / Resonance = 450 Hz

X Scan Stroke 50.0 µm
Detector Stroke 100.0 µm
Detector Offset 0.0 %

Y Scan Stroke 50.0 µm
Detector Stroke 100.0 µm
Detector Offset 0.0 %

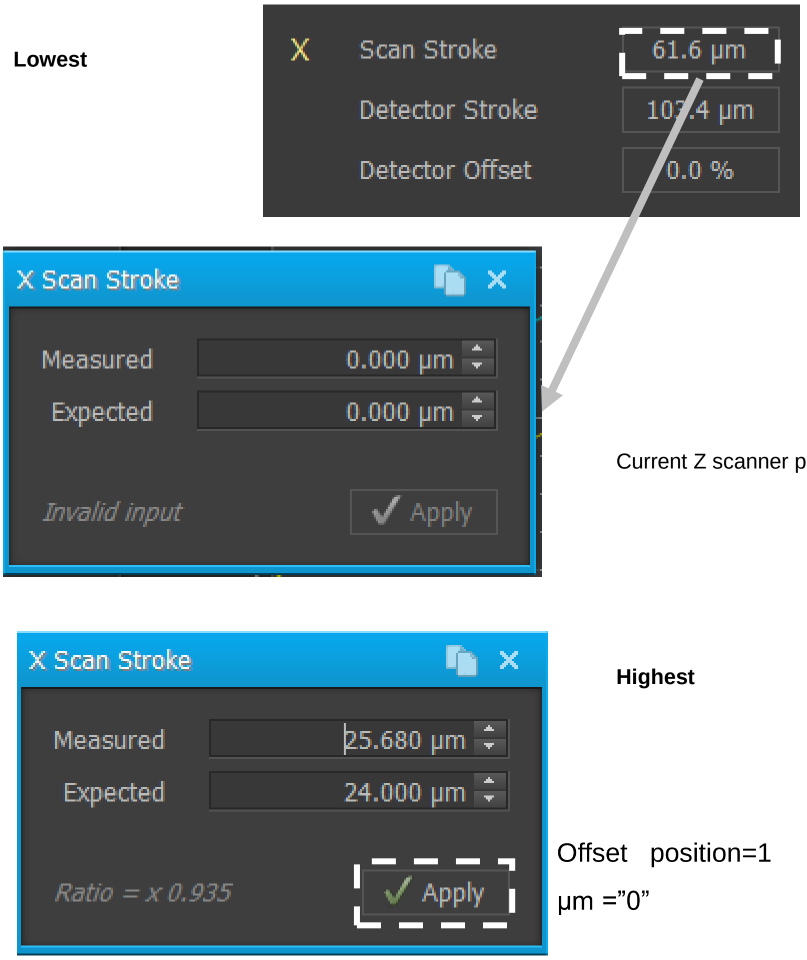
☑ XY Servo

To change XY scanner calibration values:

1. Click the appropriate display button next to the parameters to change.
2. A dialog box will open. Enter the measured and expected values for the desired parameter.
3. Click **Apply**. The software will calibrate the scanner automatically.

Figure 5-21 gives an example of how to change the X **Scan Stroke** value.

Figure 5-21. XY scanner calibration example



Lowest

Scan Stroke 61.6 µm
Detector Stroke 103.4 µm
Detector Offset 0.0 %

Measured 0.000 µm
Expected 0.000 µm
Invalid input

Current Z scanner position

Highest

Measured 25.680 µm
Expected 24.000 µm
Ratio = x 0.935

Offset position=1 µm =”0”

- **Stroke Calibration**

Stroke calibration changes the movement in the X or Y direction. Scan signals are used for calibration of open loop scanning (XY servo off). Detector signals are used for calibration of the detector used for closed loop scanning (XY servo on). It is verified by checking the measured scanner movement against a known structure. For example, if a known 3µm×3µm grating sample is measured, the width of three gratings is known to be 3µm×3 gratings=9µm. If the actual measured value is 9.8µm, then the X or Y scanner needs calibration. In this example, depending on the direction of measurement, you would enter 9µm and 9.8µm in the **Expected** and **Measured** fields for the X or Y row.

- **Offset Detector**

The offfset detector is used to center scanner movement within the stroke range. For the detectors’ offset calibration, you should enter the **Offset** value. This value describes how the detector shifts from the origin in the X and Y directions. You can estimate the **Offset** values by performing a sweep test of the X and Y scan and monitoring the non-zero X and Y coordinates of the origin in the the **Oscilloscope** screen. Then the X and Y detectors can be calibrated by entering the **Offset** value and then clicking **Apply**. For more information, please refer to the NX User's Manual.

Panel	Function
Measured X(Y) Scan/Detector	Input the measured XY scan/detector's stroke length.
Expected X(Y) Scan Detector	Input the known XY scan/detector's stroke length.
Offset of X(Y) Detector	Input how the detector shifts from the origin.

**XY Scan: XY movement in open loop (XY servo off)*
**XY Detector: XY movement in closed loop (XY servo on)*

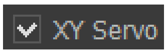
- **Sweep X**

Click this button to sweep the X scanner in full bias range and display the result in the Sweep Result panel on the right. With this, you can check the full stroke of the X scan and X detector. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

- **Sweep Y**

Click this button to sweep the Y scanner in full bias range and display the result in the Sweep Result panel on the right. With this, you can check the full stroke of the Y scan and Y detector. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

- **XY Servo Check box**



Checking this box turns on the XY servo. Unchecking this box turns off the XY servo.

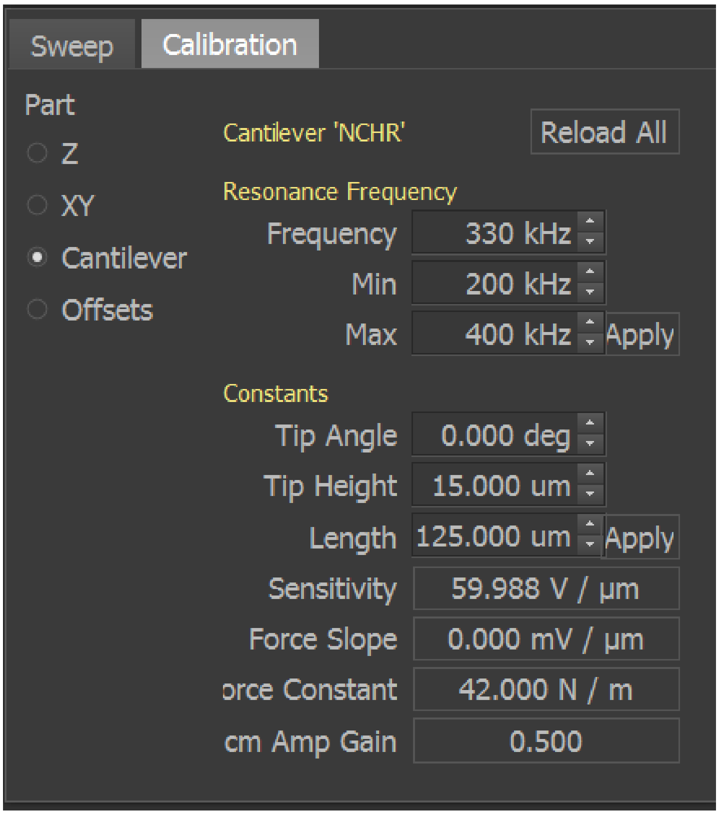
- **Config**

Clicking **config** opens the XY Servo Configuration dialog. Please see Section 8-4-11 for more information about XY servo configuration.

- **Calibration/Cantilever**

Different models of cantilevers are produced with varying force constants and resonance frequencies, resulting in differing values in various performance metrics. Because these values cannot always be obtained nondestructively, SmartScan maintains a database of known cantilever properties. This database is pre-populated with several common cantilevers. If you choose a different cantilever, you must perform a cantilever calibration and create a database entry for it. Cantilever calibration is divided four main sections: resonance frequency range, cantilever constants, A-B sensitivity, force constant, and NCM amplitude gain.

Figure 5-22. Cantilever calibration setup



Part
○ Z
○ XY
● Cantilever
○ Offsets

Cantilever 'NCHR'

Resonance Frequency
Frequency 330 kHz
Min 200 kHz
Max 400 kHz

Constants
Tip Angle 0.000 deg
Tip Height 15.000 um
Length 125.000 um
Sensitivity 59.988 V / µm
Force Slope 0.000 mV / µm
orce Constant 42.000 N / m
cm Amp Gain 0.500

- **Cantilever Resonant Frequency**

  When performing an NCM sweep, the frequency is varied from the known minimum to the known maximum resonance range for the current cantilever type. Enter the minimum, maximum, and typical resonant frequencies for your cantilever. These values are usually provided by the cantilever manufacturer. Click **Apply** to finish calibration.

- **Cantilever Constants**

  Descriptions for cantilever constants are provided by the manufacturer and defined as follows:

Tip Angle	This is the angle between the cantilever arm and the tip.
Tip Height	This is the height of the tip, defined as the length from the end of the tip to the center of the cantilever beam. This value is provided by the cantilever manufacturer.
Cantilever Length	This is the length of the cantilever. This value is provided by the cantilever manufacturer.

To change values, update values in the appropriate fields and click **Apply**.

- **A-B sensitivity calibration**

  As the cantilever moves across a sample surface and deflects upwards or downwards, the A-B signal on the PSPD is changed because the beam is reflected off the top of the cantilever. The A-B sensitivity value determines how much the A-B signal changes in respect to the cantilever deflection (A-B sensitivity=A-B/height).

  To input this value automatically using acquired data, click the **Data** button. A dialog box will appear. Select a file containing an FD curve obtained in contact mode. Select the linear region and click **Apply**. The A-B Sensitivity Cantilever Calibration dialog is shown in Figure i-6.

- **Force Constant**

  Input the typical force constant for the cantilever. You can find this value in the cantilever manufacturer’s specifications. Update the field for the force constant and click **Apply** to save the force constant to the cantilever file listed at the top of the view area. [Thermal Tune]

- **NCM Amp Gain**

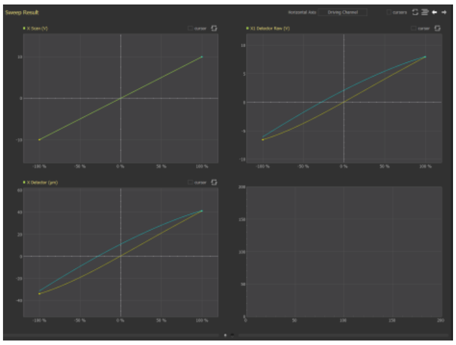
  The A-B(AC) signal on the PSPD is amplified by a lock-in circuit. This electronics gain is called **NCM Amp Gain** (V/V). The value for **NCM Amp Gain** can be entered into the text field. Click **Apply** to save the values into the cantilever calibration.

  To determine the gain automatically, click the **Data** button, which opens the NCM Amplitude Calibration Dialog window.

Sweep Result

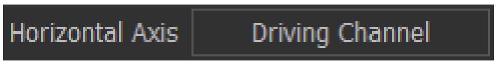
The Sweep Result workspace displays up to eight signal channels resulting from sweeping the driving signal. Figure i-6 shows the Sweep Result workspace.

Figure 5-23. Sweep Result workspace



The horizontal axis of the all the graphs displayed can be set by clicking the **Horizontal Axis** button and choosing the desired parameter from the drop-down menu. The name of the channel used for the horizontal axis will be displayed in the button.

Figure 5-24. Horizontal Axis button with Driving Channel selected



Options buttons for the Sweep Result graphs are as follows:

☐ cursors Displays cursors on all sweep result graphs

⟳ Auto scales the graph to display the enter curve

☰ Allows for graphs to be rearranged by clicking and dragging graphs to the desired location. Re-click the button once rearrangement is complete.

← → Moves to the previous or next page of graphs in the sweep results.

For more information about the Sweep Result workspace and Graphs View.

Chapter 6. AFM in Contact Mode

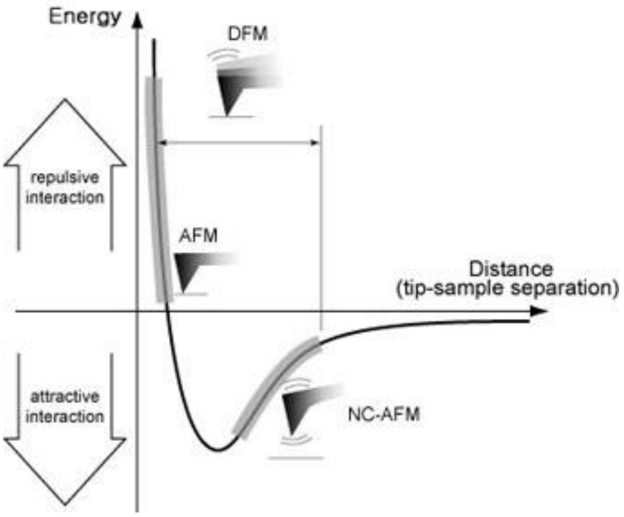
6-1. Principle of Contact Mode AFM

The AFM (Atomic Force Microscope) is an instrument that is used to study the surface structure of a sample by measuring the force between atoms.

At the lower end of the Z scanner, there is a cantilever of very tiny dimensions: 100 ㎛ long, 10 ㎛ wide and 1 ㎛ thick, which is manufactured by means of micro-machining techniques. At the free end of the cantilever, there is a very sharp cone-shaped or pyramid-shaped tip. As the distance between the atoms at this tip and the atoms on the surface of the sample becomes shorter, these two sets of atoms will interact with each other. As shown in Figure 6-1, when the distance between the tip and the surface atoms becomes very short, the interaction force is repulsive due to electrostatic repulsion, and when the distance gets relatively longer, the interatomic force becomes attractive due to the long-range van der Waals force.

This interatomic force between atoms can bend or deflect the cantilever, and the amount of the deflection will cause a change in the reflection angle of the laser beam that is bounced off the upper surface of the cantilever. This change in laser path will in turn be detected by the PSPD (Position Sensitive Photo Detector), thus enabling the computer to generate a map of the surface topography.

Figure 6-1. Relation between the force and the distance between atoms



In contact mode AFM the probe makes “soft contact” with the sample surface, and the study of the sample’s topography is then conducted by utilizing the repulsive force that is exerted vertically between the sample and the probe tip. Even though the interatomic repulsive force in this case is very small, on the order of 1~10 nN, the spring constant of the cantilever is also sufficiently small (less than 1 N/m), thus allowing the cantilever to react very sensitively to very minute forces. The SPM is able to detect even the slightest amount of a cantilever’s deflection as it moves across a sample surface. Therefore, when the cantilever scans a convex area (凸)of a sample, it will deflect upward, and when it scans a concave area (凹), it will deflect downward. This probe deflection will be used as a feedback loop input that is sent to an actuator (z-piezo). In order to produce an image of the surface topography, the z-piezo will maintain the same cantilever deflection by keeping a constant distance between the probe and the sample – if the cantilever tip reaches a lower area, the Z actuator will move the cantilever down by that distance, or back up if the cantilever’s tip begins rising.

6-2. Contact mode setup

To use contact mode AFM, select the appropriate Head mode as follows:

1. Turn off the beam by unclicking the beam control check box at the bottom left portion of the Vision View
2. Once the beam is off, click the Head Mode tab at the top of parameters view and select **Contact**.
3. Turn on the beam by clicking the beam control check box

6-3. Cantilever Selection

Selecting the appropriate probe is a critical aspect of using AFM. Choosing a probe means determining the combination of a tip, which interacts with sample surface atoms, and a cantilever, which deflects depending on the interatomic forces and quantifies the deflection. Generally, the upper surface of a cantilever is coated with a metal such as gold (Au) or aluminum (Al). This coating, which enhances the surfaces reflectivity, has a thickness of about 1000 Å. There are several types of cantilevers that vary in material, shape, softness (represented by the spring constant), intrinsic frequency, and Q-factor. The type of cantilever selected is primarily determined by the measurement mode. As mentioned in Chapter 4, a "soft" cantilever is used for contact mode AFM. Typically, such cantilevers are made of silicon and have a spring constant less than 1~3 N/m. With such a low spring constant, the contact mode cantilever is sensitive to extremely small forces, and it will bend more significantly than a cantilever with a higher spring constant when exposed to an equal force. This allows the AFM to measure even extremely tiny structures.

Figure 6-2 shows the SEM image of a cantilever commonly used for contact mode, the PPP-CONTSCR series. To improve the beam reflectivity, the upper surface of the cantilever (the opposite side of the tip) is coated with aluminum.

Figure 6-2. SEM image of the shorter cantilevers (A, B, C) from a chip of the PPP-CONTSCR series

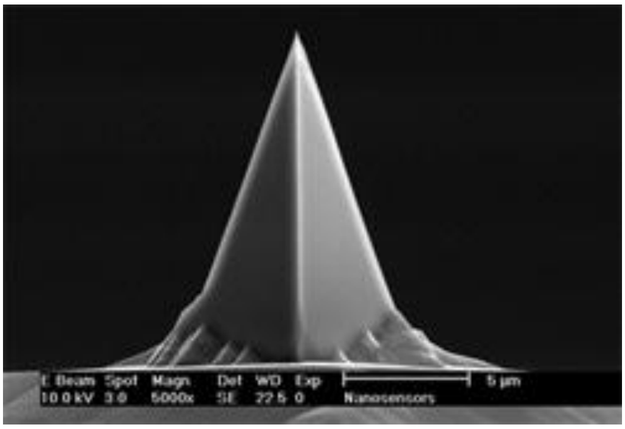


Figure 6-3 shows the detailed standardized gauge of the PPP-CONTSCR series chip. Altogether, this chip contains three cantilevers, all with different spring constants.. If the unmounted cantilevers are purchased separately, you may choose from the set of cantilevers A,B,C.

Figure 6-3. Silicon chip of the NSC36 series has 3 rectangular cantilevers.

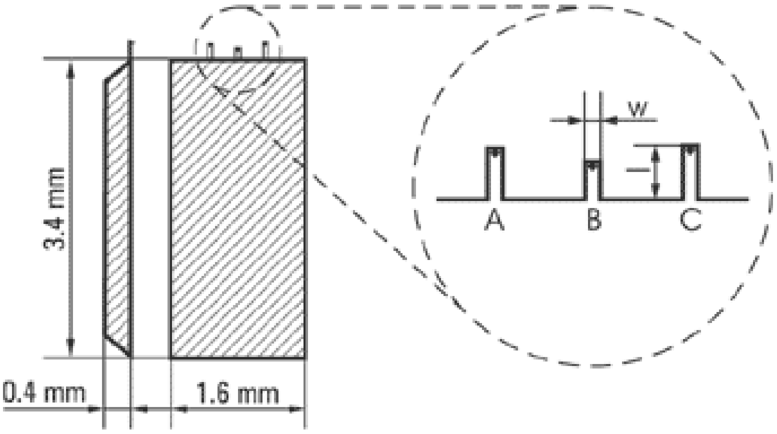


Table 6-1 shows the specification for the three cantilevers in the NSC36 series.

Table 6-1. Specifications of NSC36 Series Cantilevers

Cantilever Type	A			B			C		
	Min	Typica	Max	Min	Typica	Max	Min	Typica	Max
Length, l±5, μm		110			90			130	
width, w±3, μm		35			35			35	
Thickness, μm	0.7	1	1.3	0.7	1	1.3	0.7	1	1.3
Resonant frequency, kHz	65	105	150	95	155	230	50	75	105
Force constant, N/m	0.3	0.95	2.5	0.5	1.75	5	0.2	0.6	1.5

6-4. Measurement Procedure

The measurement procedure hereafter is the same as in Chapter 6. Please review Chapter 6.

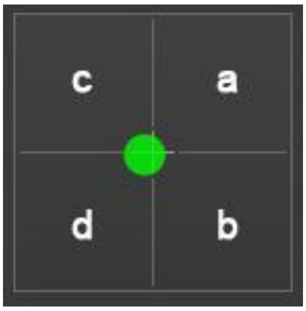
Chapter 7. Lateral Force Microscopy (LFM)

7-1. Principle of Lateral Force Microscopy (LFM)

The principle of Lateral Force Microscopy (LFM) is very similar to that of Contact mode AFM. Whereas in contact mode we measure the deflection of the cantilever in the vertical direction to gather sample surface information, we measure the deflection of the cantilever in the horizontal direction in LFM. The lateral deflection of the cantilever is a result of the force applied to the cantilever when it moves horizontally across the sample surface, and the magnitude of this deflection is determined by the frictional coefficient, the topography of the sample surface, the direction of the cantilever movement, and the cantilever's lateral spring constant. Lateral Force Microscopy is very useful for studying a sample whose surface consists of inhomogeneous compounds. It is also used to enhance contrast at the edge of an abruptly changing slope of a sample surface, or at a boundary between different compounds.

Since the LFM measures the cantilever movement in the horizontal direction as well as the vertical one to quantitatively indicate the surface friction between the probe tip and the sample, it uses a PSPD (position sensitive photo detector) that consists of four domains (quad-cell), as shown in Figure 9-1.

Figure 7-1. Quad-cell PSPD



Generally, in AFM, to measure the topography of a sample surface, the "A-B" signal is used. This signal is related to the difference between the upper cells (a+c) and the lower cells (b+d) of the PSPD.

Topographic information = A-B = (a+c)-(b+d)

The LFM("A-B") signal, which is related to the change in the surface friction on a sample surface, measures the deflection of the cantilever in the horizontal direction and can be represented as the difference in the signals recorded in the right cells (Intensity) and the left cells (c+d).

Frictional information = LATERAL = (Intensity) – (c+d)

Figure 7-2. AFM and LFM signal

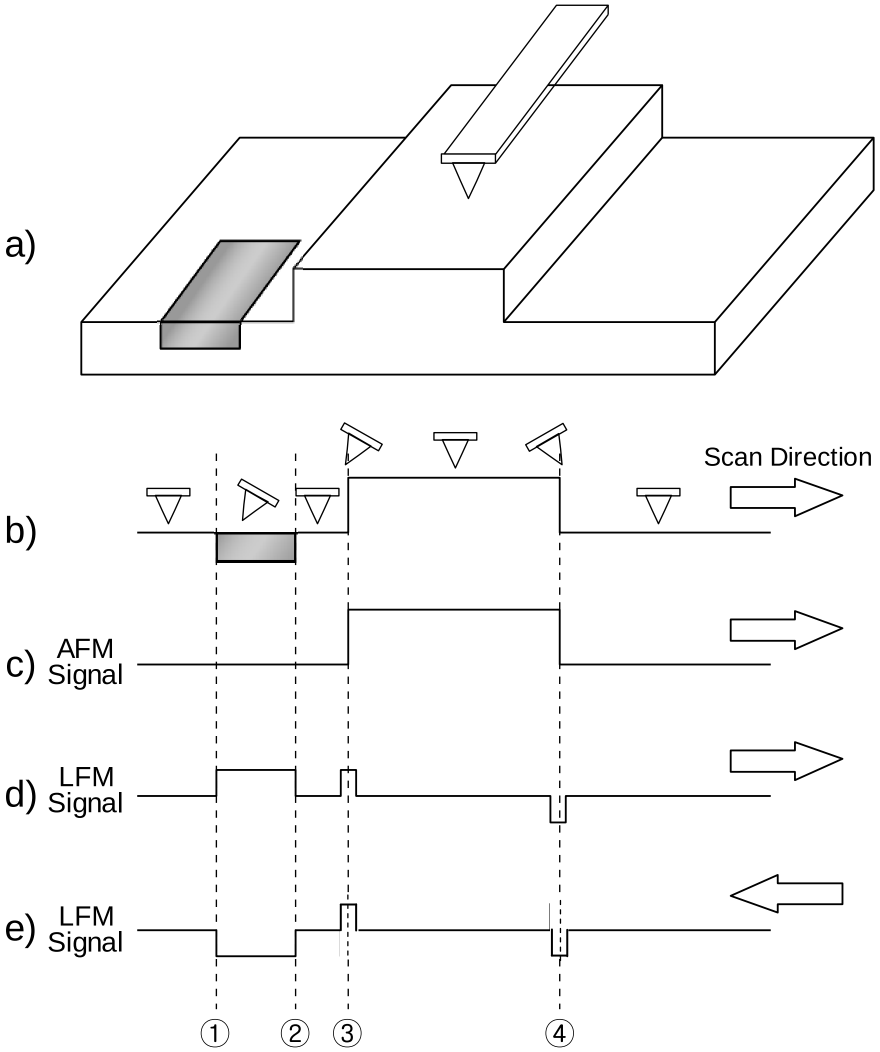


Figure 7-2 (a) shows a surface structure with a centrally located step with low, smooth areas on either side. The flat part on the left contains a domain with a relatively high frictional coefficient. **Profile b** indicates the cantilever’s deflection as it encounters topographic features as well as different frictional coefficients as it scans from left to right. **Profile c** is an AFM image of the surface topography and structure; it is represented by the change in the vertical deflection of the cantilever which does not include the horizontal deflection. **Profile d** and **Profile e** show the LFM signal which indicates the horizontal deflection of the cantilever. When scanning left-to-right, the surface structure of a sudden peak will instantaneously twist the cantilever to the right. This results in a lateral force signal with a convex shape as seen in Figure 7-2 (d) ③. The opposite occurs when the probe encounters a sudden downward step as depicted at location ④. The region between ① and ② indicates an area on the sample surface where there is a material with a higher surface frictional coefficient compared to the surrounding area. There are no distinguishable surface features that will allow the user to differentiate this region utilizing the height signal. Even though the topographical information is the same between ① and ②, there will be a conspicuous difference noticeable in the LFM signal. When the cantilever scans this area from left to right, an increase in relative friction will cause it to tilt to the right, thus producing an increase in the LFM signal.

Figure 7-2 (e) shows the LFM signal when the scan direction is reversed. If the cantilever scans direction as indicated by the arrow, there will be no change in the LFM signal at region ③ and ④ which are related to the topographic features of the sample surface. However, when the scan direction is reversed, the cantilever will now tilt to the left in the area where the frictional coefficient between ① and ② is larger, yielding a decrease in the LFM signal in this area.

Considering the simple comparison described above, the LFM result contains the surface frictional information as well as the surface topographical information.

Hence, when you analyze the result of the LFM measurement, it is necessary to distinguish the information due to difference in the frictional coefficient from the information due to the change in the sample surface topography by taking the AFM image into account.

7-2. Conversion to LFM

As mentioned above, since lateral force mode is an extension of contact mode, the Head mode will be set to “Contact mode”.

1. Turn off the beam by unclicking the beam control check box at the bottom left portion of the Vision View.
2. Once the beam is off, click the Head Mode tab at the top of parameters view and select **Contact**.
3. Turn on the beam by clicking the beam control check box.

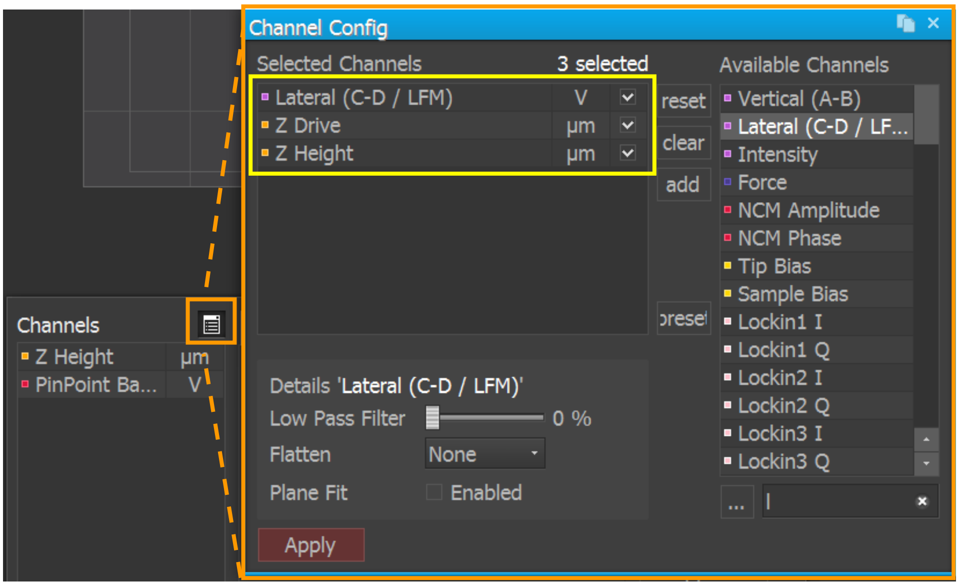
7-3. Cantilever Selection

The Lateral Force Microscope (LFM) measures the horizontal deflection of the cantilever under the same conditions as contact AFM. Therefore, LFM uses the same type of cantilever.

7-4. Measurement Procedure

You can obtain an LFM image and a topographic image simultaneously when you measure in contact mode. If you press the (▤) button, the Config window will appear as shown in Figure 7-3 below. You can take an LFM image if you selected ‘Lateral Force’ option in this “Input Configuration” box. Also, LPF and Flattening can be chosen based on the sample. It is recommended to consult the SmartScan™ software manual for instructions on how to set them.

Figure 7-3. Setup for LFM mode



Channel Config

Selected Channels 3 selected

Lateral (C-D / LFM)	V	☑
Z Drive	µm	☑
Z Height	µm	☑

Details 'Lateral (C-D / LFM)'

Low Pass Filter 0 %

Flatten None

Plane Fit ☐ Enabled

Channels

Z Height	µm
PinPoint Ba...	V

The procedure to measure in ‘Lateral Force’ mode is the same as that in contact mode.

Chapter 8. AFM in Non-Contact Mode

8-1. Principle of Non-contact Mode AFM

There are two major forces, the static electric repulsive force and attractive force, existing between atoms a short distance apart: The static electric repulsive forces (F_{ion}) between ion cores and the static electric attractive forces (F_{el}) between valence electrons and ion cores. When the distance between the atoms at the end of the probe tip and the atoms on the sample surface become much shorter, the repulsive forces between them become dominant, and the force change due to the distance change becomes greater and greater. Therefore, contact AFM measures surface topography by utilizing the system's sensitive response to the Repulsive Coulomb Interactions that exist between the ion cores when the distance between the probe tip and the sample surface atoms is very small. However, as shown in Figure 8-1, when the distance between the probe tip and the sample atoms is relatively large, the attractive force F_{el} becomes dominant. Ion cores become electric dipoles due to the valence electrons in the other atoms. The force induced by the dipole-dipole interaction is the van der Waals Force. Non-contact AFM (NC-AFM) measures surface topography by utilizing this attractive atomic force in relatively larger distance between the tip and a sample surface.

Figure 8-1. Concept diagram of contact mode and non-contact mode

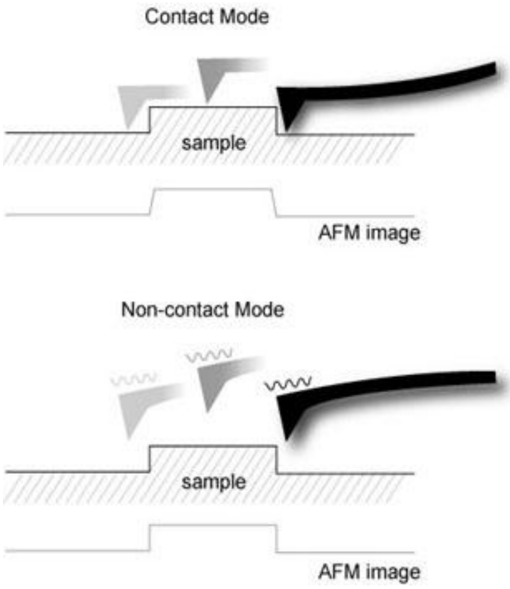


Figure 8-1 compares the movement of the probe tip relative to the sample surface for images being acquired between in contact AFM and non-contact AFM. Contact AFM uses the “physical contact” between the probe tip and the sample surface, whereas non-contact AFM does not require this contact with the sample. In Non-Contact mode, the force between the tip and the sample is very weak so that there is no unexpected change in the sample during the measurement. Therefore, Non-Contact AFM is very useful when a biological sample or another very soft sample is being measured; the tip will also have an extended lifetime because it is not abraded during the scanning process. On the other hand, the force between the tip and the sample in the non-contact regime is very low, and it is not possible to measure the deflection of the cantilever directly. So, Non-Contact AFM detects the changes in the phase or the vibration amplitude of the cantilever that are induced by the attractive force between the probe tip and the sample while the cantilever is mechanically oscillated near its resonant frequency.

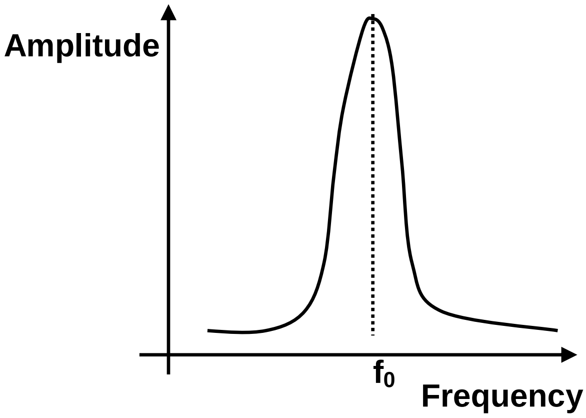
A cantilever used in Non-Contact AFM typically has a resonant frequency between 100 kHz and 400 kHz with a vibration amplitude of a few nanometers. Because of the attractive force between the probe tip and the surface atoms, the cantilever’s vibration at its resonant frequency near the sample surface experiences a shift in the spring constant from its intrinsic spring constant (k_o). This is called the effective spring constant (k_{eff}), and the following equation holds:

$$k_{eff} = k_o - F' \quad (1)$$

When the attractive force is applied, k_{eff} becomes smaller than k_0 since the force gradient F' (=∂F/∂) is positive. Accordingly, the stronger the interaction between the surface and the tip (in other words, the closer the tip is brought to the surface), the smaller the effective spring constant becomes. This alternating current method (AC detection) creates a more sensitive responds to the force gradient as opposed to the force itself. Thus, it is also applied in such techniques as MFM (Magnetic Force Microscopy and Tapping mode).

A bimorph is used to mechanically vibrate the cantilever. When the bimorph's drive frequency reaches the vicinity of the cantilever's natural/intrinsic vibration frequency (f_0), resonance will take place, and the vibration that is transferred to the cantilever becomes very large. This intrinsic frequency can be detected by measuring and recording the amplitude of the cantilever vibration while scanning the drive frequency of the voltage being applied to the bimorph. Figure 8-2 displays the relationship between the cantilever's amplitude and the vibration frequency. From this output, we can determine the cantilever's intrinsic frequency.

Figure 8-2. Resonant frequency



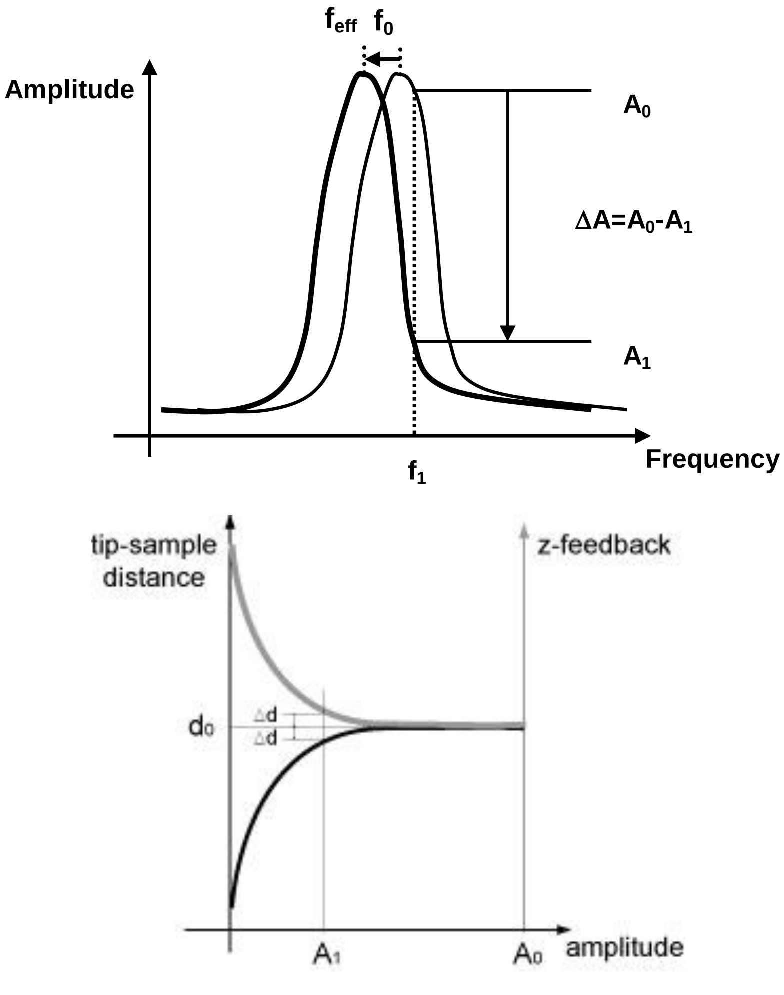
On the other hand, the spring constant affects the resonant frequency (f_0) of the cantilever, and the relation between the spring constant (k_0) in free space and the resonant frequency (f_0) is as in Equation (2).

$$f_0 = \sqrt{\frac{k_0}{m}} \quad (2)$$

As in Equation (1), since k_{eff} becomes smaller than k_0 due to the attractive force, f_{eff} too becomes smaller than f_0 as shown in Figure 8-3 (a). If you vibrate the cantilever at the frequency f_1 (a little larger than f_0), where a steep slope is observed in the graph representin g free space frequency vs. amplitude, the amplitude change (ΔA) at f_1 becomes very large even with a small change of intrinsic frequency caused by atomic attractions. Therefore, the amplitude change measured in f_1 reflects the distance change (Δd) between the probe tip and the surface atoms.

If the change in the intrinsic frequency, resulting from the interaction between the surface atoms and the probe or the amplitude change (ΔA) at a given frequency (f_1), can be measured, the non-contact mode feedback loop will then compensate for the distance change between the tip and the sample surface as shown in Figure 8-3 (b). By maintaining constant cantilever’s amplitude (A_0) and distance (d_0), non-contact mode can measure the topography of the sample surface by using the feedback mechanism to control the Z scanner movement following the measurement of the force gradient represented in Equation (1).

Figure 8-3. (a) Resonant frequency shift (b) Amplitude vs Z-feedback



8-2. Non-contact mode setup

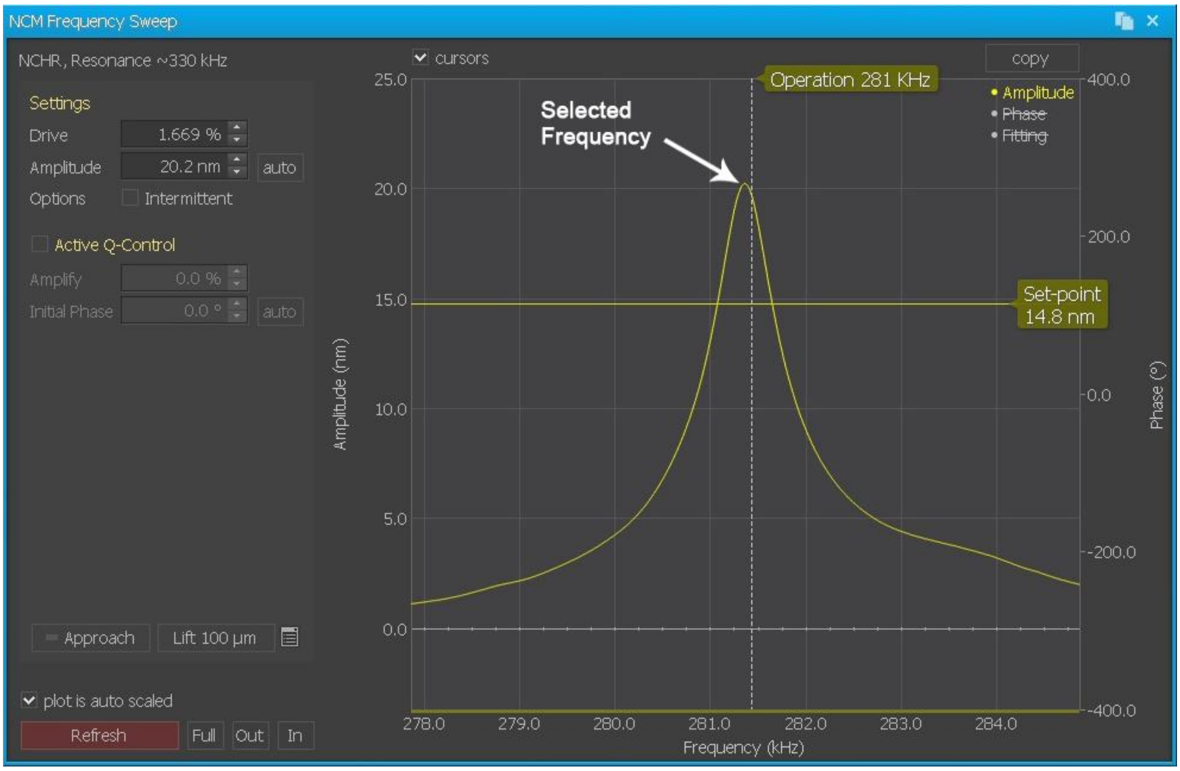
The non-contact mode setup can be done easily by selecting NC-AFM as the Head m ode, similar to the setup for contact mode explained in Section 2 of Chapter 8.

1. Turn off the beam switch by unclicking the beam control check box on the bottom left portion of the Vision View.
2. Once the beam is off, click the Head Mode tab at the top of parameters view and select **NCM**.
3. Turn on the beam by clicking the beam control check box.

8-3. Resonant Frequency setup

Once the Head mode is selected as NC-AFM, turn on the beam by clicking the beam control check box. The system will then automatically find the resonant frequency. Instead of turning the beam on and off, you can also access the Frequency Sweep dialog by clicking the ( ) NCM Sweep button in the Scan Control Window.

Figure 8-4. Resonant Frequency setup in Non-Contact Mode



NCM Frequency Sweep

NCHR, Resonance ~330 kHz

Settings

Drive 1.669 %

Amplitude 20.2 nm

Options ☐ Intermittent

☐ Active Q-Control

Amplify 0.0 %

Initial Phase 0.0 °

☑ plot is auto scaled

☑ cursors

Operation 281 KHz

Set-point 14.8 nm

When the “NCM Frequency Sweep window opens, you can manually select the resonant frequency as follows.

1. If the ‘Refresh’ button or ‘Zoom Out’ button is clicked, one unit on the X-axis represents 5 kHz as shown above.

2. Select the resonant frequency as follows: First, press the ‘Refresh’ button and then the graph of frequency vs amplitude will appear. Press the ‘Refresh’ button again while adjusting the drive % to make the strongest peak fall within 20nm in the Y-axis(You can check the Y-axis unit on the upper left corner of graph. It is adjustable using the mouse wheel). After adjusting the height of the peak, press the (Zoom) “In” button until the X-axis unit is 1kHz/div

3. After positioning the mouse pointer on the slope just to the right hand side of the strongest peak as shown in Figure 8-4, click on it with the left mouse button and a ‘+’ sign will appear. The location of the ‘+’ sign corresponds to the selected frequency f1 at which the cantilever will vibrate in non-contact mode. After positioning the mouse pointer on the red horizontal line, move this red line up and down while holding the left mouse button; this will allow you to change the set point value. In general, make the set point just higher than half of the peak height, and press the “OK” button once to enter the selection.

   The value of the drive amplitude(%) and set point can also be changed in the “Scan Control” window.

8-4. Cantilever selection

The non-contact mode cantilever has a relatively large frequency since the non-contact mode uses the vibrating cantilever method which enables to measure the force gradient by the amplitude and phase change due to the interaction between the probe and a sample surface. Figure 8-5 shown below is a SEM image of a typical non-contact mode cantilever, the PPP-NCHR series. The upper surface of the cantilever (the opposite side of the tip) is coated with aluminum (Al) to enhance the beam reflectivity.

Figure 8-5. SEM image of ULTRASHARP silicon cantilever (the PPP-NCHR series)

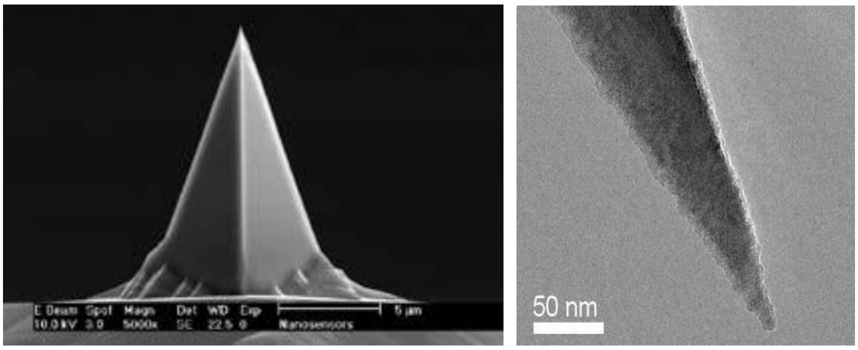


Figure 8-6 shows the standard dimensions of the NCHR series chip. The thickness of the chip is 0.4 mm, and a rectangular shaped cantilever is at the end of the chip. Table 8-1 lists the specifications for this cantilever. The non-contact mode cantilever has a thickness of about 4㎛, and the spring constant is very large (42N/m) relative to that of a contact mode cantilever.

Figure 8-6. Silicon chip of the NCHR series has 1 rectangular cantilever

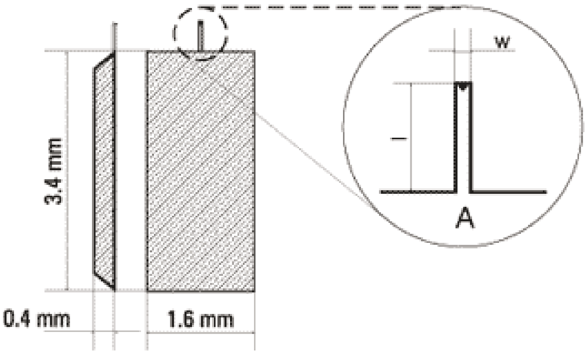


Table 8-1. NCHR series Cantilever Specifications

Cantilever Type	Cantilever Length, l ± 5, ㎛	Cantilever Width, w ± 3, ㎛	Cantilever Thickness, ㎛			Resonant Frequency, kHz			Force Constant, N/m		
			min	typical	max	min	typical	max	min	typical	max
A	125	30	3.0	4.0	5.0	204	330	497	10	42	130

8-5. Measurement Procedure

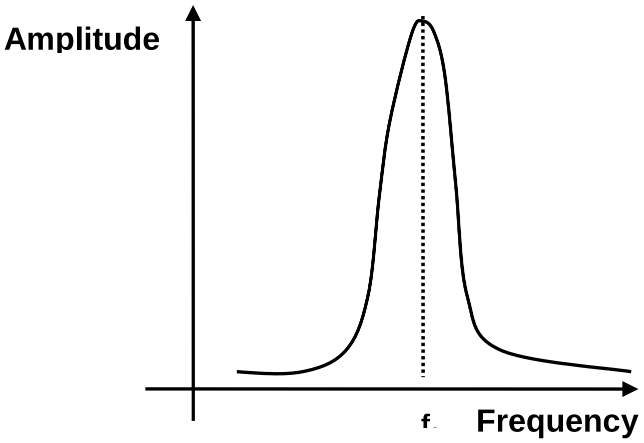
The measurement procedure hereafter is the same as in Chapter 6.
Please refer to Chapter 6.

Chapter 9. Tapping mode

9-1. Principle of Tapping mode

Tapping mode is very similar to Non-contact mode AFM in many ways such as the applied force and the measurement principle. Tapping mode is a hybrid of the two most fundamental measurement methods, represented by contact mode and non-contact mode. In Tapping mode, the cantilever vibrates in free-space in the vicinity of the resonant frequency like in non-contact mode. At the same time, since the vibrating cantilever gets very close to the sample surface, it taps the surface repeatedly, and the tip “contacts” the sample surface as it does in contact mode. If you measure the amplitude of vibration of the cantilever used in Tapping mode while changing the frequency, as shown in Figure 9-1, there appears a special frequency where the amplitude resonates and amplifies greatly. This is called the intrinsic frequency (f_0).

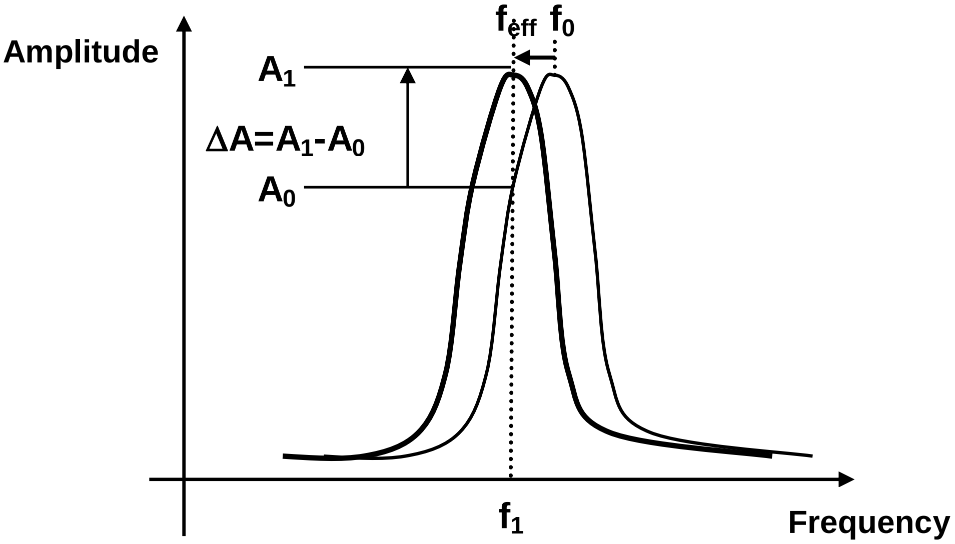
Figure 9-1. Resonant frequency

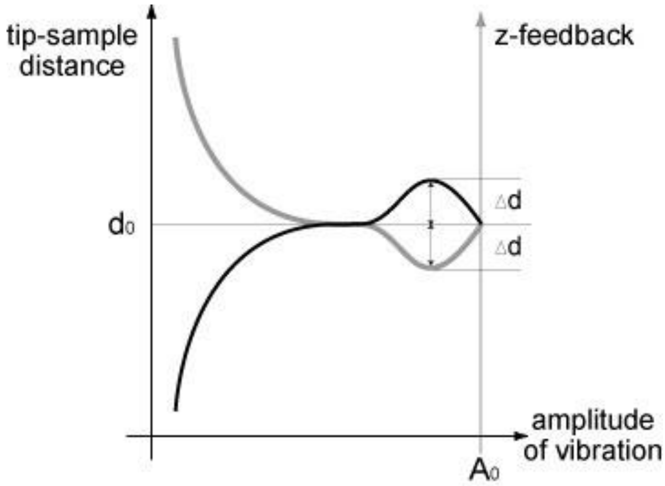


Tapping mode uses the non-contact mode feedback circuit with keeping the vibrating frequency (f1) a little bit lower than the resonant frequency while oscillating in free-space. Then, as the tip is lowered, the real spring constant reduces due to the attractive van der Waals force which increase as the tip approaches the sample surface, as shown in Figure 9-2 (a). Therefore the resonant frequency changes to effective frequency(feff) in non-contact regime and the amplitude at the frequency f1 increases by ∆A. Since the amplitude increases by ∆A, the non-contact mode feedback circuit decreases the distance between the tip and the sample surface by ∆d, indicated in the graph of vibration amplitude vs tip-sample distance and z-feedback as shown in Figure 9-2 (b). Therefore, the vibrating cantilever, which is oscillating above the sample, approaches the sample almost in contact or in collision with the surface. This method, keeping intermittent contact between the sample surface and the vibrating cantilever is called Tapping mode.

Similar to the initial approach of making contact with the sample, while scanning, a larger amplitude reduces the distance between the tip and sample, and a smaller amplitude increases the distance depending on the surface roughness to determine the surface topology.

Figure 9-2. (a) Resonant frequency shift (b) Amplitude vs. Z-feedback



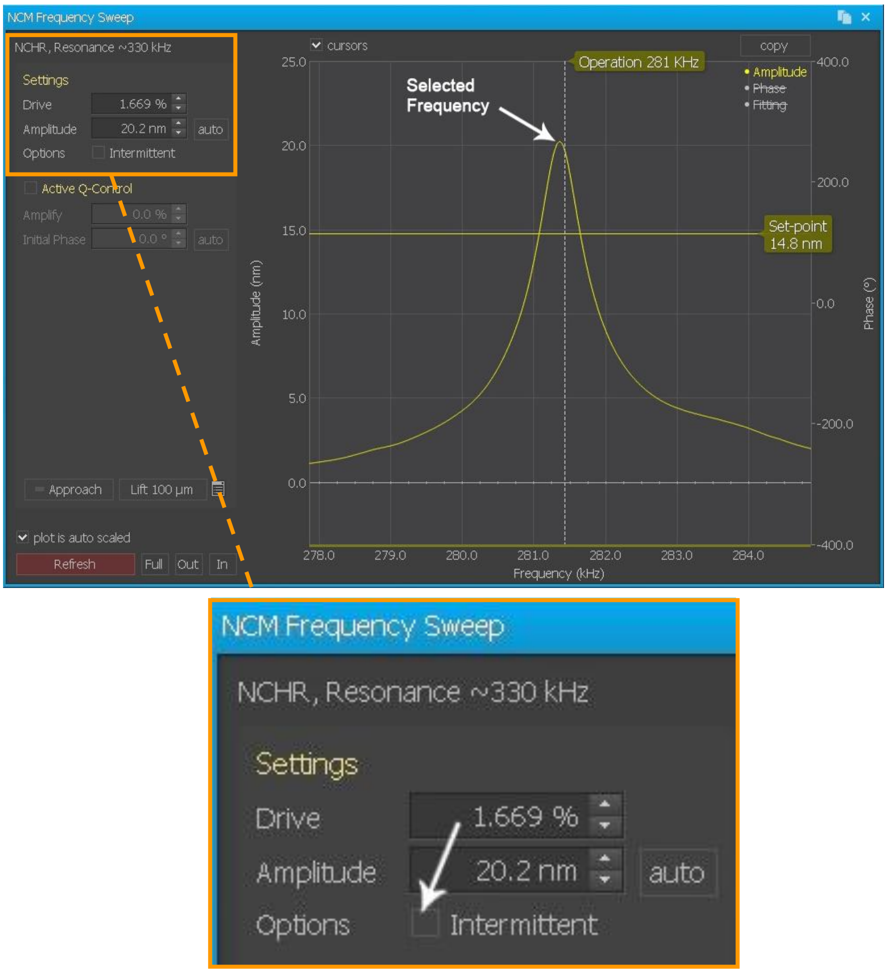


For certain samples, Tapping mode yields better measurements than contact mode or non-contact mode AFM. Tapping mode has an advantage over contact mode in the sense that it will damage the sample less since there is no frictional force as the cantilever “skips” across the sample surface instead of “dragging” across it. Since the amplitude of oscillation is so large, there is a much better chance that the probe will not be caught by the meniscus forces of moisture condensed on the sample surface, as there is with NC-AFM.

9-2. Conversion to Tapping mode

In Tapping mode, the Head mode will be set to NCM just as in non-contact mode. However, the “Intermittent” checkbox in NCM Frequency Sweep Window must be selected.

Figure 9-3. Conversion to Tapping mode



NCM Frequency Sweep

NCHR, Resonance ~330 kHz

Settings

Drive 1.669 %

Amplitude 20.2 nm auto

Options ☐ Intermittent

☐ Active Q-Control

Amplify 0.0 %

Initial Phase 0.0 ° auto

☑ plot is auto scaled

☑ cursors

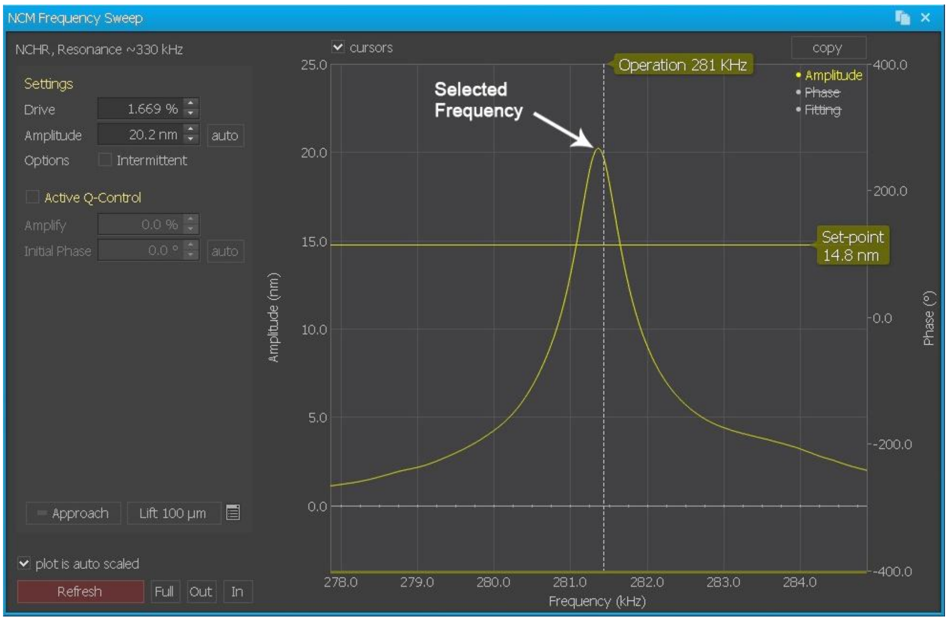
Operation 281 KHz

Set-point 14.8 nm

9-3. Resonant Frequency setup

As explained in section 1, Tapping mode uses non-contact mode feedback, but, as opposed to non-contact mode, the driving frequency should be selected at the left part of the peak in the graph. The other conditions are the same as the non-contact mode.

Figure 9-4. Resonant frequency setup in Tapping mode



NCM Frequency Sweep

NCHR, Resonance ~330 kHz

Settings

Drive 1.669 %

Amplitude 20.2 nm

Options ☐ Intermittent

☐ Active Q-Control

Amplify 0.0 %

Initial Phase 0.0 °

☑ plot is auto scaled

☑ cursors

9-4. Cantilever Selection

Since Tapping mode uses the same method as non-contact AFM, which is to vibrate the cantilever when measuring the sample surface, the same type of cantilevers are used in Tapping mode as in non-contact mode unless the user prefers a different type of cantilever for a specific purpose. See the Cantilever Selection section in the Non-Contact AFM chapter.

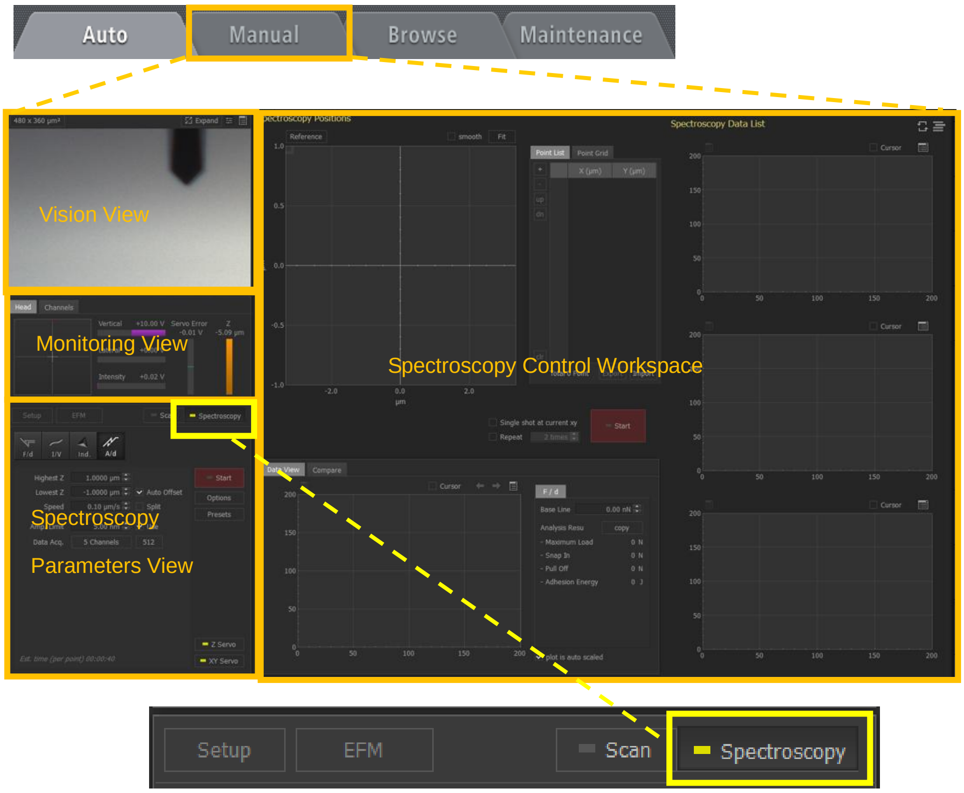
9-5. Measurement Procedure

The method of measurement of Tapping mode is the same as that of non-contact mode. The absolute value of the Set Point also means the distance between the probe tip and the sample surface, just as in non-contact mode, but the value is much smaller. The vibrating probe tip moves as if it is pecking the sample surface using the same feedback circuit. Determining the set point plays a very important role in obtaining the best image.

Chapter 10. Approach Spectroscopy

Activating spectroscopy control mode changes the workspace as shown below. To get to the Spectroscopy Control View, click the **Manual** tab, then choose the **Spectroscopy** button in the Spectroscopy Parameters View. The workspace will change to the Spectroscopy Control workspace, as shown in Figure 10-1.

Figure 10-1. Spectroscopy Control workspace



Spectroscopy control mode allows users to monitor signals at one point as a paramter change is made. The following spectroscopy modes are available:

- **FD**: Approach spectroscopy (generally referred to as force-distance spectroscopy)
- **IV**: Voltage spectroscopy (generally referred to as current-voltage spectroscopy); activated only in current atomic force microscopy (CP-AFM)

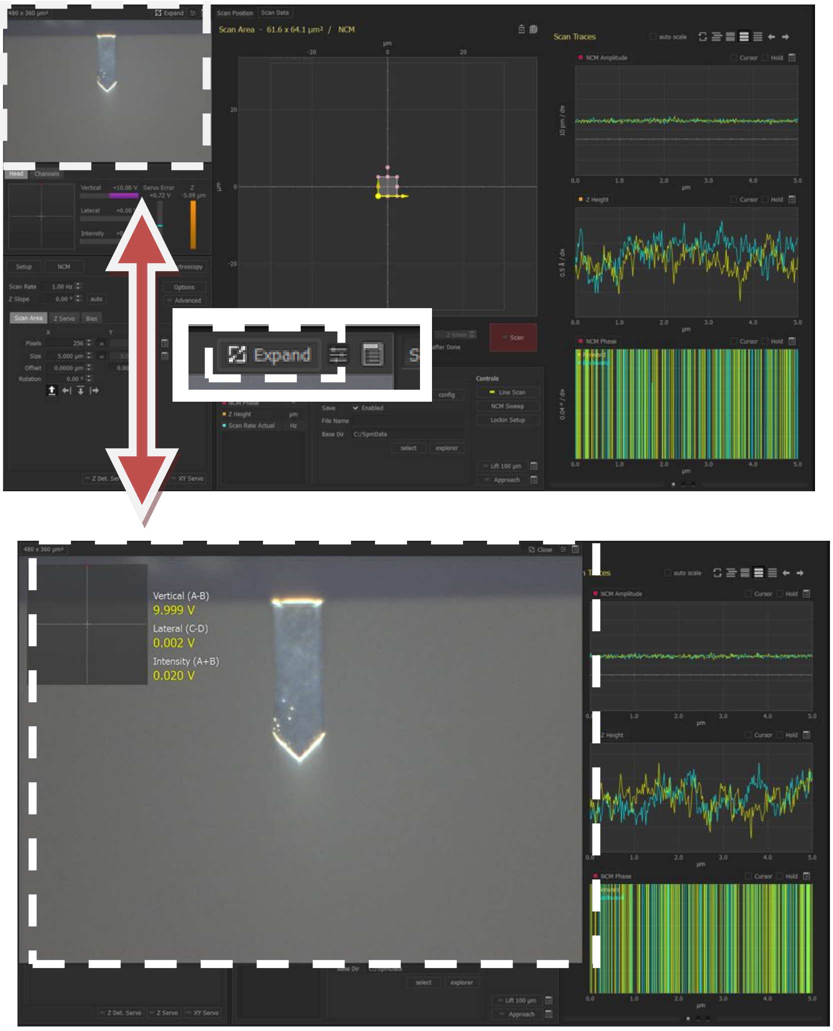
- **Ind.:** Nano-indentation
- **AD**: Amplitude spectroscopy (generally referred to as amplitude-distance spectroscopy)
- **TA**: Temperature analysis spectroscopy (used with scanning thermal microscopy)

The **Manual** tab of the Spectroscopy Control workspace includes.

Vision View

The Vision View displays the optical view from the digital camera. The camera can be focused on the cantilever or sample. Focus on the cantilever to align the beam onto the cantilever. Focus on the sample to locate the general area for imaging.

Figure 10-2. Vision View and expanded Vision View



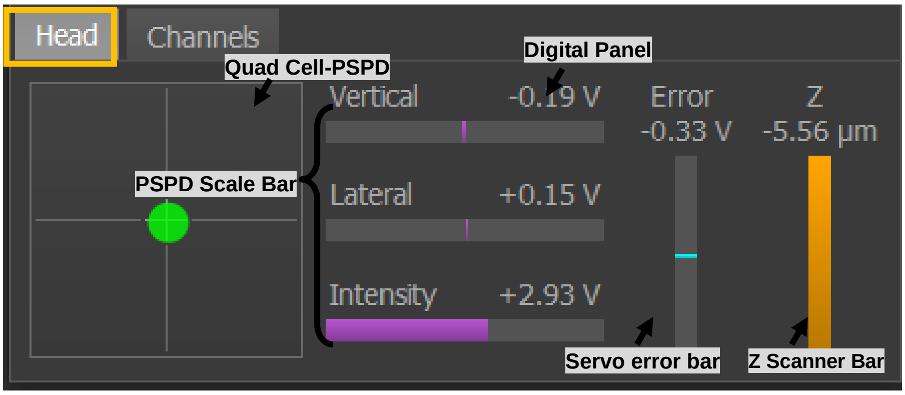
Vertical (A-B) 9.999 V
Lateral (C-D) 0.002 V
Intensity (A+B) 0.020 V

The Vision View can also be used to control a) light strength, b) turning the beam on/off, c) the XY stage, and d) the Z/focus stage. Clicking **Expand** (Expand) will expand the Vision View to allow the user to easily see the optical image.

Monitor View

The Monitor View displays useful information during measurement. The Monitor View has three tabs: **Head**, **Channels**.

Figure 10-3. Monitor View



Head Tab

As shown in Figure 10-3, the **Head** tab contains a visual representation of the quad-cell PSPD (position-sensitive photo detector) and three related scale bars (**Vertical**, **Lateral**, **Intensity**) with the value in voltage units, as displayed above. The **Head** tab also contains a servo error bar and a Z scanner bar, which display the status of the feedback loop and the Z scanner in real time.

Panel	Function
Quad Cell-PSPD	Shows the position of the reflected laser beam on the PSPD so that you can monitor the deflection of the cantilever.
Vertical	Monitors the vertical PSPD signal, such as cantilever deflection, amplitude of cantilever vibration, or tunneling current, depending on your experimental setup.
Lateral	Monitors the lateral signal, which is related to the change in the surface friction on a sample surface.
Intensity	Monitors the intensity of the reflected laser beam on the PSPD.
Servo Error Bar	Graphically displays the value of the servo error signal from the PSPD relative to the set point value. The value of the servo error signal is represented by the aqua-green bar.
Z Scan Bar	Graphically displays the Z extension of the piezoelectric scanner within its total range. The value of the Z extension is represented by an orange bar. The working range of the Z scanner is represented by this bar during each scan line.

■ Quad-cell PSPD and Scale Bars

The quad-cell PSPD can detect vertical as well as lateral deflection of the laser beam of the cantilever. The quad-cell PSPD has four cells as shown in Figure 10-4. You can get information about both surface height (AFM) and surface friction (LATERAL) during scanning by monitoring laser deflection.

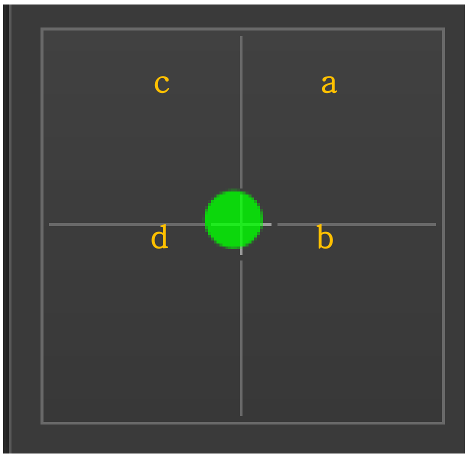
The vertical deflection of the cantilever is measured as the difference between the upper cells (A=a+c) and the lower cells (B=b+d) of the quad-cell PSPD and provides the information about the sample’s topography.

A-B signal=Topographic information=(a+c)-(b+d)

The lateral deflection of the cantilever is measured as the difference between the left cells (D=c+d) and the right cells (C=a+b) of the quad-cell PSPD and provides frictional information.

Lateral signal=C-D signal=frictional information=(a+b)-(c+d)

Figure 10-4. Quad-cell PSPD



In order to perform an approach and take an image, in general you should set the value of the A-B signal smaller than ±0.3V (the red point should be positioned at the center (crosshair) of the quad-cell PSPD display) and the value of the A+B signal (in other words, the laser total intensity) greater than 2V. You can adjust the A-B signal and the intensity signal mechanically using the PSPD adjustment screws on the head (please refer to the User’s Manual for more information).

- **Servo Error Bar**

The servo error bar graphically shows the values of the servo error signal from the PSPD relative to the set point value, the reference signal for the feedback loop.

During a scan, deflection of the cantilever changes as the tip responds to surface topography. The Z feedback loop works to keep this deflection constant during a scan by adjusting the Z position of the scanner. The deflection sensor monitors the amount of cantilever bending and sends a deflection signal to the feedback electronics. There, the deflection signal is compared to a reference signal (deflection at the set point) and an servo error signal is generated. This servo error signal is used to generate a feedback signal, which is sent to the Z scanner so that it causes the scanner to extend or retract. This feedback signal can also be used to generate an image of the sample surface.

Figure 10-5 shows the servo error bar. The aqua-green portion represents the value of the servo error signal, and the position at 0V represents the set point value. The feedback loop is optimized when the servo error signal bar matches the set point value.

- **Z Scanner Bar**

The Z scanner bar monitors the extension or retraction of the Z scanner in response to feedback voltage. The orange portion of the Z scanner bar represents the extension of the piezoelectric Z scanner within its total allowable range of motion. The upper end of the Z scanner bar represents the scanner's position when it is fully retracted. The lower end of the Z scanner bar represents the scanner's position when it is fully extended.

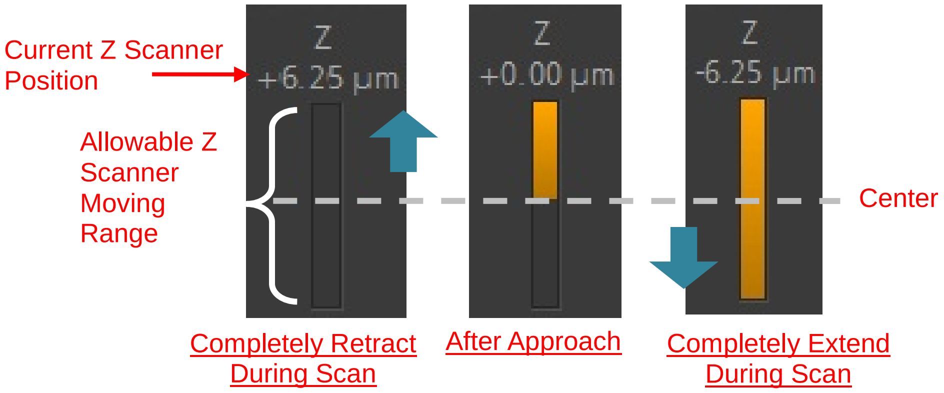
Initially, the Z scanner bar is gray, indicating that the Z scanner is fully retracted. After you enter a set point value, the Z scanner bar fills with orange color to the lower end of the Z scanner bar. This means that the Z scanner bar is fully extended and is ready to approach the sample surface.

Once tip approach is complete, you will see that half of the Z scanner bar is filled with orange. During scanning, when the probe tip encounters peaks on the surface, the Z scanner retracts (the orange bar moves toward the upper end of the Z scanner bar). When the tip encounters valleys on the sample surface, the Z scanner extends (the orange bar moves toward the lower end of the Z scanner bar).

The Z scanner bar always represents the Z scanner's maximum range of motion. Thus, depending on the Z scanner range, its relative motion is scaled differently. When the Z scanner is moving in a small range, the change of the Z scanner bar is relative to that small range, rather than the whole range.

The center of Z scanner bar is 0. As the Z scanner moves up from the center, it retracts and moves in the positive direction (+). As the Z scanner moves down from the center, it extends and moves in the negative direction (-). The value on the top of the Z scanner bar indicates the current Z scanner position.

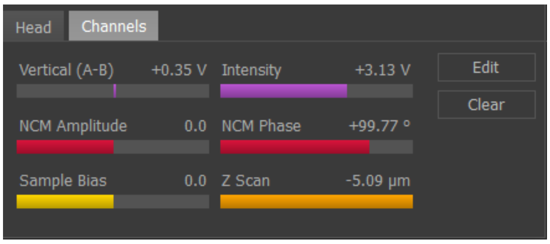
Figure 10-5. Z scanner bar


Current Z Scanner Position
Allowable Z Scanner Moving Range
Z
+6.25 µm
Z
+0.00 µm
Z
-6.25 µm
Center
Completely Retract During Scan
After Approach
Completely Extend During Scan

Channels Tab

In the **Channels** tab, you can select several input signals (up to six) and monitor them through digital panels in real time.

Figure 10-6. Channels tab



Vertical (A-B) +0.35 V
Intensity +3.13 V
NCM Amplitude 0.0
NCM Phase +99.77 °
Sample Bias 0.0
Z Scan -5.09 µm

Edit

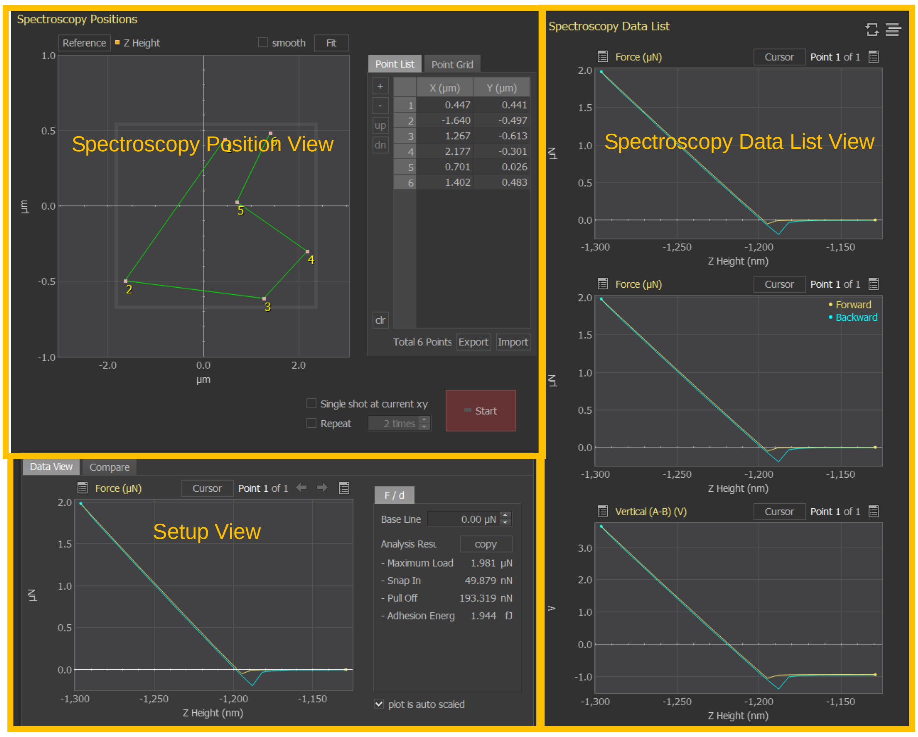
Edit opens the Channel List dialog to select signals to be monitored through the digital panel. Check the box on the right side of the the desired signal, and then click **OK** in the Channel List dialog to display the signals in the **Channels** tab.

Clear

Clicking **Clear** removes all signals displayed in the **Channels** tab.

The Spectroscopy Workspace is further separated into three main areas: the Spectroscopy Positions View, the Spectroscopy Data List, and the Setup View, as shown in Figure 10-7.

Figure 10-7. Spectroscopy control workspace



	X (µm)	Y (µm)
1	0.447	0.441
2	-1.640	-0.497
3	1.267	-0.613
4	2.177	-0.301
5	0.701	0.026
6	1.402	0.483

Total 6 Points Export Import

☐ Single shot at current xy
☐ Repeat 2 times

Base Line 0.00 µN

Analysis Resu

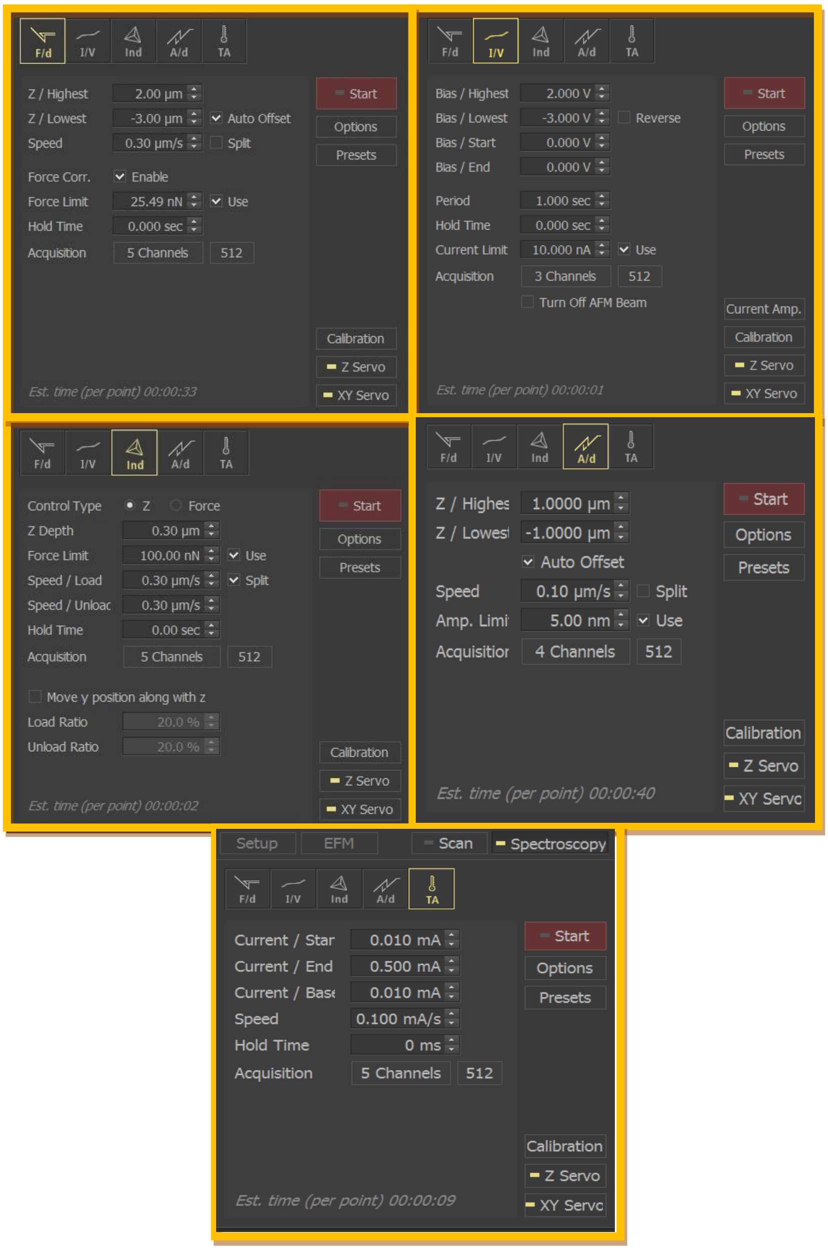
- Maximum Load	1.981	µN
- Snap In	49.879	nN
- Pull Off	193.319	nN
- Adhesion Energ	1.944	fJ

☑ plot is auto scaled

10-1. Spectroscopy Parameters View

The Spectroscopy Parameters View sets the parameters used to take the point measurement. The parameter interface changes depend on the type of spectroscopy measurement being taken. The various spectroscopy parameter setup interfaces are shown in Figure 10-8.

Figure 10-8. Spectroscopy parameter View



F/d:
Z / Highest 2.00 µm
Z / Lowest -3.00 µm ☑ Auto Offset
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 25.49 nN ☑ Use
Hold Time 0.000 sec
Acquisition 5 Channels 512
Est. time (per point) 00:00:33

I/V:
Bias / Highest 2.000 V
Bias / Lowest -3.000 V ☐ Reverse
Bias / Start 0.000 V
Bias / End 0.000 V
Period 1.000 sec
Hold Time 0.000 sec
Current Limit 10.000 nA ☑ Use
Acquisition 3 Channels 512
☐ Turn Off AFM Beam
Est. time (per point) 00:00:01

Ind:
Control Type ● Z ○ Force
Z Depth 0.30 µm
Force Limit 100.00 nN ☑ Use
Speed / Load 0.30 µm/s ☑ Split
Speed / Unloac 0.30 µm/s
Hold Time 0.00 sec
Acquisition 5 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:00:02

A/d:
Z / Highes 1.0000 µm
Z / Lowest -1.0000 µm
☑ Auto Offset
Speed 0.10 µm/s ☐ Split
Amp. Limi 5.00 nm ☑ Use
Acquisitior 4 Channels 512
Est. time (per point) 00:00:40

TA:
Current / Star 0.010 mA
Current / End 0.500 mA
Current / Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512
Est. time (per point) 00:00:09

The general procedure for spectroscopy measurement is as follows:

1. Obtain an SPM image of the sample to identify regions of interest for spectroscopy curves using Scan Control or Auto mode.
2. Change to Spectroscopy Control.
3. Select points to identify for spectroscopy measurement.
4. Select one desired spectroscopy mode and parameters for one-point spectroscopy.
5. Select the parameters related to moving between points.
6. Acquire the scan.

- **FD**: approach spectroscopy or force-distance spectroscopy

  FD spectroscopy mode supports the acquisition of force vs. distance curves, which are useful for the investigation of a sample's mechanical properties. The FD curve is a plot of the force between the tip and the sample as a function of the extension of the Z scanner.

- **IV**: voltage spectroscopy or current-voltage spectroscopy

  Used only in current atomic force microscopy (CP-AFM) mode, IV spectroscopy mode supports the acquisition of a current (I) vs. voltage (V) curve to investigate electrical properties of a sample surface. An IV curve is a plot of the current as a function of the tip bias voltage that is applied to the sample.

- **Ind**: Nano-Indentation

  Nano-indentation enables the users to perform indentation tests to measure material properties, such as nanoscale hardness and elasticity. A single indentation cycle consists of loading, holding, and unloading processes. Nano-indentation has two sub-modes: set point mode and Z scanner mode. Each sub-mode uses different parameters to control the indentation cycle. In set point mode, the force (load) between the tip and sample is varied as a linear function of time while the corresponding position of the Z scanner is measured. In Z scanner mode, the Z scanner position is varied as a linear function of time while the corresponding load applied to the tip is measured.

- **AD:** amplitude distance spectroscopy

  Amplitude spectroscopy, or amplitude-distance spectroscopy, allows users to acquire NCM amplitude and NCM phase information as a function of distance from the surface. This technique can be used to study tip-sample interaction.

- **TA:** Thermal analysis spectroscopy

Thermal analysis spectroscopy is used only with SThM for SThM probe temperature calibration.

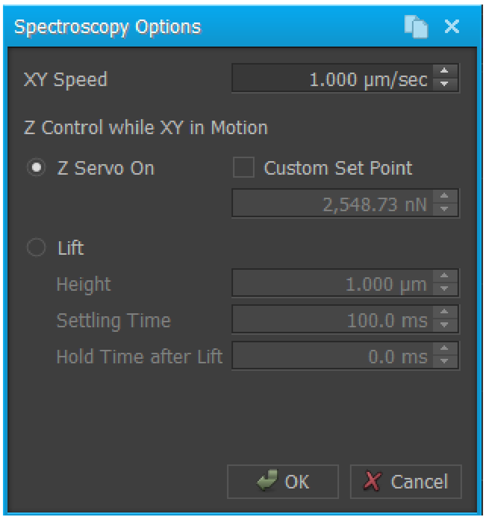
*For detailed information of these modes, refer to the User’s Manual or the Mode Manual.

Start begins the spectroscopy data curve at the current XY position. To take spectroscopy curves of the entire point list or point grid, use the **Start** button found in the Spectrocopy Positions area

10-1-1. Options

Clicking **Options** opens the Spectroscopy Options dialog. The Spectroscopy Options dialog allows you to control how the Z scanner behaves while the XY scanner is moving in spectroscopy modes.

Figure 10-9. Spectroscopy Options dialog



Spectroscopy Options

XY Speed 1.000 µm/sec

Z Control while XY in Motion

● Z Servo On ☐ Custom Set Point

2,548.73 nN

○ Lift

Height 1.000 µm

Settling Time 100.0 ms

Hold Time after Lift 0.0 ms

- **XY Speed**

  This field determines how fast the XY scanner moves to relocate the sample relative to the tip. When in **Z Servo On** mode, a high XY speed may be too fast for the Z servo to prevent the tip from being damaged.

- **Z Control while XY in Motion**

  When moving between two measurement points, the cantilever may crash into variations in the sample surface, which may damage both the sample and cantilever. You can select between two different methods to keep the cantilever from crashing into the surface: **Z Servo On** and **Z Servo Off** with **Lift** options.

- **Z Servo On**

  When **Use Z Servo** is checked, the Z servo may be kept on during movement so that the Z scanner follows surface variations and keeps the cantilever from crashing. **Z Servo On** utilizes this concept.

- **Use Custom Set Point**

  When in **Z Servo On** mode, the Z servo maintains a certain set point. This option determines whether this is specified separately in the **Set Point** field or is the same as the current imaging set point. When this option is checked, the **Set Point** field is activated.

- **Set Point**

  Applicable when **Use Custom Set Point** is checked, the **Set Point** field allows you to specify the set point to maintain while moving between measurement points. By default, this value will be the same as the imaging value, but you can select a different one.

- **Lift**

  When the **Lift** radio button is selected, the Z servo is off and lift options such as **Set Point**, **Lift Height**, and **Settling Time** are activated. When the Z servo is set to be off during the motion between points, the Z scanner raises by a set distance. When the cantilever reaches the new location, a new approach is performed, and measurements resume.

- **Height**

  When in **Lift** mode, the Z scanner is raised by the value shown in this field while the cantilever moves between points. A higher value will be safer, as the cantilever is less likely to crash into sample variations, but will result in a longer reapproach time. A low value reduces reapproach time, but may be insufficient to prevent collision.

- **Settling Time**

  After the tip is relocated, the Z servo must be turned on. **Settling Time** allows the user to define how much time is given for the Z servo to activate.

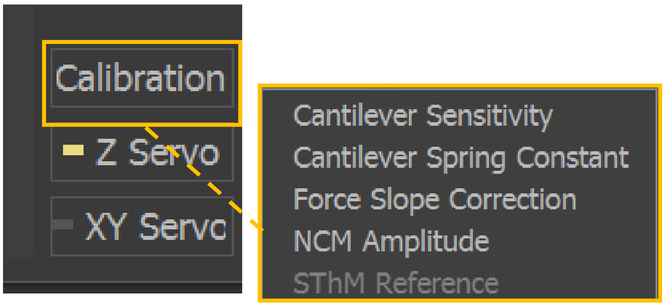
10-1-2. Presets

Presets opens the Presets window to save spectroscopy parameters so that they can be recalled at a later time.

10-1-3. Calibration

The **Calibration** button displays a pop-up menu of calibration features. The menu is displayed in Figure 10-10. The **NCM Amplitude Calibration** option is only active when a non-contact-based measurement mode is selected (NCM, tapping, EFM, or MFM).

Figure 10-10. Spectroscopy calibration menu

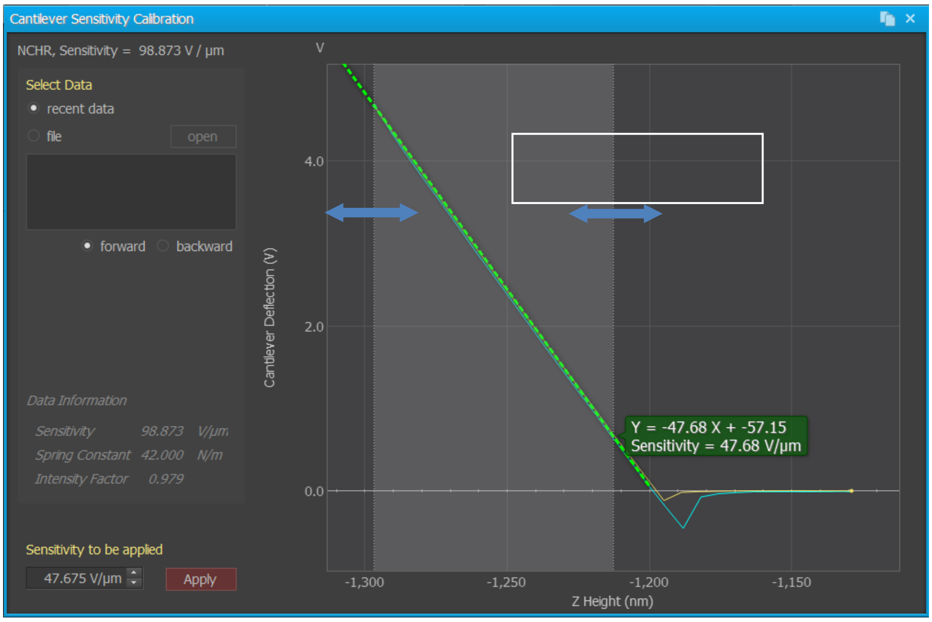


- **Calibration Sensitivity**

This option opens the Sensitivity Calibration window. The Cantilever Sensivity Calibration window is shown in Figure 10-10. To calculate the sensitivity of an FD curve:

1. Choose the data. Click **recent data** to use the data recently taken. Click **file** to sav e an FD curve taken previously.
2. Choose where the sensitivity will be calculated with the forward (approach curve) or backward data (retract curve).
3. Adjust the dotted lines of the calculation window by clicking and dragging on the ed ges of vertical rectange. As the area is adjusted, the green fitting curve will display the calculated sensitivity. For best results, the green line should follow the linear p ortion of the FD curve.
4. The **Sensitvity to be applied** display box will update the calulated sensitivity.
5. Click **Apply** to update the sensitivity of the cantilever file.

Figure 10-11. Cantilever Sensitivity Calibration window



NCHR, Sensitivity = 98.873 V / µm

● recent data

○ file

● forward ○ backward

Sensitivity 98.873 V/µm

Spring Constant 42.000 N/m

Intensity Factor 0.979

Sensitivity to be applied 47.675 V/µm

Y = -47.68 X + -57.15

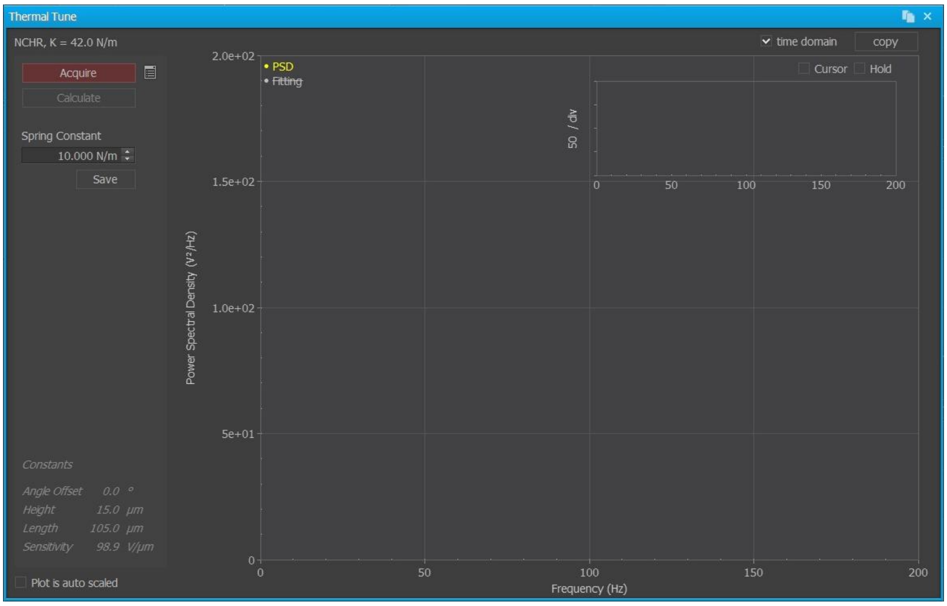
Sensitivity = 47.68 V/µm

- **Cantilever Spring Constant**

This option opens the Cantilever Spring Constant Calibration window. The Cantilever Spring Constant Calibration window is shown in Figure 10-12. To calculate the spring constant of a cantilever:

1. Change the cantilever file to the desired calibration file. This will load cantilever constants used to calculate the spring constant. For information on changing the cantilever file.
2. Install and align the laser on the cantilever.
3. Click **Acquire** to generate the power spectrum density of the thermal tune data. Clicking the **time domain** check box in the upper right corner will display the time domain of the spectrum in the upper right corner.
4. Click **Calculate** to calculate the spring constant, which will be shown in the box below.
5. Click **Save** to save the new spring constant to the cantilever file. The exact value saved to the cantilever file can be adjusted by changing the value in the Spring Constant field.

Figure 10-12. Cantilever Spring Constant Calibration window



NCHR, K = 42.0 N/m

Spring Constant 10.000 N/m

Constants

Angle Offset 0.0 °

Height 15.0 μm

Length 105.0 μm

Sensitivity 98.9 V/μm

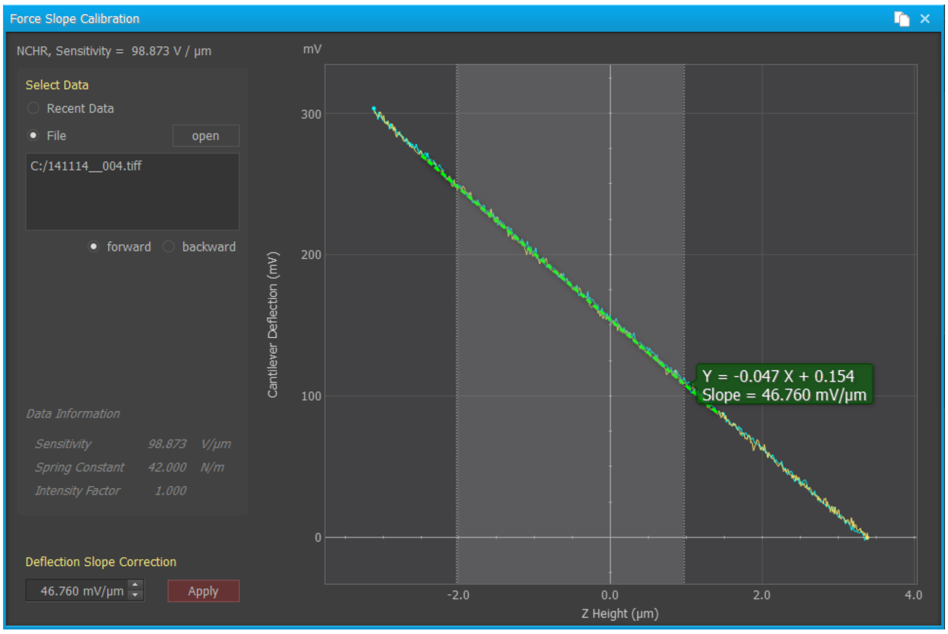
☐ Plot is auto scaled

■ Force Slope Correction

This option opens the Force Slope Correction window. The Force Slope Correction window is shown in Figure 10-13. The Force Slope Correction feature corrects the baseline of the FD curve. When the FD baseline is sloped, the curve can be corrected using the slope correction. Clicking **Apply** will correct the slope of the data by the value shown in the **Deflection Slope Correction** field.

1. Measure the force/distance curve without approach.
2. Calculate the slope by dragging the sides of the plot bar. The slope is automatically calculated when dragging the bar.
3. Enter the slope calibration in the text box, and then click **Apply**.
4. The value is uploaded to the database (V/μm) and saved in the DSP. The correction is applied when the **Enable** check box is chosen in FD Measurement Parameters.

Figure 10-13. Force Slope Calibration window



NCHR, Sensitivity = 98.873 V / µm

C:/141114__004.tiff

Sensitivity 98.873 V/µm
Spring Constant 42.000 N/m
Intensity Factor 1.000

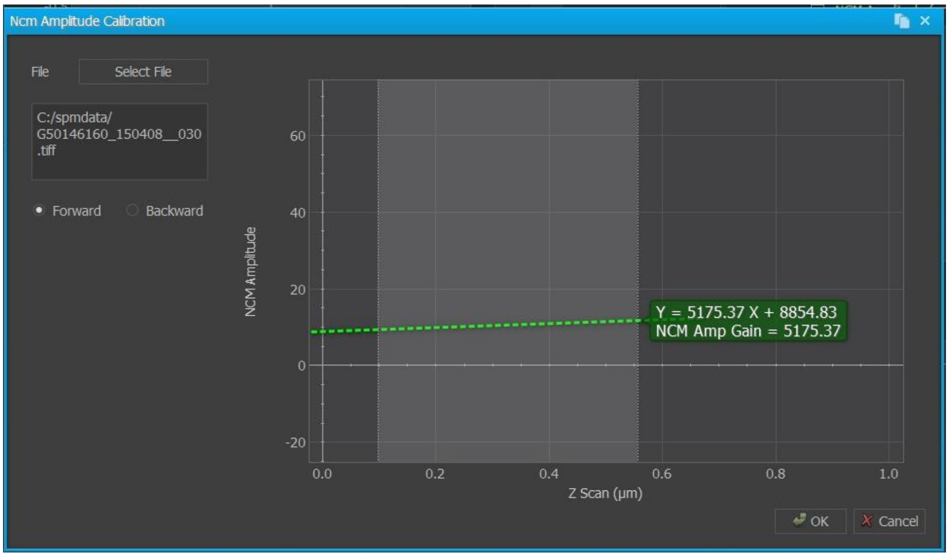
46.760 mV/µm

Y = -0.047 X + 0.154
Slope = 46.760 mV/µm

■ **NCM Amplitude**

This option opens the NCM Amplitude Calibration window. To activate the **NCM Amplitude** menu selection, SmartScan must be set to a non-contact-based scanning mode and **AD Spectroscopy** must be selected. The NCM Amplitude Calibration window is shown in Figure 10-14.

Figure 10-14. NCM Amplitude Calibration window



C:/spmdata/G50146160_150408__030.tiff

Y = 5175.37 X + 8854.83
NCM Amp Gain = 5175.37

Z Servo

Z Servo Clicking this button opens the Z Servo Configuration dialog.

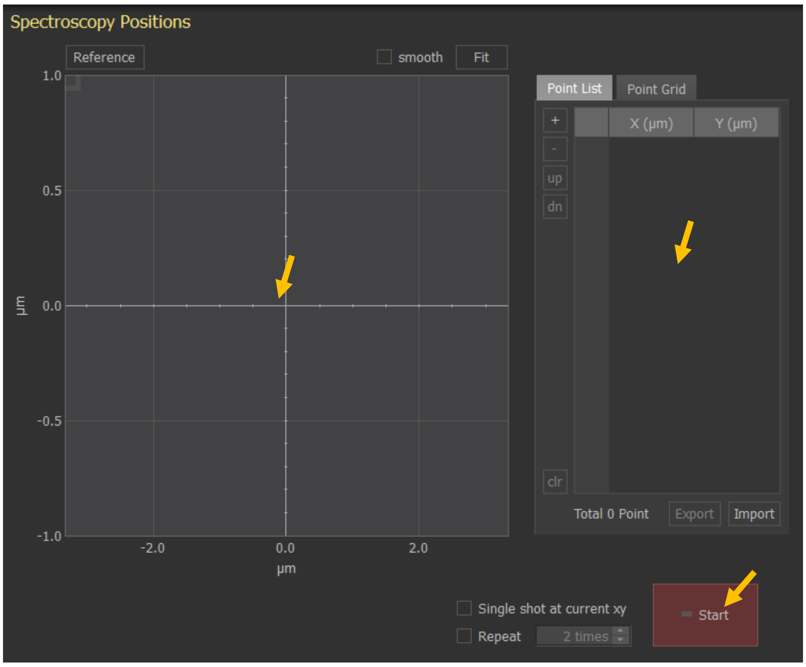
XY Servo

XY Servo Clicking this button opens XY Servo Configuration dialog.

10-2. Spectroscopy Positions View

You can select the points from the Spectroscopy Positions View to indicate where you want to obtain spectroscopy data within the scan area.

Figure 10-15. Spectroscopy Positions



10-2-1. Reference and Point List

The Reference window displays the last image acquired. This image can be used as a reference to determine the desired points for measurement.

- **Adding a point**

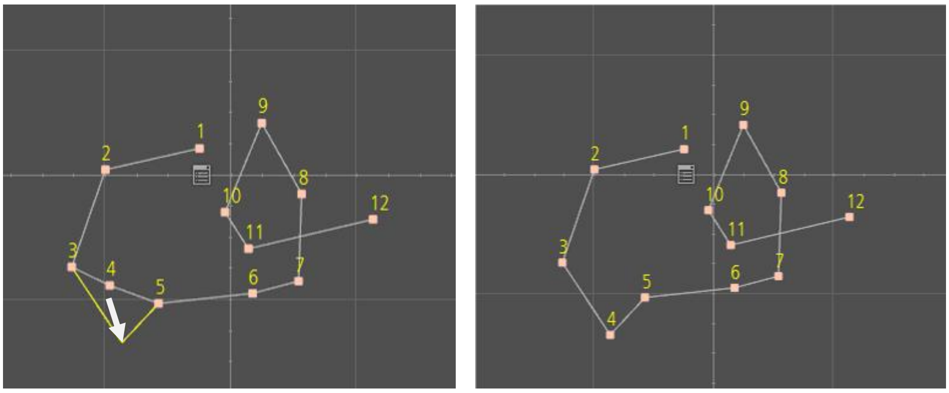
Measurement points can be added by left-clicking on the refrence at the desired location. This will create a single numbered point on the reference. Subsequent clicks will add points to the reference. XY coordinates of the added points will be displayed on the Point

List. Additional points can also be added by clicking on the **+** button next to the Point List. New points can be inserted between two existing measuring points by clicking on the line between the two points in the reference.

- **Moving a point**

Measurement points can be moved by clicking and dragging the numbered point on the reference or by changing the coordinate values in the Point List.

Figure 10-16. Moving a spectroscopy point. Left: original position and movement direction; right: final position after move.



- **Deleting a point**

Measurement points can be deleted by highlighting the point on the Point List and clicking the **–** button.

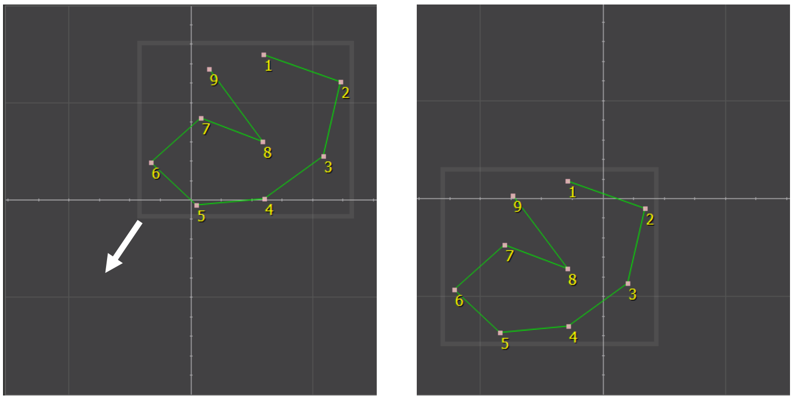
- **Changing Measurement Order**

The spectroscopy will be measured in ascending order starting from 1. To change the order, click the point on the Point List to hightlight the point and use the **up** or **dn** button to move the point up or down on the Point List.

- **Moving All Spectroscopy Points**

To move the entire Point List as a whole, hover above the border surrounding the points. Once the cursor changes to the **Move** tool, click on the border and drag the spectroscopy points box to the new location.

Figure 10-17. Moving all spectroscopy points. Left: original position and movement direction; right: final position after move.

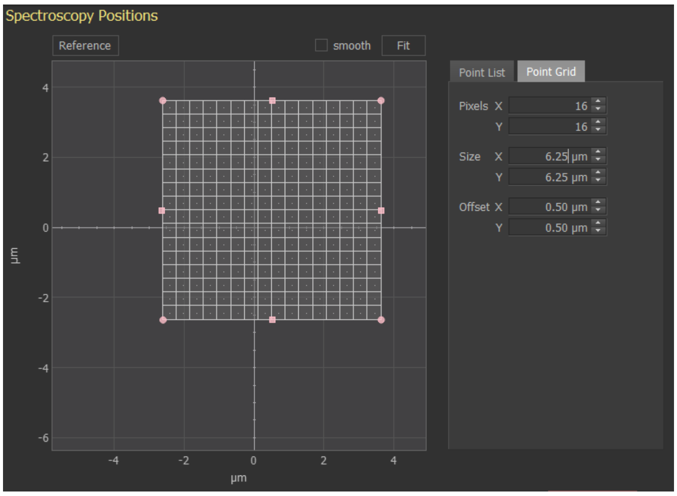


10-2-2. Point Grid

After selecting Point Grid Spectroscopy Positions View, a white grid with pink dots will appear in Reference area. The white box indicates the grid size. Depending on the selected grid pixels, the box is divided. The measurement points will be automatically selected on all the center points of each divided small box. When you click **Start**, the spectroscopy measurements will be acquired, starting from the left bottom corner, using the parameters in parameters control panel. For example, when the grid size is 4x4, 16 measurements are acquired following the order below.

Grid points, size, and offset can be changed under the **Point Grid** tab. Size and offset can be changed visually in the Reference View. The size of the grid box can be changed by clicking and dragging any of the pink dots on the grid box. The offset can be adjusted by clicking and dragging the entire grid box once the hand cursor is visible.

Figure 10-18. Point grid setup and grid box



Pixels X 16
Y 16
Size X 6.25 µm
Y 6.25 µm
Offset X 0.50 µm
Y 0.50 µm

10-2-3. Single Shot at Current xy

When the **Single shot** box is checked, a single spectroscopy curve will be performed at the current tip (XY) position when **Start** button is clicked. Point List and Point Grid information is ignored.

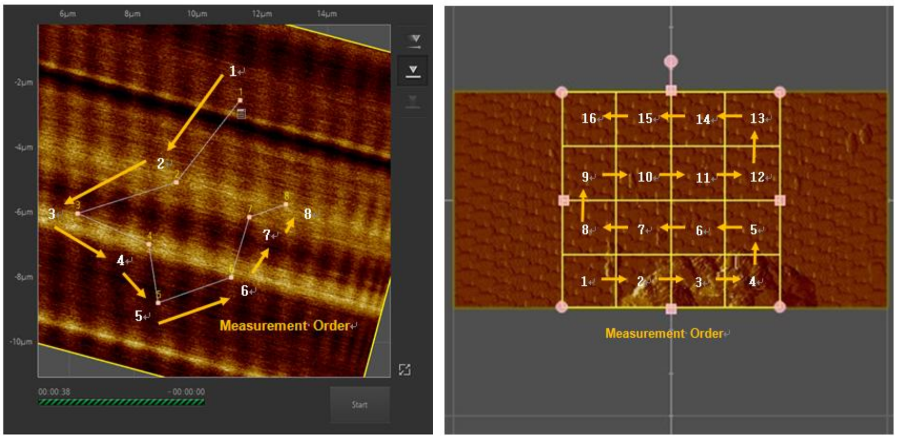
10-2-4. Repeat

This option repeats the spectroscopy curves the number of times indicated. Values between 2 and 100 can be entered.

10-2-5. Start

Spectroscopy measurements will be acquired in numerical order using the parameters in the parameters control panel. This procedure produces a) a single spectroscopy curve (Single shot), b) a collection of curves (Point List), or c) a 2-D grid of curves (Point Grid).

Figure 10-19. Point List setup (Left) and Point Grid setup (Right)



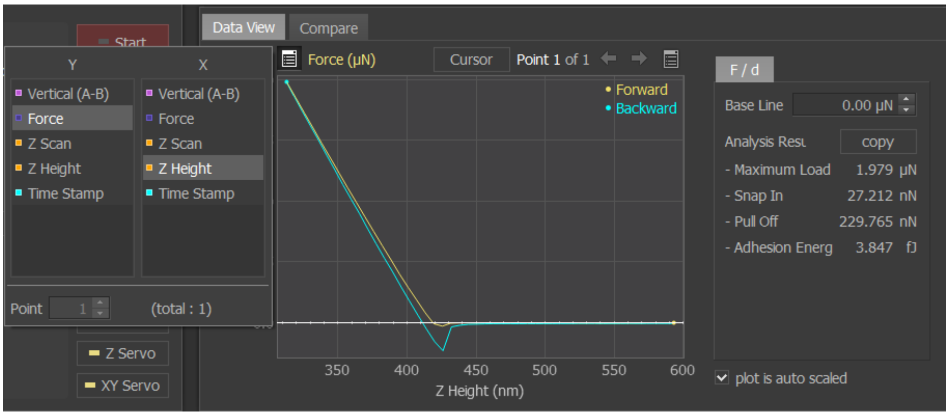
10-3. Data View

The **Data View** displays the acquired spectroscopy data. Figure 10-20 shows the Data View. For the FD spectroscopy curve, analysis results are listed to the right of the plot.

10-3-1. Axis Menu

Choose the **Compare** tab to compare data from different point curves.

Figure 10-20. Data View Axis menu



Point 1 (total : 1)

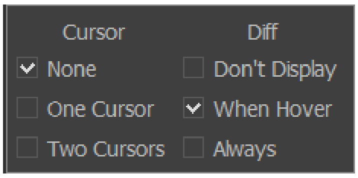
Base Line 0.00 µN

- Maximum Load 1.979 µN
- Snap In 27.212 nN
- Pull Off 229.765 nN
- Adhesion Energ 3.847 fJ

☑ plot is auto scaled

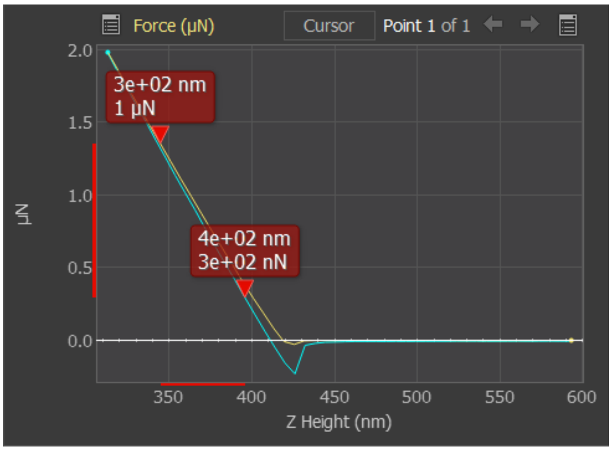
10-3-2. Cursor

Figure 10-21. Cursor pop-up box



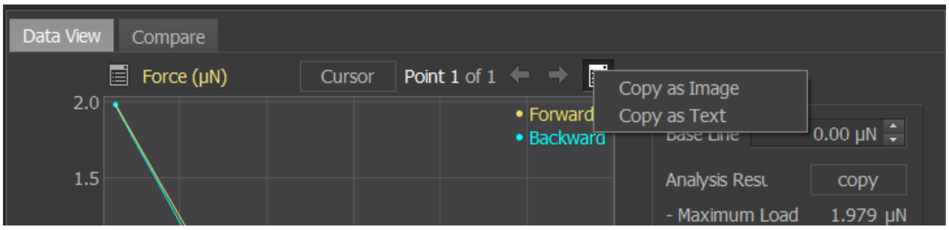
Cursor	Diff
☑ None	☐ Don't Display
☐ One Cursor	☑ When Hover
☐ Two Cursors	☐ Always

Figure 10-22. Single cursor example



10-3-3. Copy Menu

Figure 10-23. Copy menu pop-up box



10-3-4. Compare Tab

Choose the **Compare** tab to compare data from different point curves taken within the same Point List or Point Grid run.

10-4. Spectroscopy Data List View

As shown in Figure below, the Spectroscopy Data List View is an oscilloscope window that can be used to display selected input and output signals immediately after spectroscopy measurement. Following spectroscopy measurement, the signals will be updated immediately. To check the results already obtained during the measurement, click the desired point.

The Spectroscopy Data List View can display up to three graphs on the same screen.

10-4-1. Rescale

This control rescales all plots simultaneously so that curve data fits on the oscilloscope screen. Double-clicking on each plot automatically rescales the display. The scale can also be controlled manually using the mouse wheel. The vertical axis on the screen may be rescaled accordingly.

10-4-2. Relocate

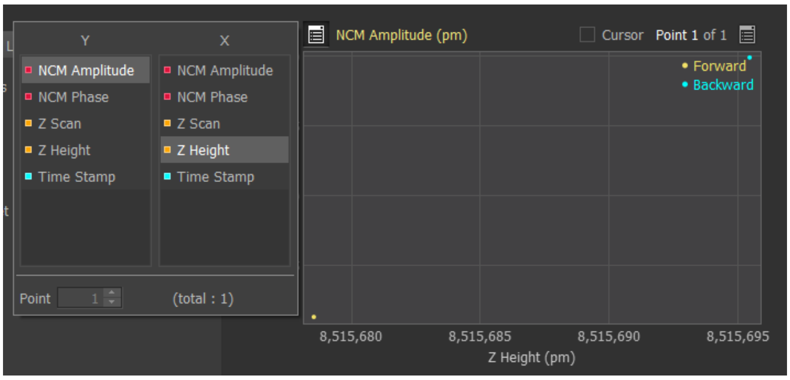
Relocate each plot by clicking and dragging it after clicking this icon.

10-4-3. Axis Menu

This control is used to set the X and Y axis of spectroscopy data. The **Axis** menu is located on the left side of the plot. Clicking this button opens a drop-down menu to choose the signals displayed for X and Y. The drop-down menu for the Spectroscopy Data List is shown in Figure 10-24.

Highlight the desired signals to be displayed in X and Y. If multiple points are taken during a measurement cycle, specific points can be displayed by changing the point number in the **Point** field at the bottom of the menu.

Figure 10-24. Spectroscopy data axis



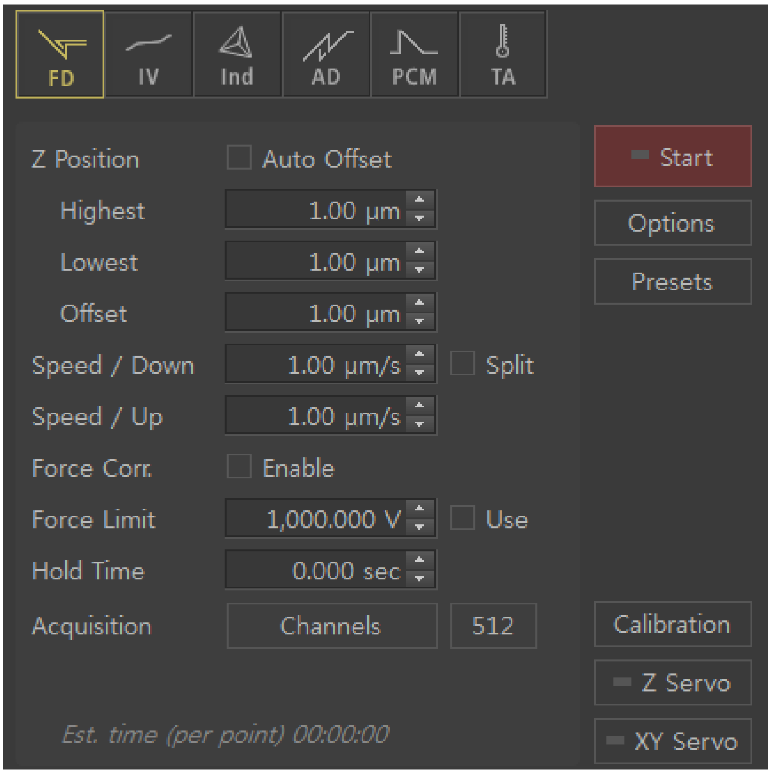
10-4-4. Copy Menu (Right)

Clicking this opens the **Copy** menu. The **Copy** menu is located on the right side of the Spectroscopy plot. The copy choices are **Copy to Image** or **Copy to Text**.

10-5. FD Spectroscopy

Force spectroscopy measures the force (deflection of the the cantilever) as the tip is brought toward and away from the surface. The FD parameters in the Spectoscopy Parameter View can be found in Table 10-25.

Figure 10-25. FD spectroscopy parameters



Z Position ☐ Auto Offset
Highest 1.00 µm
Lowest 1.00 µm
Offset 1.00 µm
Speed / Down 1.00 µm/s ☐ Split
Speed / Up 1.00 µm/s
Force Corr. ☐ Enable
Force Limit 1,000.000 V ☐ Use
Hold Time 0.000 sec
Acquisition Channels 512

Est. time (per point) 00:00:00

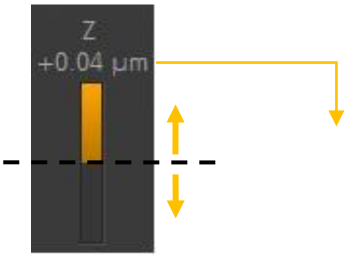
Table 10-1. Controls in FD spectroscopy mode

Controls	**Function**
Z/Highest	Z scanner retracts (away from the sample) to the max value distance from the offset position. Input range is [(-1/2~1/2) x Z scanner’s maximum movement range] when **Z Offset** turns on and [(-1~+1) x Z scanner maximum movement range] when **Z Offset** turns off.
Z/Lowest	Z scanner extends (towards the sample) until it reaches the min value distance from the offset position. Input range is [(-1/2~1/2) x scanner’s maximum movement range] when **Z Offset** turns on and [(-1~+1) x scanner maximum movement range] when **Z Offset** turns off.
Z/Offset	When **Auto Offset** is unchecked, the **Offset** box is shown. This is the starting value of the Z scanner for an FD curve (see Auto Offset, below).
Auto Offset	When **Auto Offset** is checked, the offset position is determined by the set point value in the Scan Control window.
Speed	Speed of Z scanner extension and retraction
Split	When the **Split** box is checked, the speed of the retraction (up) and extension (down) of the scanner can be controlled independently.
Down Speed	Speed of Z scanner extension
Up Speed	Speed of Z scanner retraction
Force Corr	The force correction applied to the FD curve
Force Limit	When the force applied to the cantilever exceeds the force limit, the Z scanner does not extend any farther. To protect the tip, lower the force limit.
Use	When **Use** is checked, the allowable maximum force (force limit **Force Corr**) is determined by the value in the text box to the left.
Channels	Opens the Channel Config dialog. The number of channels acquired during the FD curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.

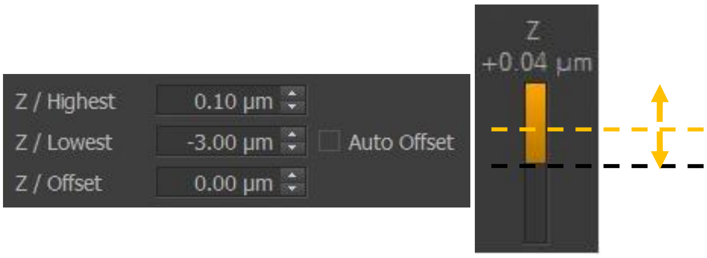
When setting the FD input range, the **Min** value must be smaller than **Max** value. If not, the system will ask you to swap the values.

- **Auto Offset**

    1) **Auto Offset On** : Z scanner moves from the highest to the lowest position using the current Z scanner position (by the Z servo) as the reference position. For example, in the figure below, the current Z scanner position to maintain the set point value is 0.04µm. This value will be used as the 0 value, or starting point, and the Z scanner will travel from +1.04µm to -0.96µm.



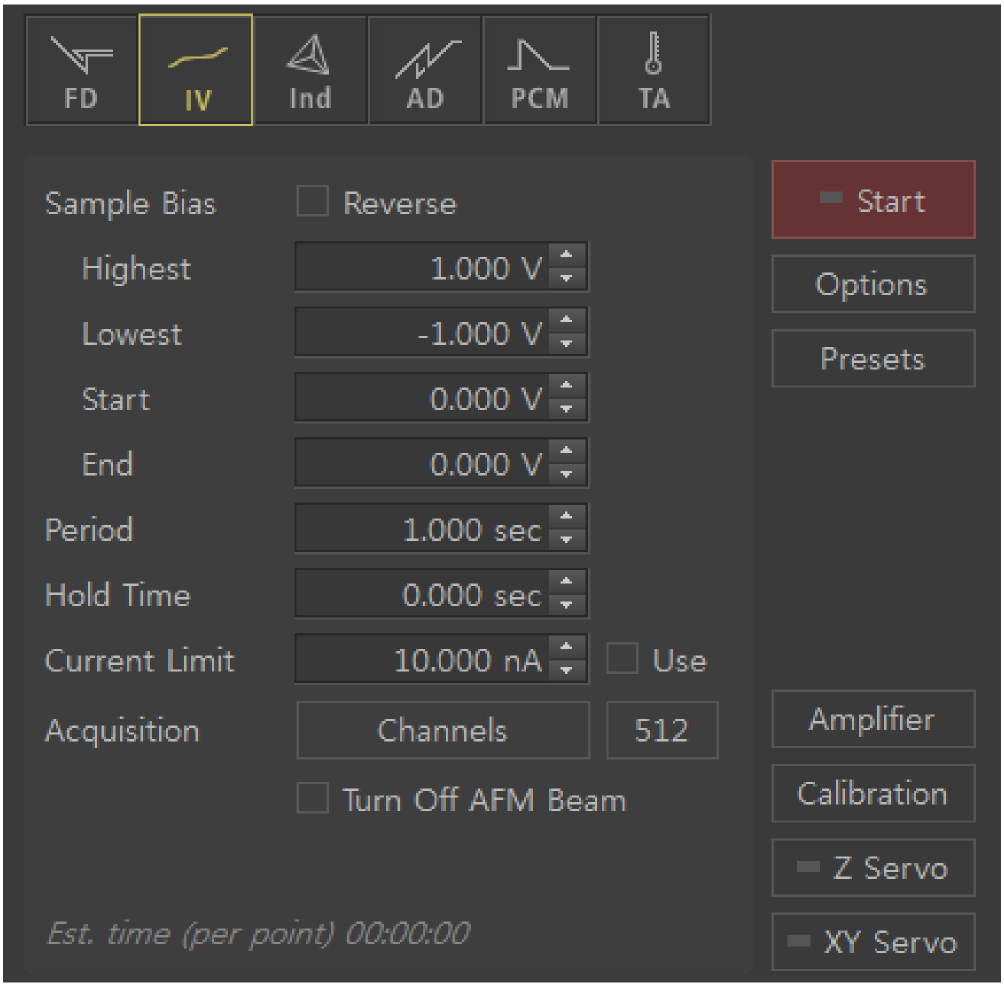
    2) **Auto Offset Off**: Z scanner moves from the highest to the lowest position using the value in the **Offset** field as the reference position or starting position. For example, in the figure below, the offset value is 1µm. This value will be used as the 0 value, or starting point, and the Z scanner will travel from 2µm to 0µm.


Z / Highest 0.10 µm
Z / Lowest -3.00 µm ☐ Auto Offset
Z / Offset 0.00 µm

10-6. IV Spectroscopy

Table 10-2, shown below, lists each control in the Spectroscopy control window with a brief description of its function.

Figure 10-26. IV Spectroscopy parameters



Sample Bias ☐ Reverse

Highest 1.000 V

Lowest -1.000 V

Start 0.000 V

End 0.000 V

Period 1.000 sec

Hold Time 0.000 sec

Current Limit 10.000 nA ☐ Use

Acquisition Channels 512

☐ Turn Off AFM Beam

Est. time (per point) 00:00:00

Table 10-2. Controls in IV spectroscopy mode

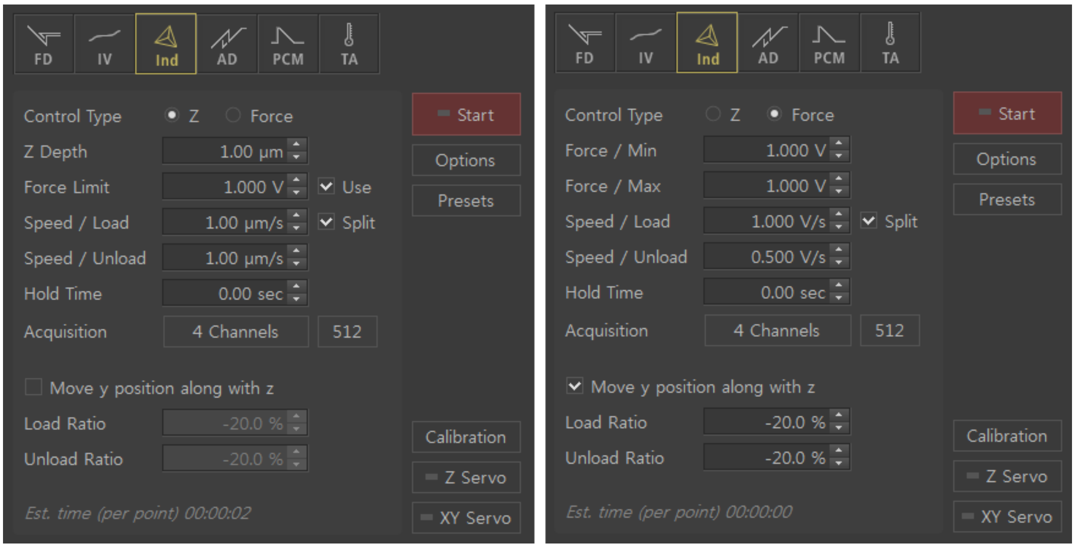
Controls	Function
Bias/Highest	Highest sample bias value in acquiring an IV curve
Bias/Lowest	Lowest sample bias value in acquiring an IV curve
Reverse	When **Reverse** is selected, the sample bias is applied in this order: Start->Lowest->Highest->End.
Bias/Start	Start sample bias in an IV curve
Bias/End	End sample bias in an IV curve
Period	Time elapsed while changing the sample bias to acquire an IV curve
Hold Time	Amount of time that the voltage is held at the start voltage value per cycle.
Current Limit	Maximum current limit. If the current reaches this limit, the sample bias will no longer be applied.
Use	When **Use** is checked, the allowable maximum current (current limit) is determined by the value in the text box to the left.
Channels	Opens the Channel Config dialog. The number of channels acquired during the IV curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Turn Off AFM Beam	The laser beam is turned off in IV spectroscopy if this option is checked. It may be useful if the laser beam affects the sample.

10-7. Indenter

Nano-Indentation has two sub-modes: Z scanner mode and force mode. Each sub-mode uses different parameters to control the indentation cycle. In force mode, the force (load) between the tip and sample is varied as a linear function of time while the corresponding position of the Z scanner is measured. In Z scanner mode, the Z scanner position is varied as a linear function of time while the corresponding load applied to the tip is measured.

Select set point mode by clicking the **Force** radio button. Click the Z radio button to select Z scanner mode.

Figure 10-27. Indenter control window



Control Type ● Z ○ Force
Z Depth 1.00 µm
Force Limit 1.000 V ☑ Use
Speed / Load 1.00 µm/s ☑ Split
Speed / Unload 1.00 µm/s
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio -20.0 %
Unload Ratio -20.0 %
Est. time (per point) 00:00:02

Control Type ○ Z ● Force
Force / Min 1.000 V
Force / Max 1.000 V
Speed / Load 1.000 V/s ☑ Split
Speed / Unload 0.500 V/s
Hold Time 0.00 sec
Acquisition 4 Channels 512
☑ Move y position along with z
Load Ratio -20.0 %
Unload Ratio -20.0 %
Est. time (per point) 00:00:00

Parameters related to controlling the measurement process for nano-indentation can be changed from the **Indenter** tab.

Table 10-3. Controls in nano-indentation mode

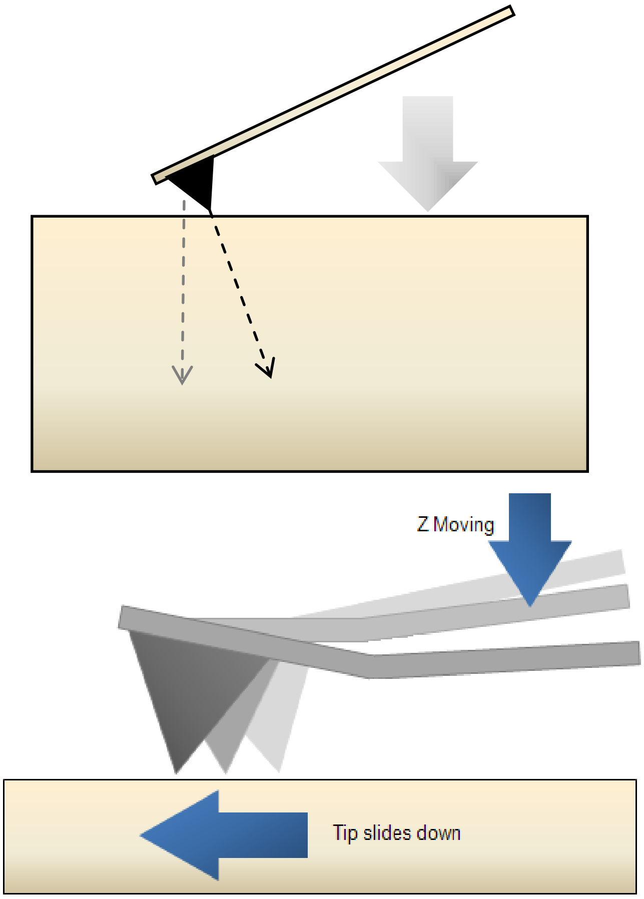
Controls	**Function**
Z or Force	When the **Z** radio button is checked, nano-indentation is performed in Z scanner mode. When the **Force** radio button is checked, nano-indentation is performed in set point mode.
Z Scanner Mode	
Z Depth	The Z scanner extends (toward the sample) until it reaches the load depth value distance. The distance is calculated from the offset position. It is activated in Z scanner mode.
Force Limit	Once at the force limit, the Z scanner does not extend any further. To protect the tip, lower the force limit.
Use	When **Use** is checked, the force is applied to the cantilever until it reaches the force limit.
Force Min	Minimum force value applied to the tip in set point mode
Force Max	Maximum force applied to the tip in set point mode
Speed	Speed of Z scanner extension/retraction
Split	When **Split** is checked, speed of scanner retraction (up) and extension (down) can be controlled independently.
Speed/Load	Speed of Z scanner extension
Speed/Unload	Speed of Z scanner retraction
Hold time	Amount of the time the indenter is held at the load depth position before it is lifted
Channels	Opens Channel Config dialog. The number of channels acquired during the indentation curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Move Y position along with Z	When this option is checked, Y scanner movemer compensation will be used to adjust the Y movement relative t the Z movement in the indentation process.
Load/Unload Ratio	Ratio between movement of Z scanner and Y scanner. This is activated when the **Move Y position along with z** box is checked. Positive values for the **Load/Unload Ratio** refer to the case where the movements of the Z scanner and Y scanner are the same. Movement of the Z scanner is always in the negative direction (extension) for **Load** and positive direction for **Unload**. Y scanner movement in a positive direction is referred to as “bottom to top,” while Z scanner movement in a positive direction is referred to as the “retraction in Z.” The allowable input range is -100.0~ +100.0%.

10-7-1. Moving the Y Scanner During Indentation

Normally, the cantilever will not be able to approach the sample top-down with zero degree cantilever tilt because an AFM cantilever has certain degree of tilt. Furthermore, it is possible for the tip to slip laterally as the indenter tip pushes down the sample.

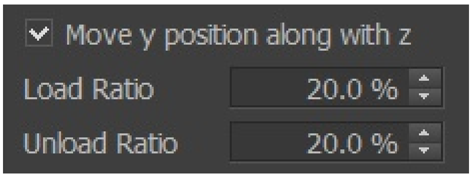
To prevent this problem, the Y scanner can be moved or adjusted to compensate for Z scanner extension. This feature is activated when the **Y Travel Ratio** button is selected.

Figure 10-28. Scanner movement during indentation



Related options can be activated as shown in figure below.

Figure 10-29. Load/Unload ratio control


☑ Move y position along with z

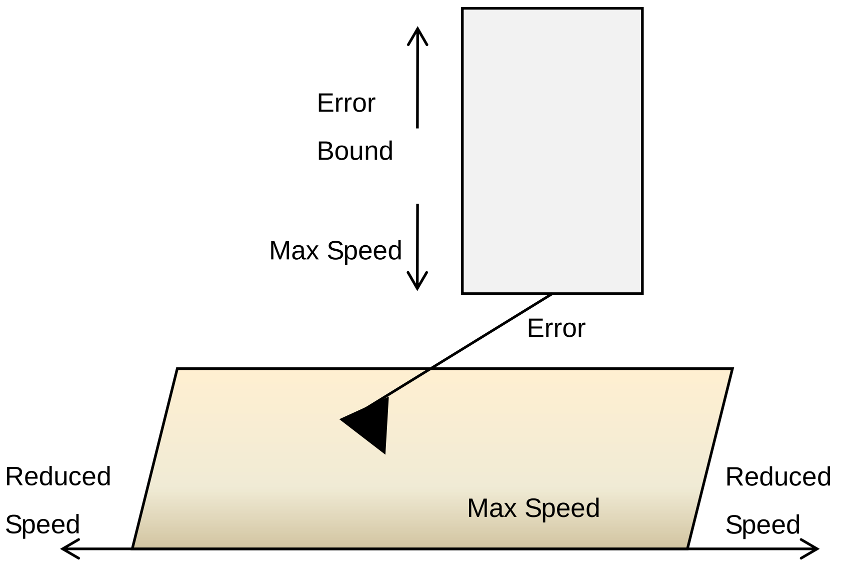
Load Ratio 20.0 %

Unload Ratio 20.0 %

In Figure 10-27, the values displayed in the Load Ratio and Unload Ratio specify the ratio between the movement of the Z scanner and the Y scanner. Inserting positive values will cause the Y scanner and Z scanner to adjust in the same direction. Inserting negative values will cause the Y scanner and Z scanner to adjust in opposite directions.

In Figure 9-7-4, when the Y scanner adjusts in the +Y direction, it adjusts in the positive direction, and vice versa. If the Z scanner shrinks, it will adjust in the positive direction, and vice versa.

Figure 10-30. Scanner direction

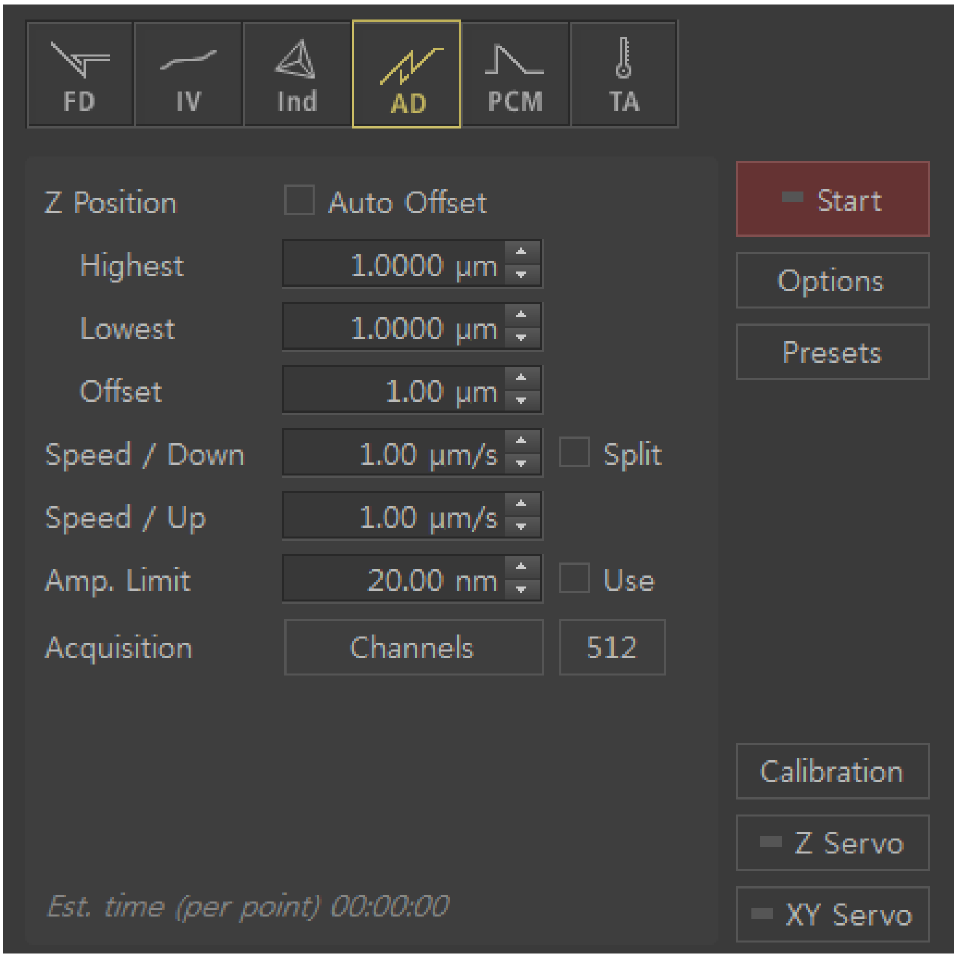


For example, when entering a loading value of 100%, as the Z scanner adjusts in the –Z direction with a certain distance, the Y scanner will adjust in the –Y direction with the same distance. When entering a loading value of -100%, as the Z scanner adjusts in the –Z direction with a certain distance, the Y scanner will adjust in the +Y direction with the same distance. For example, to improve angle of the tip (13°), it is recommended to enter a **Loading/Unloading** value of -Tan(13°) x 100 ~ -23%.

10-8. AD Spectroscopy

In AD spectroscopy, the cantilever is oscillated at a constant frequency and amplitude. As the scanner is extended and the cantilever approaches the surface, the amplitude begins to decrease. This change in amplitude can be measured as a function of distance to the surface using AD spectroscopy. Controls for AD spectroscopy can be set so that the cantilever moves a specified distance or stops at set amplitude (amplitude limit).

Figure 10-31. AD spectroscopy control window



Z Position ☐ Auto Offset

Highest 1.0000 µm

Lowest 1.0000 µm

Offset 1.00 µm

Speed / Down 1.00 µm/s ☐ Split

Speed / Up 1.00 µm/s

Amp. Limit 20.00 nm ☐ Use

Acquisition Channels 512

Est. time (per point) 00:00:00

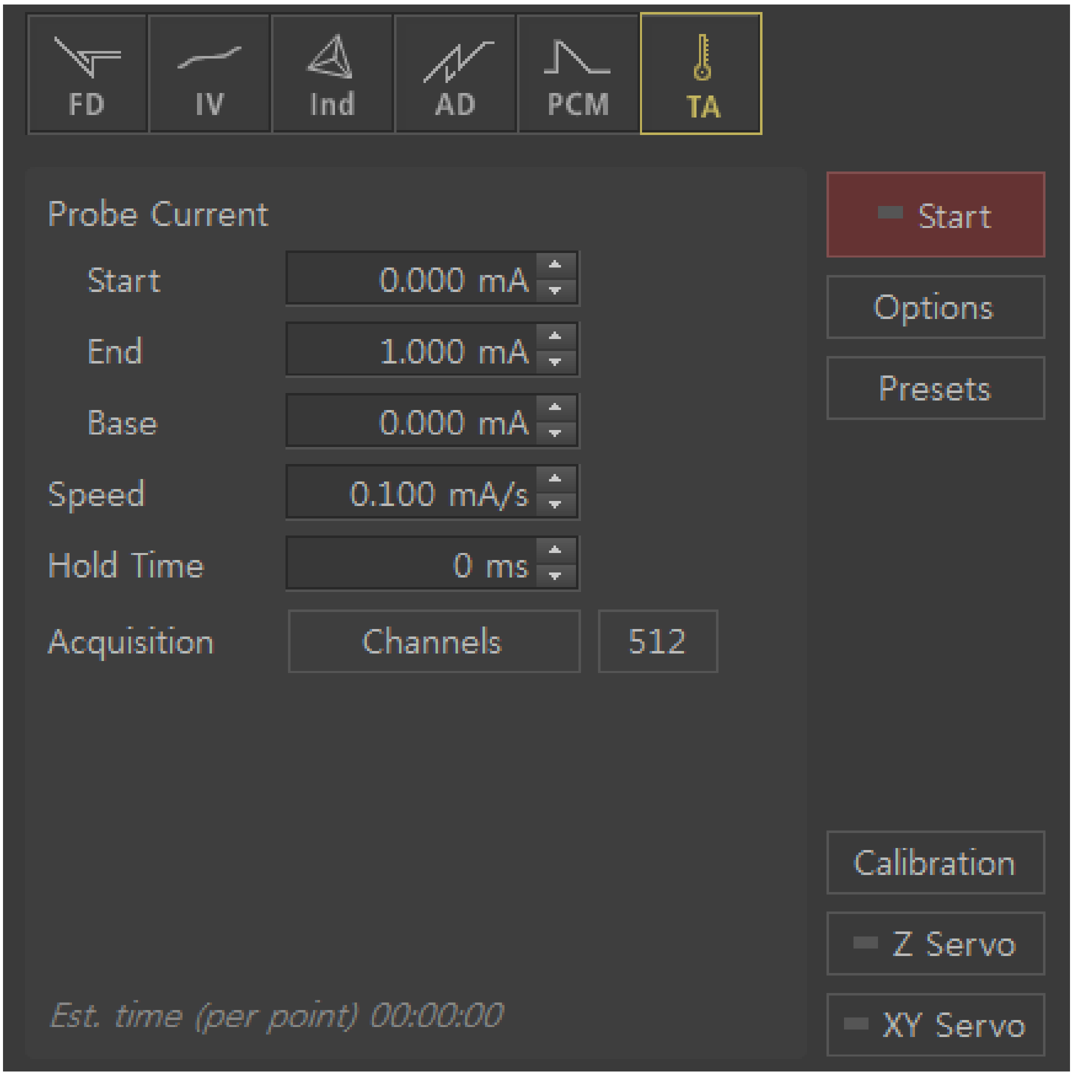
Table 10-4. Controls in AD spectroscopy mode

Controls	Function
Z/Highest	The Z scanner retracts (away from the sample); the highest value that the Z scanner will be lifted away from the surface
Z/Lowest Z	The Z scanner extends (toward the sample); the lowest value that the scan will extend toward the surface
Auto Offset	Uses the relative Z position
Speed	Speed of Z scanner extension/retraction
Split	When the **Split** box is checked, the speed of the retraction (up) and extension (down) of the scanner can be controlled independently.
Down Speed	Speed of Z scanner extension
Up Speed	Speed of Z scanner retraction
Amp Limit	Amplitude at which the cantilever will stop
Use	When **Use** is checked, the system will use the amplitude limit
Channels	Opens the Channel Config dialog. The number of channels acquired during the AD curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Start	Initiates an AD curve at the current probe location
Options	Opens the Options window
Presets	Opens the Presets window
Calibration	Opens the Calibration popup menu
Z Servo	Opens the Z Servo window
XY Servo	Opens the XY Servo window

10-9. TA Spectroscopy

Thermal analysis (TA) spectroscopy mode is used to control current through the nanothermal probe in SmartScan. When current is transmitted to the nano thermal probe, melting can occur (heating the probe tip), and change the probe’s deflection. The sample temperature measured by the probe can be calibrated in this way. TA spectroscopy mode requires SThM hardware options. Figure 10-32 shows the TA spectroscopy mode interface.

Figure 10-32. Thermal analysis spectroscopy control window



Probe Current

Start 0.000 mA

End 1.000 mA

Base 0.000 mA

Speed 0.100 mA/s

Hold Time 0 ms

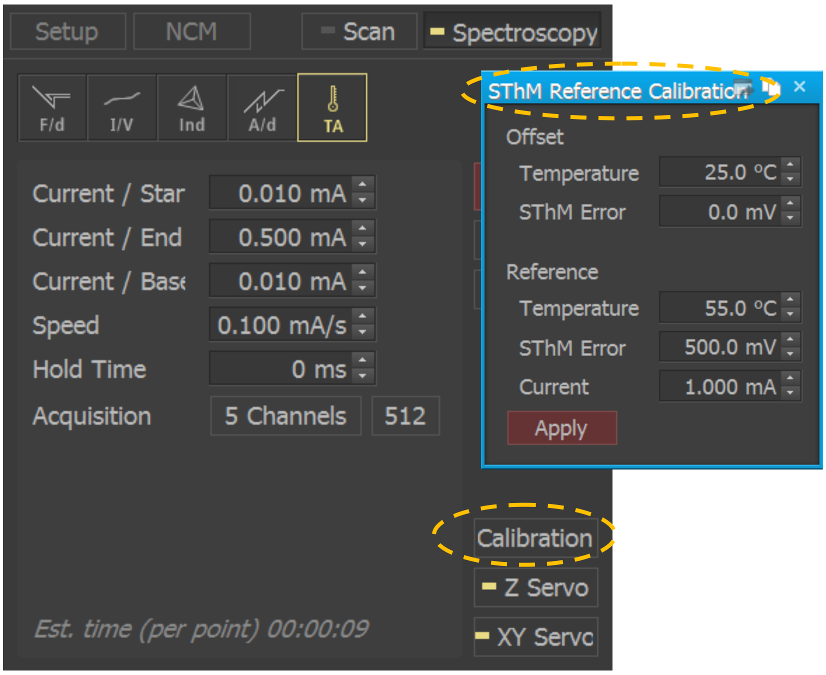
Acquisition Channels 512

Est. time (per point) 00:00:00

Table 10-5. Controls in TA spectroscopy mode

Controls	Function
Probe Current	
Start	Starting current of the temperature ramp (Min 0.01mA – Max 2.5mA)
End	Ending current of the temperature ramp (Min 0.01mA – Max 2.5mA)
Base	Base probe current before and after acquiring data
Timing	
Speed	Speed of probe's current sweep
Hold time	Amount of time that the current is held at the Start Probe Current
Channel Config	The Channel Config window allows choosing data channels to monitor and record while scanning.
Data Count	Number of points for acquiring data. The number of points can be changed by clicking the indicator button and choosing the points desired.
Start	Initiates a TA curve at the current probe location
Options	Opens the Options window
Presets	Opens the Presets window
Calibration	Opens the Calibration pop-up menu. In this mode, you can adjust the SThM parameters by selecting SThM reference
SThM Reference	
Reference: Temperature	Standard sample's melting temperature for calibration
Reference: SThM Error	SThM error (V) value when the standard sample starts to melt
Reference: Current	Probe current (mA) value when the standard sample starts to melt
Offset: Temperature	Temperature inside the acoustic enclosure
Offset: SThM Error	SThM error (V) value when the probe current is 0mA
Z Servo	Opens the Z Servo window. This function can also be use in adjusting the Set point value of the nanothermal probe.
XY Servo	Opens the XY Servo window

Figure 10-33. SThM Reference Calibration



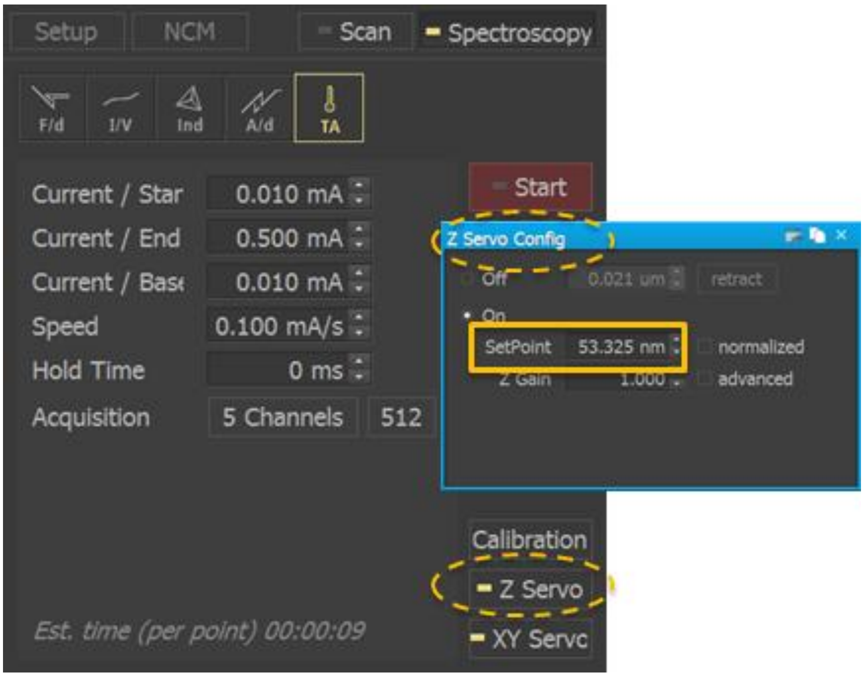
Current / Star 0.010 mA
Current / End 0.500 mA
Current / Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512

Est. time (per point) 00:00:09

Offset
Temperature 25.0 °C
SThM Error 0.0 mV

Reference
Temperature 55.0 °C
SThM Error 500.0 mV
Current 1.000 mA

Figure 10-34. Z Servo Config



Current / Star 0.010 mA
Current / End 0.500 mA
Current / Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512

Est. time (per point) 00:00:09

○ Off 0.021 um
● On
SetPoint 53.325 nm ☐ normalized
Z Gain 1.000 ☐ advanced

10-10. General Procedure for Spectroscopy measurement

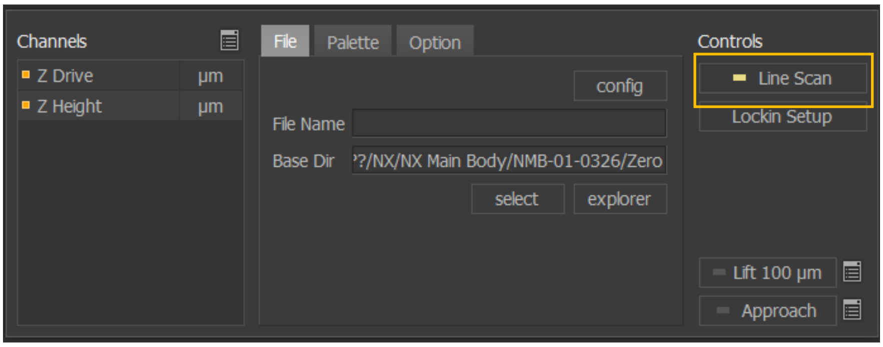
10-10-1. FD spectroscopy

- **Cantilever Selection**

In selecting the appropriate cantilever for FD spectroscopy, force constant must be closely considered. It is recommended to use cantilever with low force constant (E.g. NCSTR, FMR, NSC36) to avoid sample damage. The hardness and softness of cantilever depends on force constant value, wherein, the higher the force constant, the harder is the cantilever. Selecting the cantilever type in the Cantilever database must be done whenever the cantilever type has been changed. The parameters of the cantilever in used, should matched with the parameters of the selected cantilever. The procedure on how to select cantilever type is shown below.

1) Turn OFF the Line Scan by clicking the ***Line Scan*** button on control panel. The yellow light on the Line Scan button denotes that it is ON.

Figure 10-35. Turn OFF the Line Scan



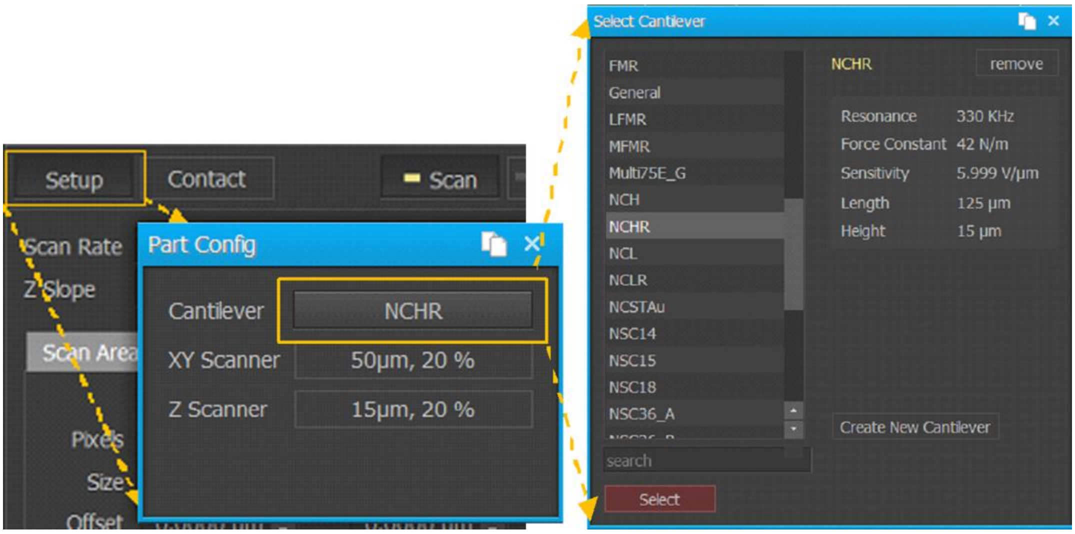
File Name

Base Dir ?/NX/NX Main Body/NMB-01-0326/Zero

2) Open Part Config window by clicking the ***Setup*** tab on control panel. Open the Cantilever Selection Window by clicking the **Cantilever type** button. The Select Cantilever Window shows the list of common cantilevers offered by Park Systems. If the cantilever type is not on the list, create a new cantilever list by clicking the **Create New Cantilever** button (Refer to Section **4-1-1. Probe Setup** in the attached SmartScan manual**).**

3)Click **Select** button to activate the selected cantilever type.

Figure 10-36. Select Cantilever



Cantilever NCHR
XY Scanner 50µm, 20 %
Z Scanner 15µm, 20 %

NCHR
Resonance 330 KHz
Force Constant 42 N/m
Sensitivity 5.999 V/µm
Length 125 µm
Height 15 µm

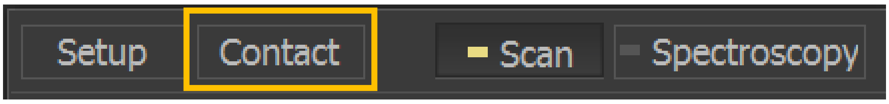
- **General Procedure for FD Spectroscopy measurement**

1) Replace current cantilever in the system with low force constant cantilever and mount sample.

2) Select the type of cantilever in Cantilever Database (Refer to Section 1: Cantilever Selection of this procedure for more information).

3) Switch to ***Contact Mode*** by clicking the Head Mode button in control panel.

Figure 10-37. Select Contact mode

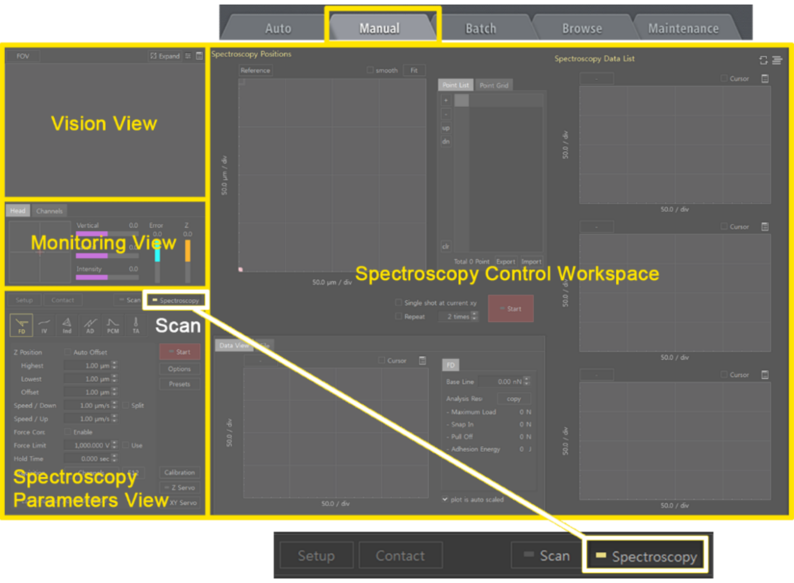


4) Approach the tip towards the sample

5) Acquire image of the sample to identify regions of interest for FD curve acquisition. This process can be skipped and instead, a random point on the sample can be selected.

6) Switch to Spectroscopy Control by clicking ***Spectroscopy*** button in control panel.

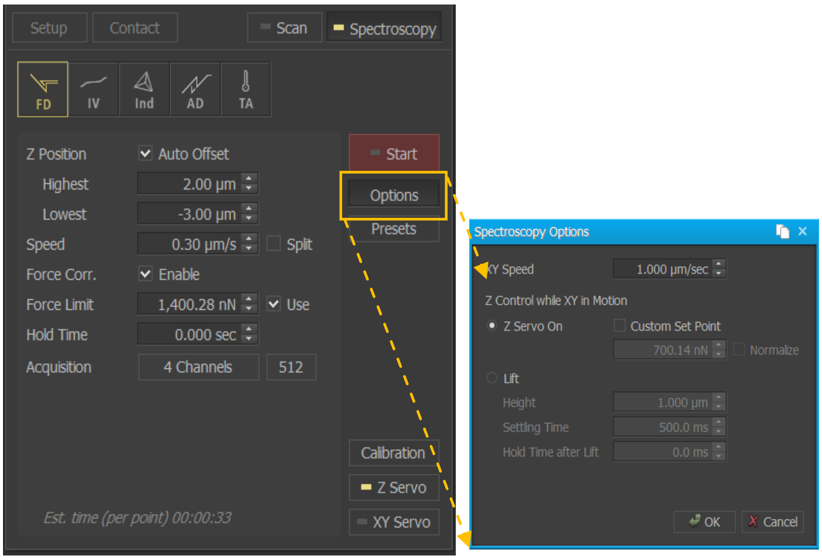
Figure 10-38. Select Spectroscopy mode



7) Select FD spectroscopy by clicking the ***FD*** button in the spectroscopy view.

8) Open Spectroscopy Options window by clicking the ***Options*** button in the Setup menu. Set the parameters to prevent the tip from crashing the into the sample surface as it is being moved to a new measurement location. (Refer to Section 9-1-2 in the attached SmartScan manual).

Figure 10-39. Set the parameters for FD Spectroscopy Options



Z Position ☑ Auto Offset
Highest 2.00 µm
Lowest -3.00 µm
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 1,400.28 nN ☑ Use
Hold Time 0.000 sec
Acquisition 4 Channels 512
Est. time (per point) 00:00:33

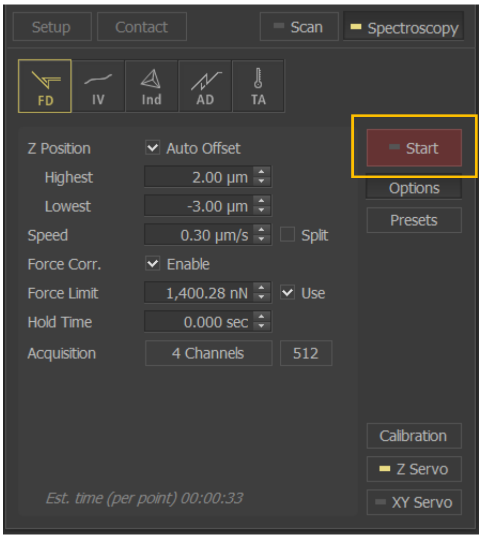
Spectroscopy Options
XY Speed 1.000 µm/sec
Z Control while XY in Motion
● Z Servo On ☐ Custom Set Point
700.14 nN ☐ Normalize
○ Lift
Height 1.000 µm
Settling Time 500.0 ms
Hold Time after Lift 0.0 ms

9) Select points at which to take FD measurements on the reference image.

There are three ways to do this.

a) First is by clicking the ***Start*** button, the tip will approach the sample and perform FD measurement at the current location.

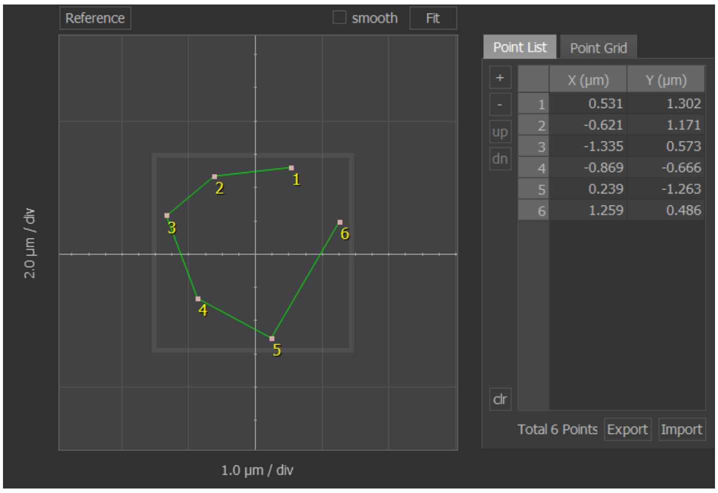
Figure 10-40. Clicking the FD Start button



Z Position ☑ Auto Offset
Highest 2.00 µm
Lowest -3.00 µm
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 1,400.28 nN ☑ Use
Hold Time 0.000 sec
Acquisition 4 Channels 512
Est. time (per point) 00:00:33

b) Next, is to add points to a list. By clicking the location on the reference image, a point will be added to the list. Points can also be added directly by entering values into the Points List, which is accessible by selecting the ***Edit Points*** item in the context

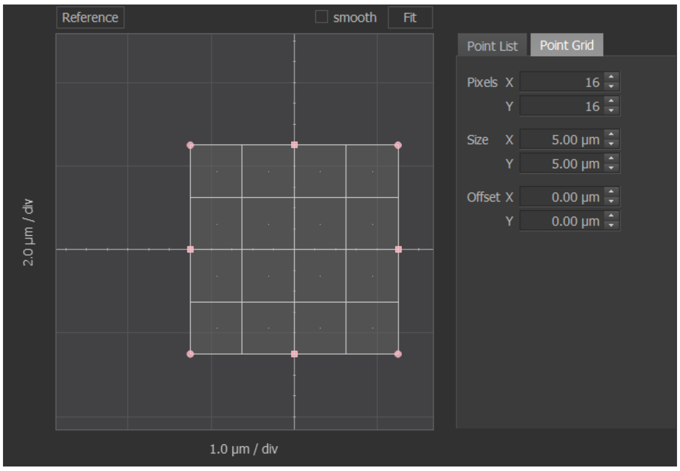
Figure 10-41. Add points to a list



	X (µm)	Y (µm)
1	0.531	1.302
2	-0.621	1.171
3	-1.335	0.573
4	-0.869	-0.666
5	0.239	-1.263
6	1.259	0.486

Lastly, is to use Map, which designates evenly spaced points on matrix that is overlaid on the sample surface. (Refer to Section 9-2 Spectroscopy Positions View in the attached SmartScan manual for more information)

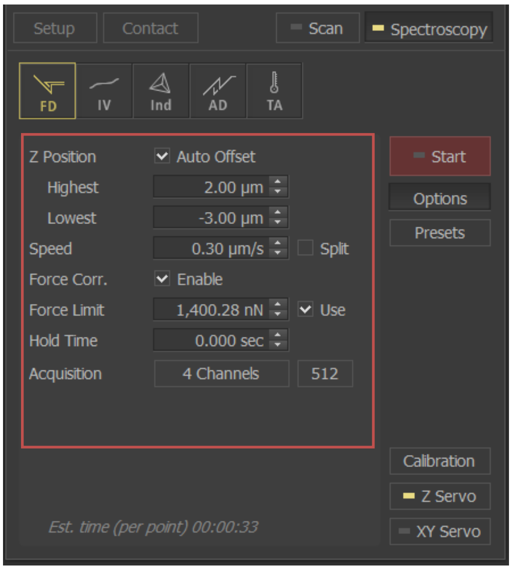
Figure 10-42. How to use map



Pixels X 16
Y 16
Size X 5.00 µm
Y 5.00 µm
Offset X 0.00 µm
Y 0.00 µm

10) Set the parameters in the FD spectroscopy window to obtain optimum data measurement. *(Refer to Section 9-6 in the attached SmartScan manual*

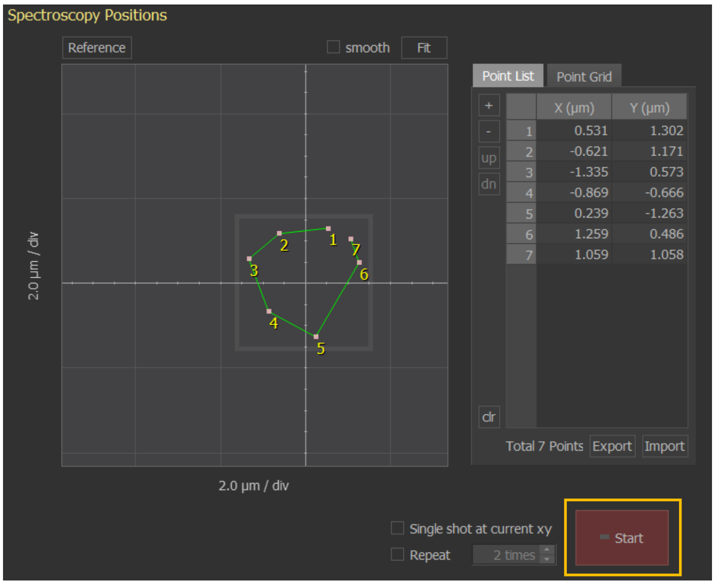
Figure 10-43. Set the Parameters in the FD spectroscopy



Z Position ☑ Auto Offset
Highest 2.00 µm
Lowest -3.00 µm
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 1,400.28 nN ☑ Use
Hold Time 0.000 sec
Acquisition 4 Channels 512
Est. time (per point) 00:00:33

11) Acquire FD Spectroscopy data by clicking the ***Start*** button. If the points of interest are designated using the Point list or Map, click the ***Start*** button found in the Spectroscopy Control Workspace.

Figure 10-44. Acquire FD spectroscopy data



	X (µm)	Y (µm)
1	0.531	1.302
2	-0.621	1.171
3	-1.335	0.573
4	-0.869	-0.666
5	0.239	-1.263
6	1.259	0.486
7	1.059	1.058

12) Once all of the measurement are complete, perform a curve analysis in the XEI software by right-clicking on the file in the buffer window and select “***Select to XEI***”.

If the user needs to perform an absolute measurement in the sample, the Cantilever Sensitivity and Cantilever Spring Constant must be calibrated prior measuring the actual sample. Calibration is done by following the procedures below:

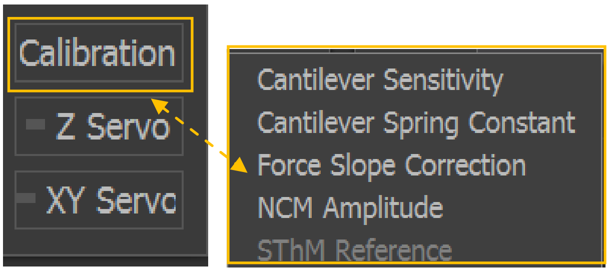
1. Replace current cantilever in the system with low force constant cantilever and mount a hard sample for calibration.

   The sample used in calibration must be different with the actual sample to be measured, this is, to avoid sample damage. It’s recommended to use hard sample (E.g. Silicon) during calibration to get accurate measurement for actual sample with soft and hard material.

2. Perform procedure 2 to 12 of the General procedure of FD Spectroscopy measurement.

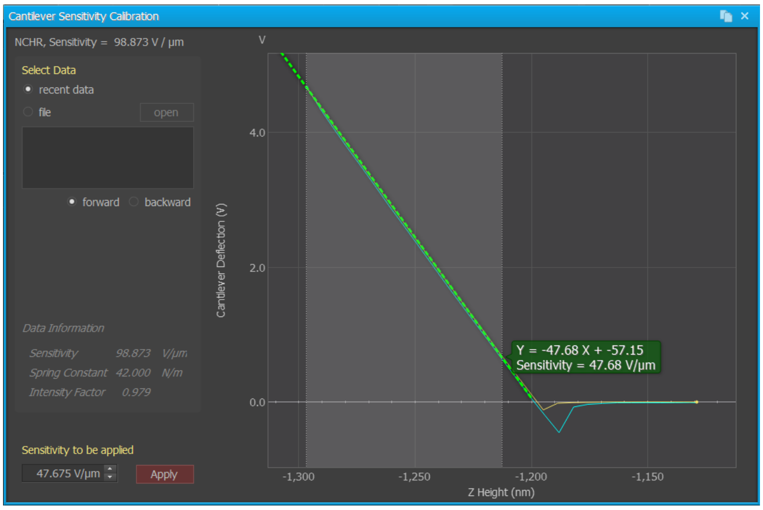
3. Open the Calibration features by clicking the ***Calibration*** button.

Figure 10-45. Open the Calibration features



4. Perform Cantilever Sensitivity Calibration. *(Refer to Section 9-1-4 Calibration in the attached SmartScan manual)*

Figure 10-46. Cantilever Sensitivity Calibration


Cantilever Sensitivity Calibration

NCHR, Sensitivity = 98.873 V / µm

Select Data: ● recent data ○ file

● forward ○ backward

Data Information

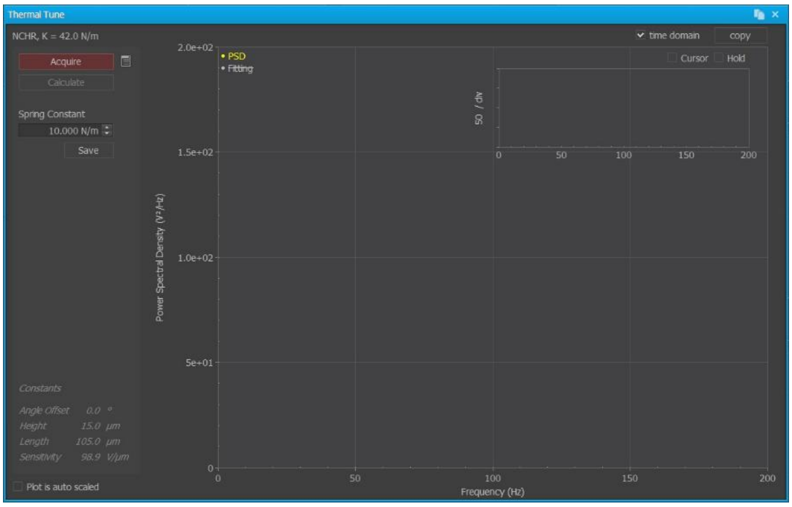
Sensitivity	98.873	V/µm
Spring Constant	42.000	N/m
Intensity Factor	0.979	

Sensitivity to be applied: 47.675 V/µm

Y = -47.68 X + -57.15
Sensitivity = 47.68 V/µm

5. Perform Cantilever Spring Constant Calibration. (Refer to Section 9-1-4 Calibration in the attached SmartScan manual)

Figure 10-47. Spring Constant Calibration


Thermal Tune

NCHR, K = 42.0 N/m

Spring Constant: 10.000 N/m

Constants

Angle Offset	0.0	°
Height	15.0	µm
Length	105.0	µm
Sensitivity	98.9	V/µm

☐ Plot is auto scaled

☑ time domain

☐ Cursor ☐ Hold

10-10-2. IV spectroscopy

- **Cantilever Selection**

The type of cantilever in IV spectroscopy must be coated by conductive material.

This is to measure the current between the tip and the sample. It is also important to consider the type of sample and its application, since the cantilever tip is in contact with the sample during measurement. It is recommended to use Conductive Diamond Coated (CDC) type of cantilever for sample with high conductivity. This is because the coating on the cantilever will be easily taken off by the high current flown between the cantilever and the sample. On the other hand, CDC cantilever is not recommended for soft sample, since CDC has hard tip that can damage the sample surface, which can result to inaccurate height and unstable current measurement.

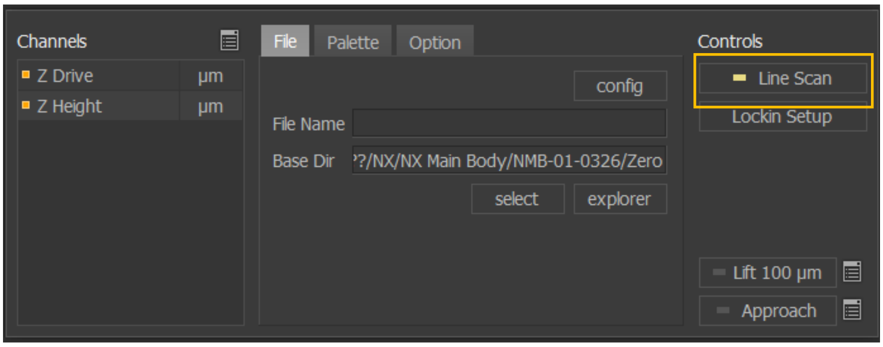
For IV spectroscopy, conductive cantilever chip should be mounted on the chip carrier with wire. Cantilever Chip-Wire-Metal of chip carrier should be electronically connected by an electro-conductive adhesive such as silver paste. During operation, the wire in the chip carrier is connected into the AFM head.

Selecting the cantilever type in the Cantilever database must be done whenever the cantilever type has been changed. The parameters of the cantilever in used, should matched with the parameters of the selected cantilever. The procedure on how to select cantilever type is shown below.

1) Turn OFF the Line Scan by clicking the ***Line Scan*** button on control panel.

   The yellow light on the Line Scan button denotes that it is ON.

Figure 10-48. Turn OFF the Line Scan

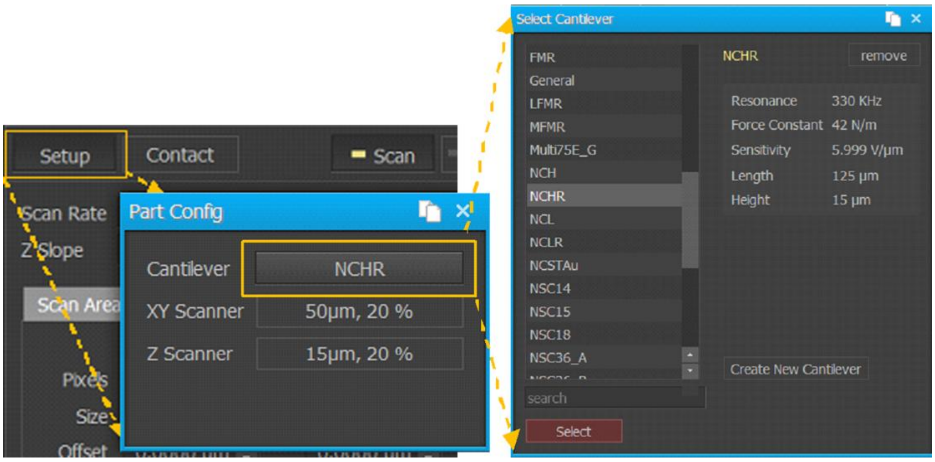


File Name

Base Dir ?/NX/NX Main Body/NMB-01-0326/Zero

2) Open Part Config window by clicking the ***Setup*** tab on control panel and open the Cantilever Selection Window by clicking the cantilever type button. The Select Cantilever Window shows the list of common cantilevers offered by Park Systems. If the cantilever type is not on the list, create a new cantilever list by clicking the **Create New Cantilever** button.

Figure 10-49. Select Cantilever



Cantilever NCHR

XY Scanner 50µm, 20 %

Z Scanner 15µm, 20 %

NCHR

Resonance 330 KHz

Force Constant 42 N/m

Sensitivity 5.999 V/µm

Length 125 µm

Height 15 µm

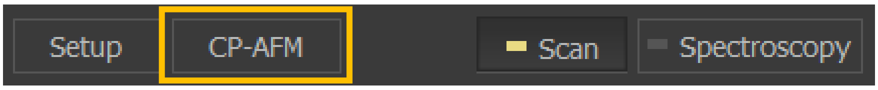
3) Click **Select** button to activate the selected cantilever type.

- **General Procedure for IV Spectroscopy measurement**
  1) Replace current cantilever in the system with the appropriate cantilever for the sample and application.

  2) Setup the Variable Current amplifier hardware. There are two types of Variable Current Amplifier that can be used, External and Internal Variable amplifier and each have different hardware setup. *(Refer to the CP-AFM manual for more information)*

  3) Select the type of cantilever in Cantilever Database (Refer to Cantilever Selection procedure for more information).

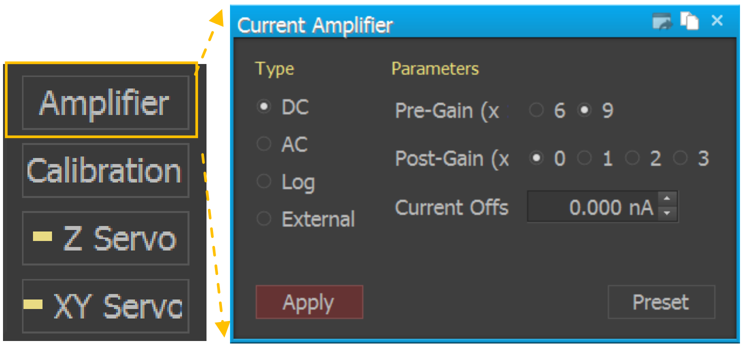
Figure 10-50. Select CP-AFM mode



4) Switch to CP-AFM Mode by clicking the **Head Mode** button in control panel.

5) Select the type of amplifier and adjust the parameters in the Current Amplifier window. *(Refer to Section 5-7 Current Amplifier in the attached SmartScan manual)*

Figure 10-51. Adjust the Current Amplifier parameters



● DC
○ AC
○ Log
○ External

Pre-Gain (x ○ 6 ● 9
Post-Gain (x ● 0 ○ 1 ○ 2 ○ 3
Current Offs 0.000 nA

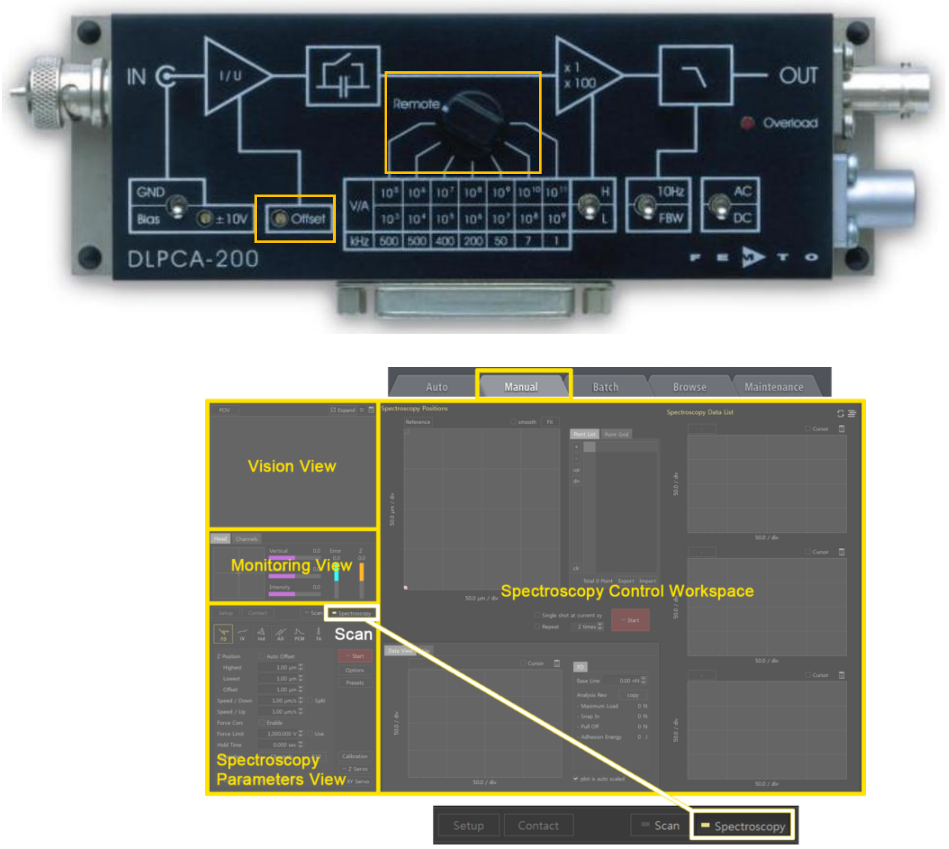
For External Current Amplifier, the gain setting on the Current Amplifier window should match the gain setting on the hardware in order to display the proper current units. The gain should be adjusted manually by turning the Remote knob depending on the desired value. The current offset should also be adjusted using screw driver.

6) Approach the tip towards the sample

7) Acquire image of the sample to identify regions of interest for IV curve acquisition. This process can be skipped and instead, a random point on the sample can be selected instead.

8) Switch to Spectroscopy Control by clicking ***Spectroscopy*** button in control panel.

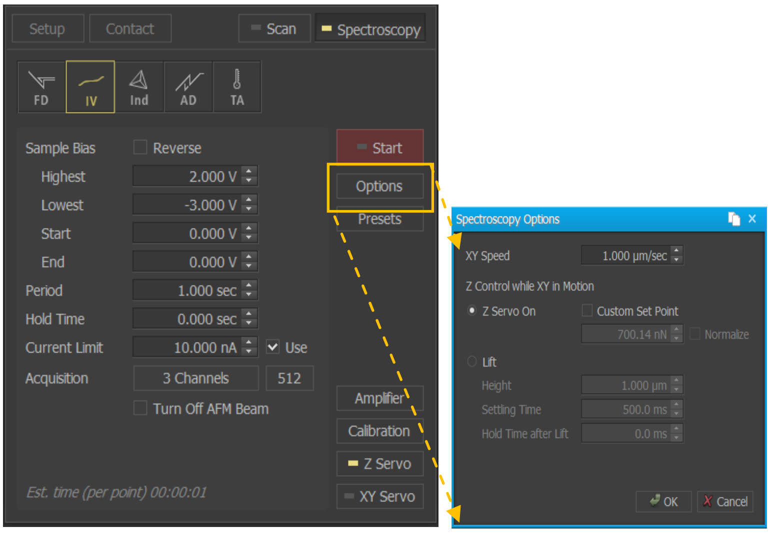
Figure 10-52. Clicking Spectroscopy button with setting to IV Convertor gain



9) Switch to IV spectroscopy mode by clicking the ***IV*** button in the spectroscopy view.

10) Open Spectroscopy Options window by clicking the Options button in the Setup menu. Set the parameters to prevent the tip from crashing into the sample surface as it is being moved to a new measurement location. *(Refer to Section 9-1-2 in the attached SmartScan manual).*

Figure 10-53. Set the parameters for IV Spectroscopy Options



Sample Bias ☐ Reverse
Highest 2.000 V
Lowest -3.000 V
Start 0.000 V
End 0.000 V
Period 1.000 sec
Hold Time 0.000 sec
Current Limit 10.000 nA ☑ Use
Acquisition 3 Channels 512
☐ Turn Off AFM Beam
Est. time (per point) 00:00:01

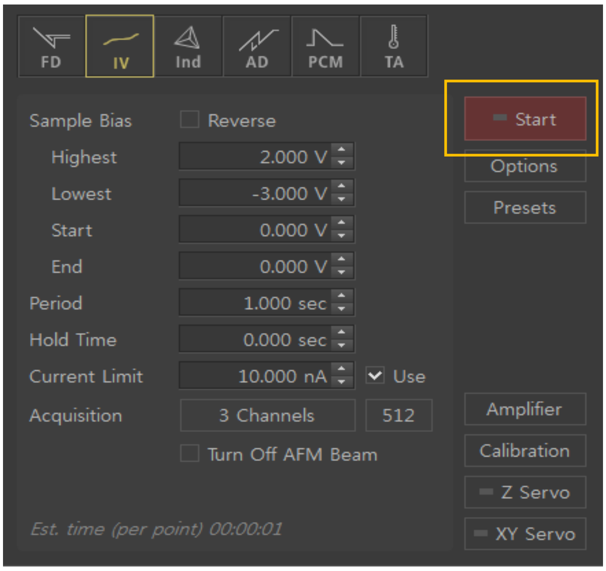
XY Speed 1.000 µm/sec
Z Control while XY in Motion
● Z Servo On ☐ Custom Set Point
700.14 nN ☐ Normalize
○ Lift
Height 1.000 µm
Settling Time 500.0 ms
Hold Time after Lift 0.0 ms

11) Select points at which to take IV measurements on the reference image.

There are three ways to do this.

a. First is by Clicking the ***Start*** button, the tip will approach the sample and perform FD measurement at the current location.

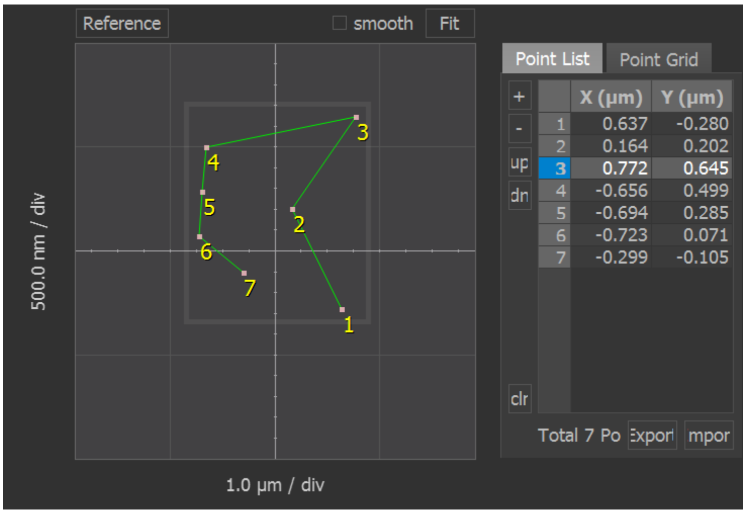
Figure 10-54. Clicking the IV Start button



Sample Bias ☐ Reverse
Highest 2.000 V
Lowest -3.000 V
Start 0.000 V
End 0.000 V
Period 1.000 sec
Hold Time 0.000 sec
Current Limit 10.000 nA ☑ Use
Acquisition 3 Channels 512
☐ Turn Off AFM Beam
Est. time (per point) 00:00:01

b. Next, is to add points to a list. By clicking the location on the reference image, a point will be added to the list. Points can also be added directly by entering values into the Points List, which is accessible by selecting the ***Edit Points*** item in the context menu

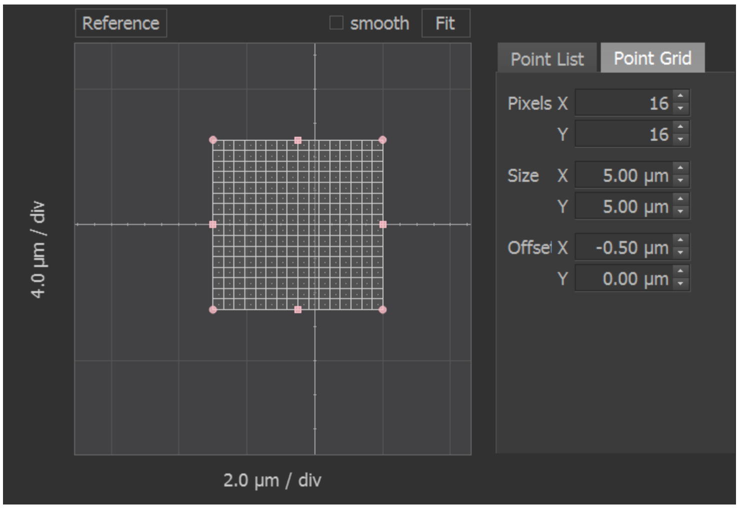
Figure 10-55. Add points to a list



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105

c. Lastly, is to use Map, which designates evenly spaced points on matrix that is overlaid on the sample surface. *(Refer to Section 9-2 Spectroscopy Positions View in the attached SmartScan manual for more information)*

Figure 10-56. How to use map



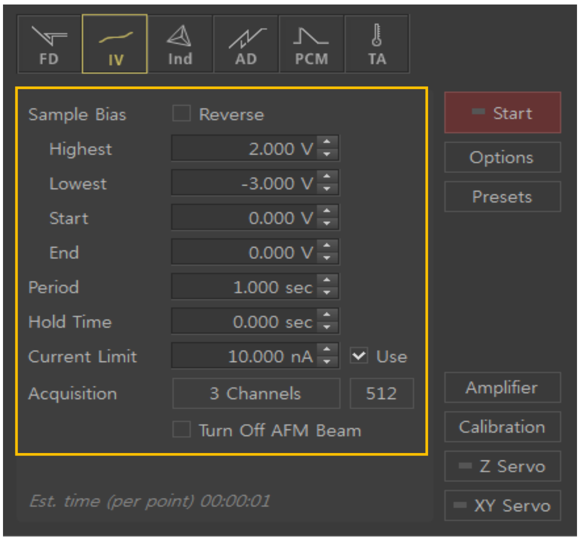
Pixels X 16
Y 16

Size X 5.00 µm
Y 5.00 µm

Offse X -0.50 µm
Y 0.00 µm

12) Set the parameters in the IV spectroscopy window to obtain optimum data measurement. *(Refer to Section 9-6 in the attached SmartScan manual)*

Figure 10-57. Set the Parameters in the IV spectroscopy

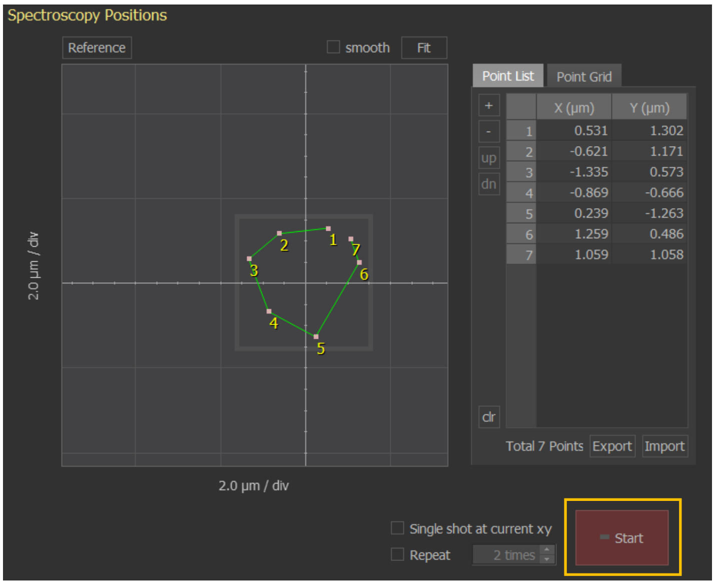


Sample Bias ☐ Reverse
Highest 2.000 V
Lowest -3.000 V
Start 0.000 V
End 0.000 V
Period 1.000 sec
Hold Time 0.000 sec
Current Limit 10.000 nA ☑ Use
Acquisition 3 Channels 512
☐ Turn Off AFM Beam

Est. time (per point) 00:00:01

13) Acquire IV Spectroscopy data by clicking the **Start** button. If the points of interest are designated using the Point list or Map, click the **Start** button found in the Spectroscopy Control Workspace.

Figure 10-58. Acquire IV spectroscopy data



	X (µm)	Y (µm)
1	0.531	1.302
2	-0.621	1.171
3	-1.335	0.573
4	-0.869	-0.666
5	0.239	-1.263
6	1.259	0.486
7	1.059	1.058

Total 7 Points

☐ Single shot at current xy
☐ Repeat 2 times

14) Once all of the measurement are complete, perform a curve analysis in the XEI software by right-clicking on the file in the buffer window and select “***Select to XEI***”.

10-10-3. Indentation spectroscopy

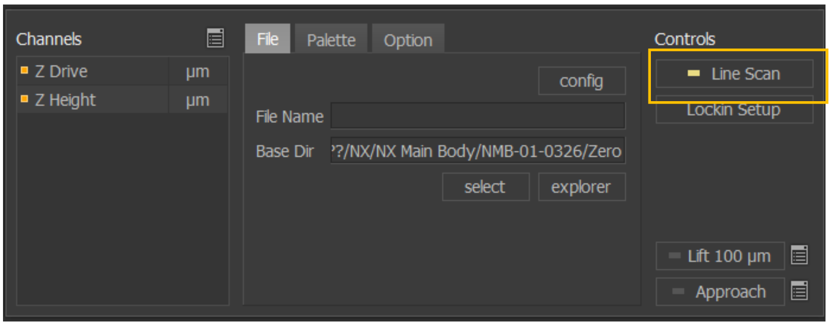
- **. Cantilever Selection**

The cantilever used for Indentation spectroscopy is a Diamond Tip cantilever. In this type of spectroscopy, the cantilever is pressed down to the sample with excessive force to indent and measure its mechanical property. The depth and the area of the indent are correlated with the hardness. The force constant of a cantilever, the shape of the tip, and other mechanical properties such as tip glue determine the total force exerted onto a sample. Therefore, hard material such as diamond with sharp edge is more effective in high resolution and sensitivity indentation.

Selecting the cantilever type in the Cantilever database must be done whenever the cantilever type has been changed. The parameters of the cantilever in used, should matched with the parameters of the selected cantilever. The procedure on how to select cantilever type is shown below.

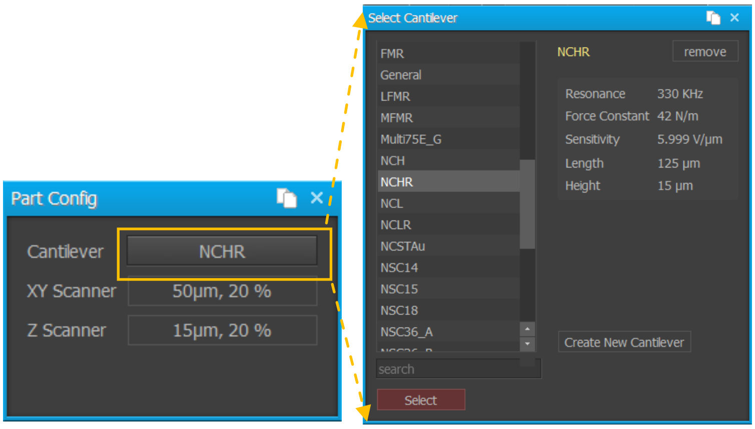
1) Turn OFF the Line Scan by clicking the ***Line Scan*** button on control panel. The yellow light on the Line Scan button denotes that it is ON.

Figure 10-59. Turn OFF the Line Scan



2) Open Part Config window by clicking the ***Setup*** tab on control panel and Open the Cantilever Selection Window by clicking the cantilever type button. The Select CantileverWindow shows the list of common cantilevers offered by Park Systems. If the cantilever type is not on the list, create a new cantilever list by clicking the **Create New Cantilever** button (Refer to Section **4-1-1. Probe Setup** in the attached SmartScan manual).

Figure 10-60. Select Cantilever



Cantilever NCHR
XY Scanner 50µm, 20 %
Z Scanner 15µm, 20 %

NCHR
Resonance 330 KHz
Force Constant 42 N/m
Sensitivity 5.999 V/µm
Length 125 µm
Height 15 µm

3) Click **Select** button to activate the selected cantilever type.

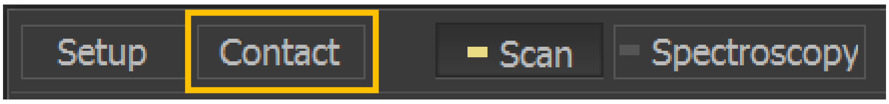
- **General Procedure for Indentation Spectroscopy measurement**

1) Once all of the measurement are complete, perform a curve analysis by right-clicking on the file in the buffer window and select “Select to XEI”.

2) Select the type of cantilever in Cantilever Database (Refer to Cantilever Selection procedure for more information).

3) Switch to ***Contact Mode*** by clicking the Head Mode button in control panel.

Figure 10-61. Select Contact mode

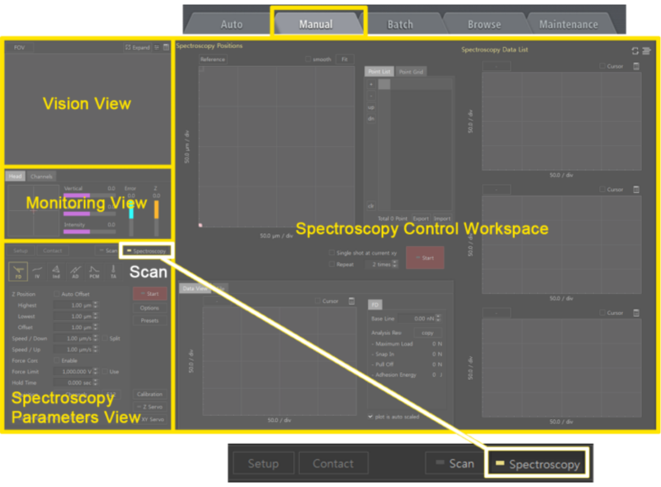


4) Approach the tip to the sample.

5) Acquire image of the sample to identify regions of interest for Indentation spectroscopy. This process can be skipped and instead, a random point on the sample can be selected instead.

6) Switch to Spectroscopy Control by clicking ***Spectroscopy*** button in control panel.

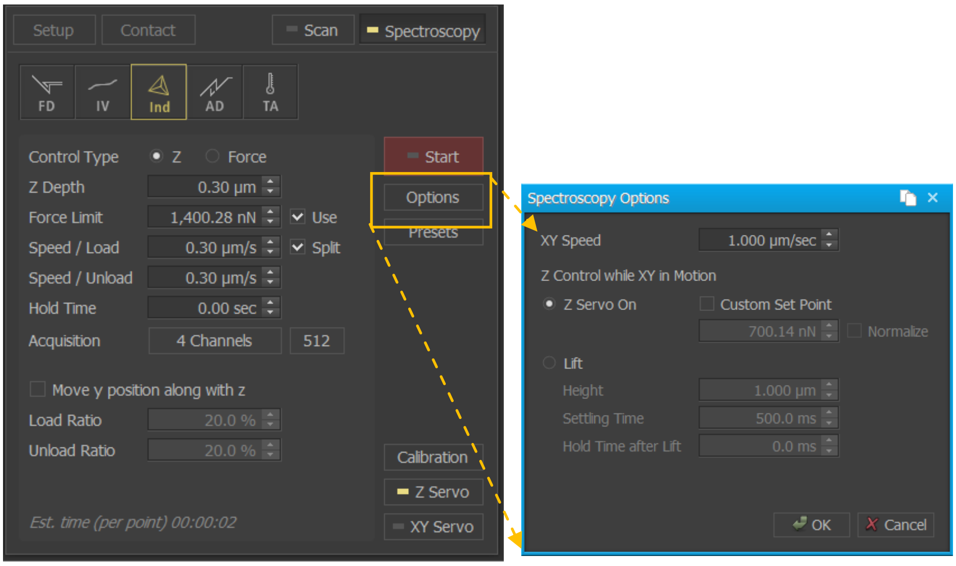
Figure 10-62. Clicking Spectroscopy button



7) Switch to Indentation spectroscopy mode by clicking the ***Ind*** button in the spectroscopy view.

8) Open Spectroscopy Options window by clicking the ***Options*** button in the Setup menu. Set the parameters to prevent the tip from crashing the into the sample surface as it is being moved to a new measurement location. (Refer to Section 9-1-2 in the attached SmartScan manual).

Figure 10-63. Set the parameters for Indentation Spectroscopy Options



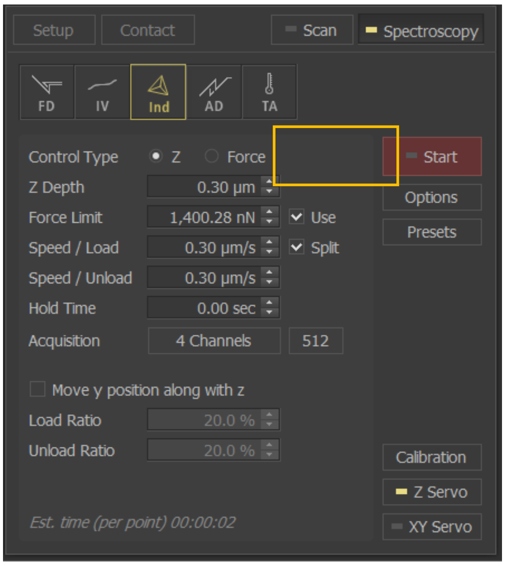
Control Type ● Z ○ Force
Z Depth 0.30 µm
Force Limit 1,400.28 nN ☑ Use
Speed / Load 0.30 µm/s ☑ Split
Speed / Unload 0.30 µm/s
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:00:02

Spectroscopy Options
XY Speed 1.000 µm/sec
Z Control while XY in Motion
● Z Servo On ☐ Custom Set Point
700.14 nN ☐ Normalize
○ Lift
Height 1.000 µm
Settling Time 500.0 ms
Hold Time after Lift 0.0 ms

9) Select points for Indentation measurements on the reference image. There are three ways to do this.

a. First is by clicking the **Start** button, the tip will approach the sample and perform FD measurement at the current location.

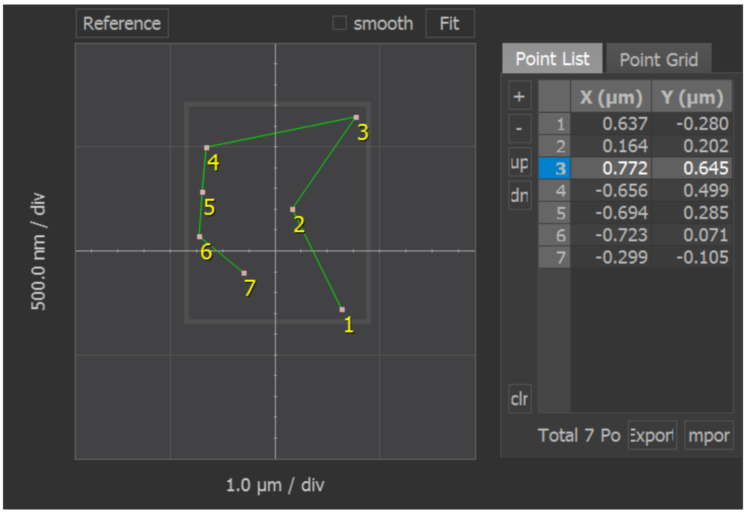
Figure 10-64. Clicking the Indentation Start button



Control Type ● Z ○ Force
Z Depth 0.30 µm
Force Limit 1,400.28 nN ☑ Use
Speed / Load 0.30 µm/s ☑ Split
Speed / Unload 0.30 µm/s
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:00:02

b. Next, is to add points to a list. By clicking the location on the reference image, a point will be added to the list. Points can also be added directly by entering values into the Points List, which is accessible by selecting the Edit Points item in the context menu

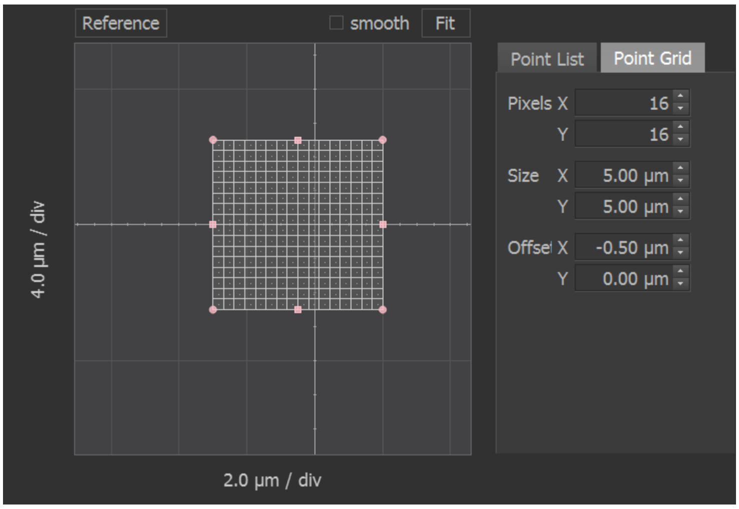
Figure 10-65. Add points to a list



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105

c. Lastly, is to use Map, which designates evenly spaced points on matrix that is overlaid on the sample surface. (Refer to Section 9-2 Spectroscopy Positions View in the attached SmartScan manual for more information)

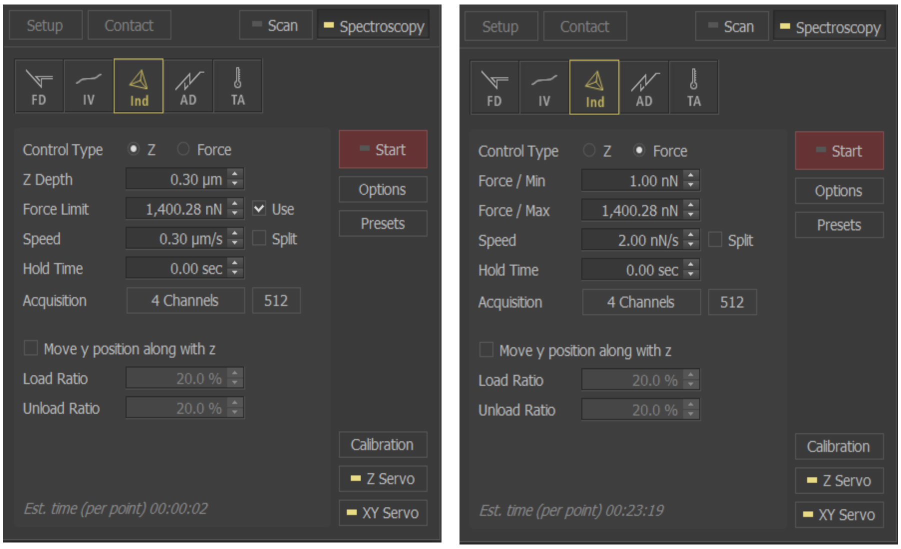
Figure 10-66. How to use map



Pixels X 16
Y 16
Size X 5.00 µm
Y 5.00 µm
Offset X -0.50 µm
Y 0.00 µm

10) Set the parameters in the Indenter tab to obtain optimum data measurement. Indentation has two sub-modes: Z scanner mode and force mode. Each sub-mode uses different parameters to control the indentation cycle. (Refer to Section 9-7 in the attached SmartScan manual)

Figure 10-67. Set the Parameters in the Indentation spectroscopy

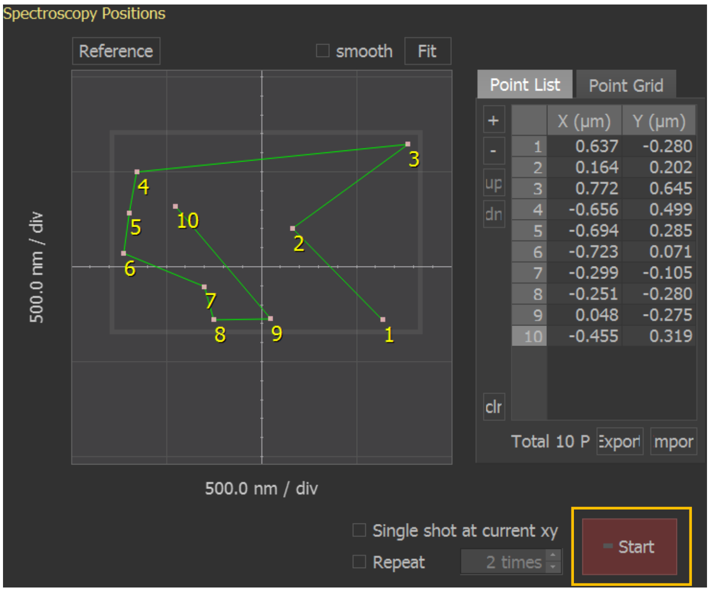


Control Type ● Z ○ Force
Z Depth 0.30 µm
Force Limit 1,400.28 nN ☑ Use
Speed 0.30 µm/s ☐ Split
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:00:02

Control Type ○ Z ● Force
Force / Min 1.00 nN
Force / Max 1,400.28 nN
Speed 2.00 nN/s ☐ Split
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:23:19

11) Acquire Indentation Spectroscopy data by clicking the Start button. If the points of interest are selected using the Point list or Map, click the ***Start*** button found in the Spectroscopy Control Workspace.

Figure 10-68. Acquire Indentation spectroscopy data



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105
8	-0.251	-0.280
9	0.048	-0.275
10	-0.455	0.319

☐ Single shot at current xy
☐ Repeat 2 times

12) Once all of the measurement are complete, perform a curve analysis in the XEI software by right-clicking on the file in the buffer window and select “***Select to XEI***”.

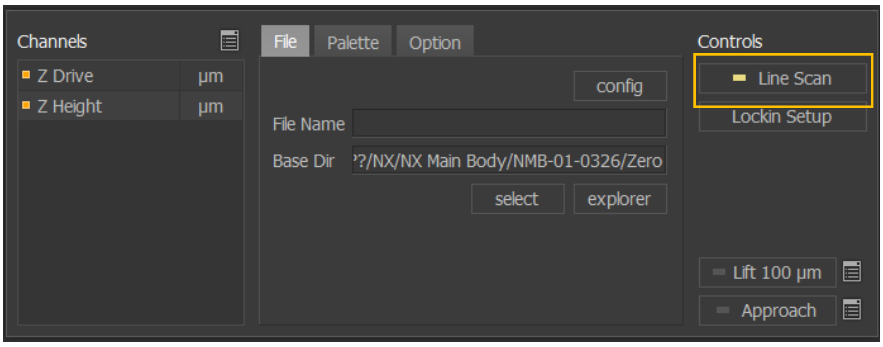
10-10-4. AD spectroscopy

- **Cantilever Selection**

  - In selecting the appropriate cantilever for AD spectroscopy, force constant must be closely considered. It is recommended to use cantilever with high force constant (E.g. NCHR) to measure accurate amplitude during operation. AD spectroscopy allows users to acquire NCM amplitude and NCM phase information as a function of distance from surface to study tip-sample interaction. During NCM, the cantilever vibrates and the changes in the amplitude reflect the changes in distance between the tip and the surface. The hardness and softness of cantilever depends on force constant value, wherein, the higher the force constant, the harder is the cantilever. Therefore, using a cantilever with low force constant in NCM will result to excessive vibration and inaccuracy of amplitude measurement.
    Selecting the cantilever type in the Cantilever database must be done whenever the cantilever type has been changed. The parameters of the cantilever in used, should matched with the parameters of the selected cantilever. The procedure on how to select cantilever type is shown below.

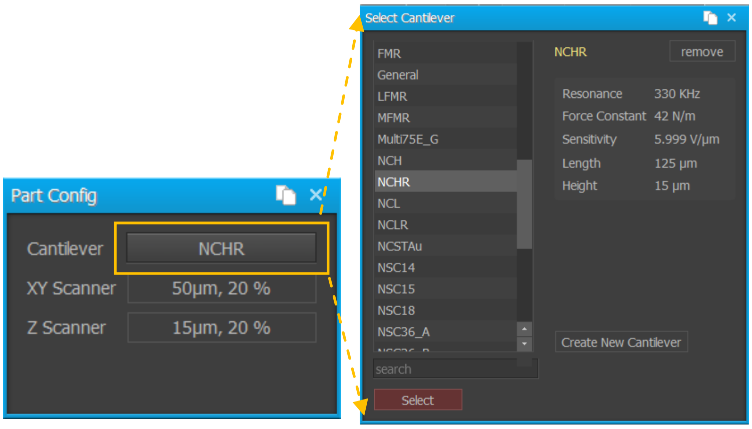
1) Turn OFF the Line Scan by clicking the ***Line Scan*** button on control panel. The yellow light on the Line Scan button denotes that it is ON.

Figure 10-69. Turn OFF the Line Scan



2) Open Part Config window by clicking the ***Setup*** tab on control panel and Open the Cantilever Selection Window by clicking the cantilever type button. The Select CantileverWindow shows the list of common cantilevers offered by Park Systems. If the cantilever type is not on the list, create a new cantilever list by clicking the **Create New Cantilever** button. (Refer to Section **4-1-1. Probe Setup** in the attached SmartScan manual)

Figure 10-70. Select Cantilever


Part Config

Cantilever: NCHR

XY Scanner: 50µm, 20 %

Z Scanner: 15µm, 20 %

Select Cantilever

NCHR

Resonance: 330 KHz

Force Constant: 42 N/m

Sensitivity: 5.999 V/µm

Length: 125 µm

Height: 15 µm

3) Click **Select** button to activate the selected cantilever type.

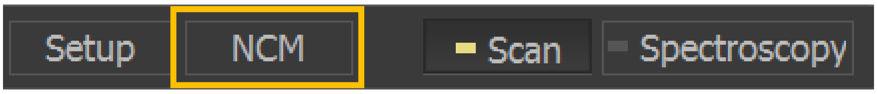
- **General Procedure for AD Spectroscopy measurement**

1) Replace current cantilever in the system with low force constant cantilever.

2) Select the type of cantilever in Cantilever Database (Refer to Section 1: Cantilever Selection of this procedure for more information).

3) Switch to NCM Mode by clicking the ***Head Mode*** button in control panel.

Figure 10-71. Select NCM mode

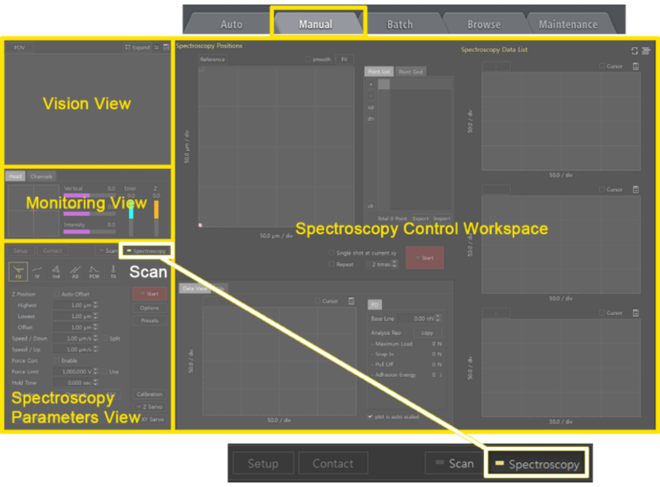


4) Approach the tip towards the sample

5) Acquire image of the sample to identify regions of interest for AD curve acquisition. This process can be skipped and instead, a random point on the sample can be selected.

6) Switch to Spectroscopy Control by clicking ***Spectroscopy*** button in control panel.

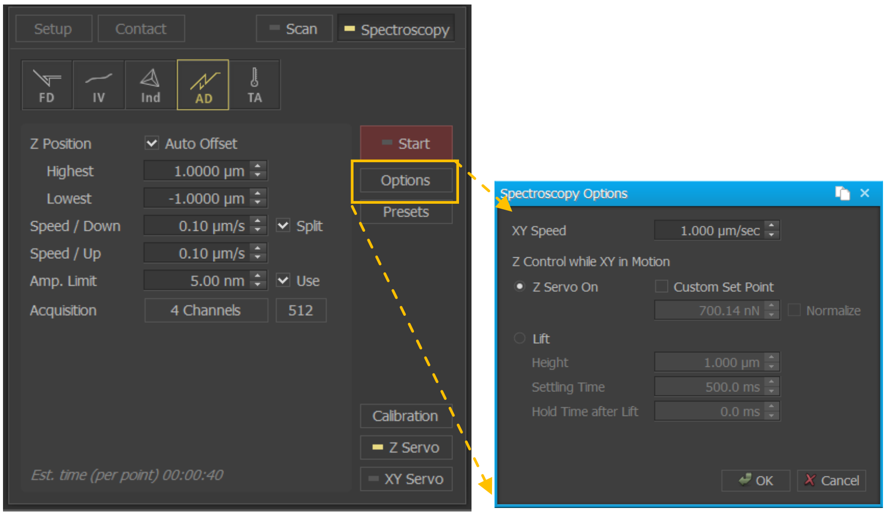
Figure 10-72. Clicking Spectroscopy button



7) Select AD spectroscopy by clicking the ***AD*** button in the spectroscopy view.

8) Open Spectroscopy Options window by clicking the ***Options*** button in the Setup menu. Set the parameters to prevent the tip from crashing the into the sample surface as it is being moved to a new measurement location. (Refer to Section 9-1-2 in the attached SmartScan manual).

Figure 10-73. Set the parameters for AD Spectroscopy Options



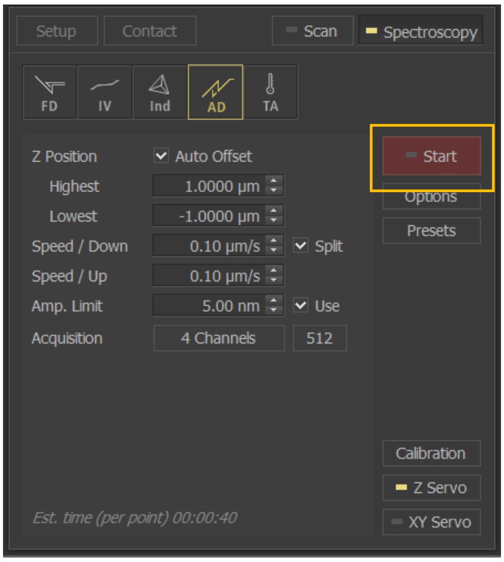
Z Position ☑ Auto Offset
Highest 1.0000 µm
Lowest -1.0000 µm
Speed / Down 0.10 µm/s ☑ Split
Speed / Up 0.10 µm/s
Amp. Limit 5.00 nm ☑ Use
Acquisition 4 Channels 512
Est. time (per point) 00:00:40

Spectroscopy Options
XY Speed 1.000 µm/sec
Z Control while XY in Motion
● Z Servo On ☐ Custom Set Point
700.14 nN ☐ Normalize
○ Lift
Height 1.000 µm
Settling Time 500.0 ms
Hold Time after Lift 0.0 ms

9) Select points at which to take AD measurements on the reference image. There are three ways to do this.

a. First is by clicking the ***Start*** button, the tip will approach the sample and perform AD measurement at the current location.

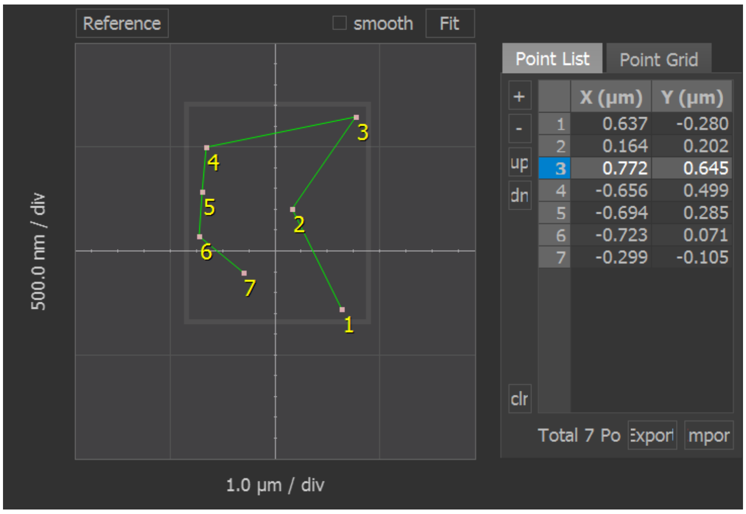
Figure 10-74. Clicking the AD Start button



Z Position ☑ Auto Offset
Highest 1.0000 µm
Lowest -1.0000 µm
Speed / Down 0.10 µm/s ☑ Split
Speed / Up 0.10 µm/s
Amp. Limit 5.00 nm ☑ Use
Acquisition 4 Channels 512
Est. time (per point) 00:00:40

b. Next, is to add points to a list. By clicking the location on the reference image, a point will be added to the list. Points can also be added directly by entering values into the Points List, which is accessible by selecting the ***Edit*** ***Points*** item in the context menu

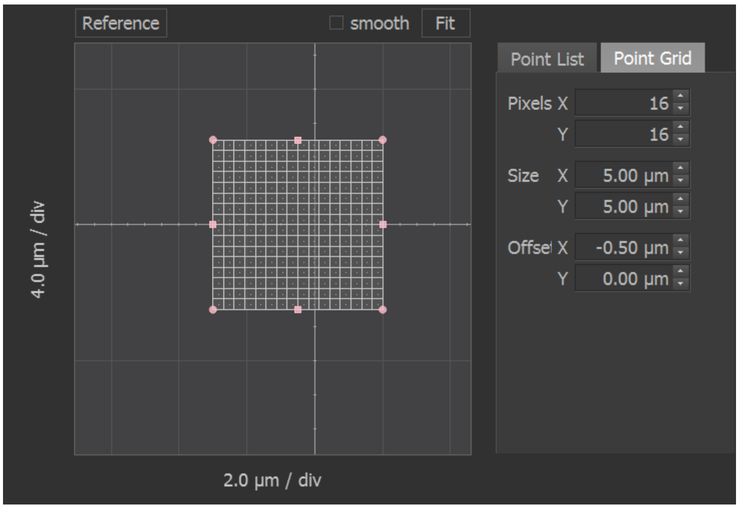
Figure 10-75. Add points to a list



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105

c. Lastly, is to use Map, which designates evenly spaced points on matrix that is overlaid on the sample surface. *(Refer to Section 9-2 Spectroscopy Positions View in the attached SmartScan manual for more information)*

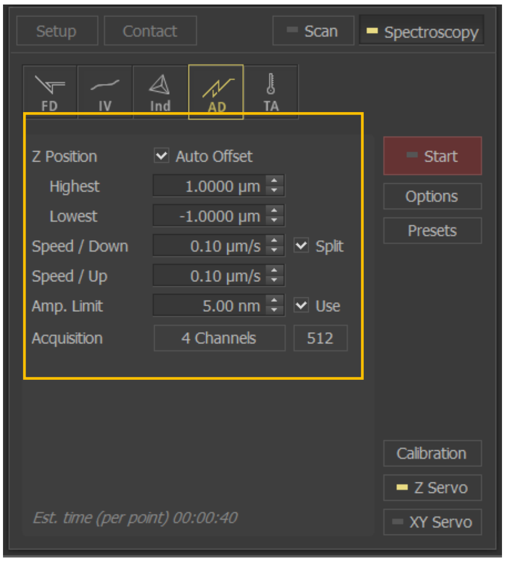
Figure 10-76. How to use map



Pixels X 16
Y 16
Size X 5.00 µm
Y 5.00 µm
Offse X -0.50 µm
Y 0.00 µm

10) Set the parameters in the AD spectroscopy window to obtain optimum data measurement. (Refer to Section 9-8 in the attached SmartScan manual)

Figure 10-77. Set the Parameters in the AD spectroscopy

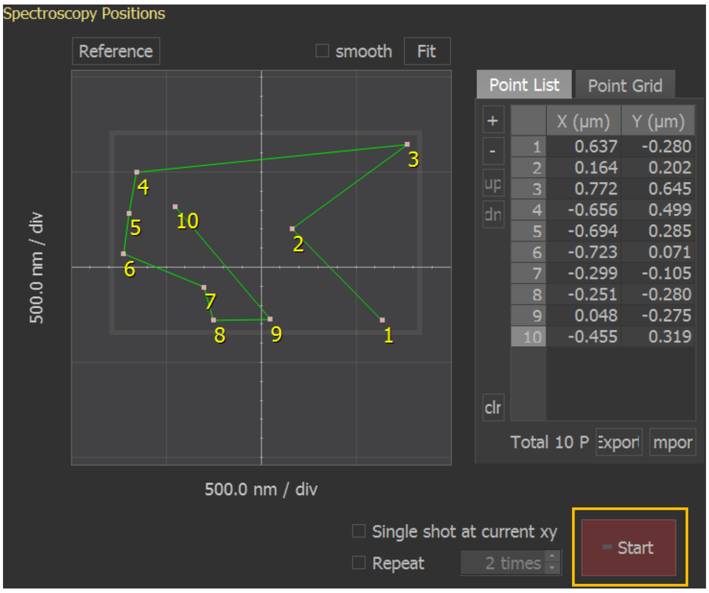


Z Position ☑ Auto Offset
Highest 1.0000 µm
Lowest -1.0000 µm
Speed / Down 0.10 µm/s ☑ Split
Speed / Up 0.10 µm/s
Amp. Limit 5.00 nm ☑ Use
Acquisition 4 Channels 512

Est. time (per point) 00:00:40

Acquire AD Spectroscopy data by clicking the ***Start*** button. If the points of interest are designated using the Point list or Map, click the Start button found in the Spectroscopy Control Workspace.

Figure 10-78. Acquire AD spectroscopy data



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105
8	-0.251	-0.280
9	0.048	-0.275
10	-0.455	0.319

Total 10 P

☐ Single shot at current xy
☐ Repeat 2 times

11) Once all of the measurement are complete, perform a curve analysis by right-clicking on the file in the buffer window and select ***"Select to XEI".***

10-10-5. TA spectroscopy

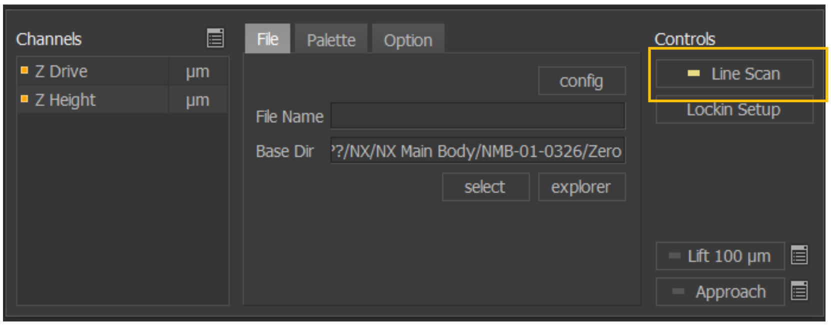
- **Cantilever Selection**

The type of cantilever used in TA spectroscopy measurement is Thermal Probe with a resistive element. Thermal probe serves as a resistance thermometer (or a heater in CCM mode) and at the same time as Contact AFM probe. As a resistance thermometer in TCM, its temperature changes as the tip scans the surface according to the surface temperature. Temperature change of the resistive element leads to change of its resistance. By running a constant current through the tip and measuring the resistance, the temperature of a very small region can be measured. As a resistive heater in CCM, Sufficient energy is applied to the probe tip to keep it at a set temperature via a feedback loop. The feedback loop senses the error signal and adjusts the Probe Current to cancel out the Error signal. The Probe Current, via feedback loop, increases or decreases the energy supplied to the tip in order to maintain a constant temperature and therefore a constant resistance.

Selecting the cantilever type in the Cantilever database must be done whenever the cantilever type has been changed. The parameters of the cantilever in used, should matched with the parameters of the selected cantilever. The procedure on how to select cantilever type is shown below.

1) Turn OFF the Line Scan by clicking the ***Line Scan*** button on control panel. The yellow light on the Line Scan button denotes that it is ON.

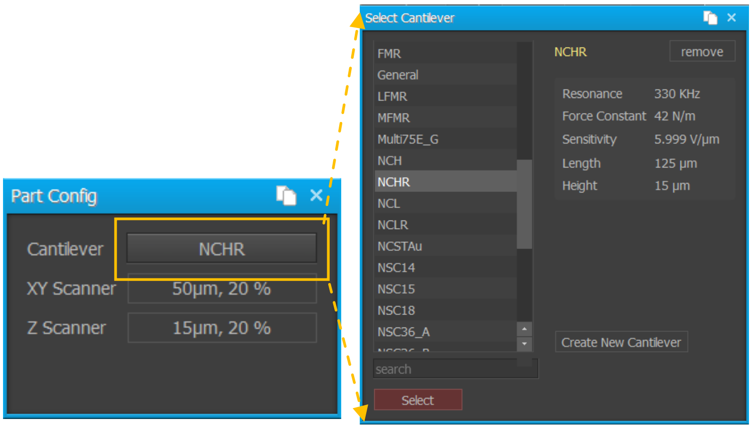
Figure 10-79. Turn OFF the Line Scan



File Name
Base Dir ?/NX/NX Main Body/NMB-01-0326/Zero

2) Open Part Config window by clicking the ***Setup*** tab on control panel and Open the Cantilever Selection Window by clicking the cantilever type button. The Select CantileverWindow shows the list of common cantilevers offered by Park Systems. If the cantilever type is not on the list, create a new cantilever list by clicking the **Create New Cantilever** button (Refer to Section **4-1-1. Probe Setup** in the attached SmartScan manual**).**

Figure 10-80. Select Cantilever



Cantilever: NCHR
XY Scanner: 50µm, 20 %
Z Scanner: 15µm, 20 %

NCHR
Resonance: 330 KHz
Force Constant: 42 N/m
Sensitivity: 5.999 V/µm
Length: 125 µm
Height: 15 µm

3) Click **Select** button to activate the selected cantilever type.

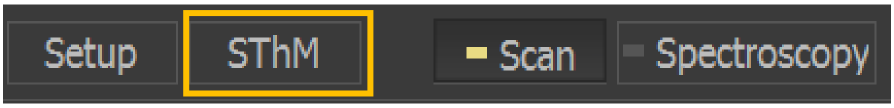
- **General Procedure for TA Spectroscopy measurement**

1) Setup SThM toolkits and replace current cantilever using Thermal Probe with a resistive element.

2) Select the type of cantilever in Cantilever Database (Refer to Cantilever Selection procedure for more information).

3) Switch to SThM Mode by clicking the Head Mode button in control panel.

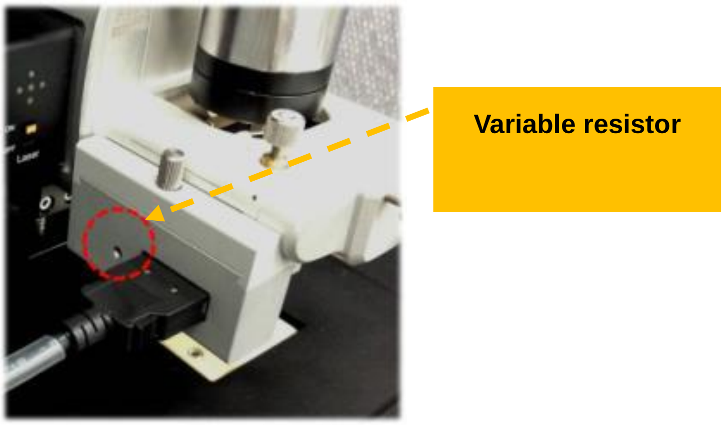
Figure 10-81. Select SThM mode



Load SThM standard sample with known melting point temperature.

4) Sweep the Probe Current signal and adjust the variable resistor located in the HEM with a flat head screw driver to establish same STHM Error value between 0mA and 0.1mA position. *(Refer to SThM manual for more information)*

Figure 10-82. Adjust the Variable resistor

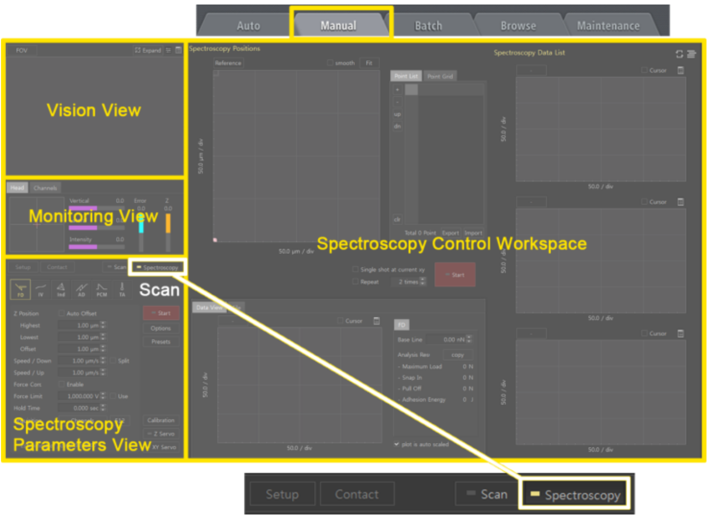


Approach the tip to the sample.

5) Acquire image of the sample to identify regions of interest for Indentation spectroscopy. This process can be skipped and instead, a random point on the sample can be selected.

6) Switch to Spectroscopy Control by clicking Spectroscopy button in control panel.

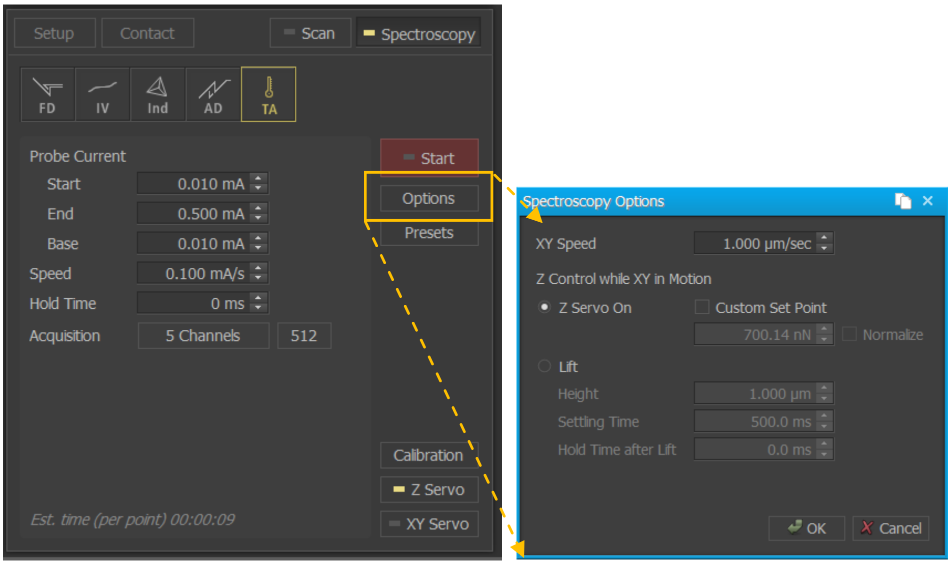
Figure 10-83. Clicking Spectroscopy button



7) Switch to TA spectroscopy mode by clicking the ***TA*** button in the spectroscopy view.

8) Open Spectroscopy Options window by clicking the ***Options*** button in the Setup menu. Set the parameters to prevent the tip from crashing into the sample surface as it is being moved to a new measurement location. (Refer to Section 9-1-2 in the attached SmartScan manual).

Figure 10-84. Set the parameters for TA Spectroscopy Options



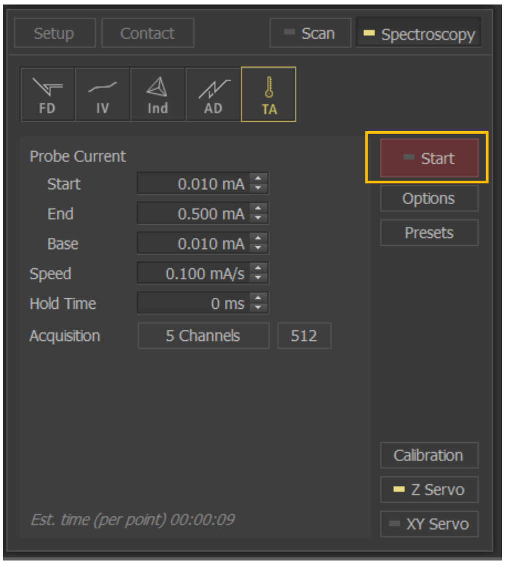
Probe Current
Start 0.010 mA
End 0.500 mA
Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512
Est. time (per point) 00:00:09

XY Speed 1.000 µm/sec
Z Control while XY in Motion
● Z Servo On ☐ Custom Set Point
700.14 nN ☐ Normalize
○ Lift
Height 1.000 µm
Setting Time 500.0 ms
Hold Time after Lift 0.0 ms

Select points at which to take Indentation measurements on the reference image There are three ways to do this.

a. First is by clicking the **Start** button, the tip will approach the sample and perform FD measurement at the current location.

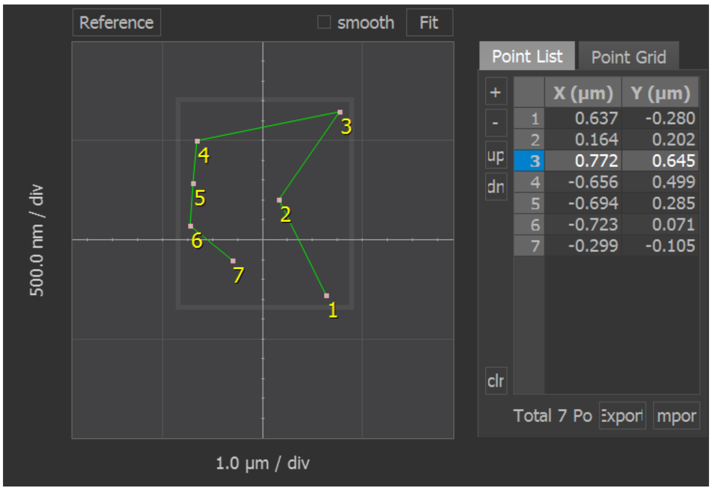
Figure 10-85. Clicking the TA Start button



Probe Current
Start 0.010 mA
End 0.500 mA
Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512
Est. time (per point) 00:00:09

b. Second is to add points to a list. Clicking on a location in the reference image, will add a point to the list. Points can also be added directly by entering values into the Points List, which is accessible by selecting the Edit Points item in the context menu

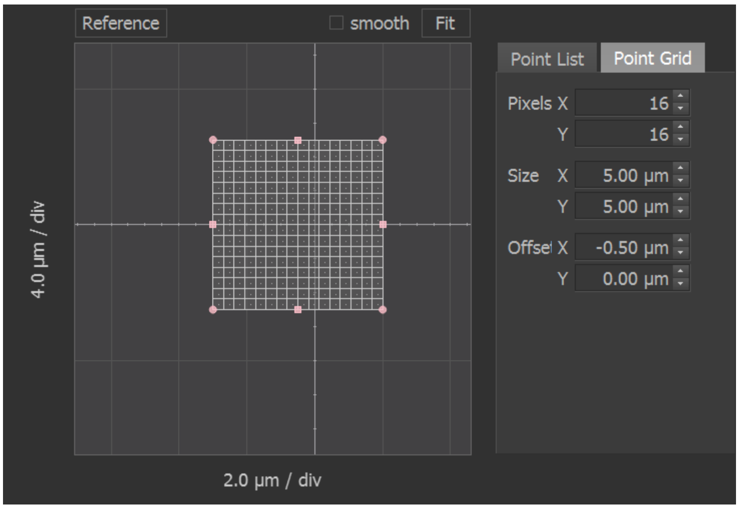
Figure 10-86. Add points to a list



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105

c. Third is to use Map, which designates evenly spaced points on matrix that is overlaid on the sample surface.

Figure 10-87. How to use map

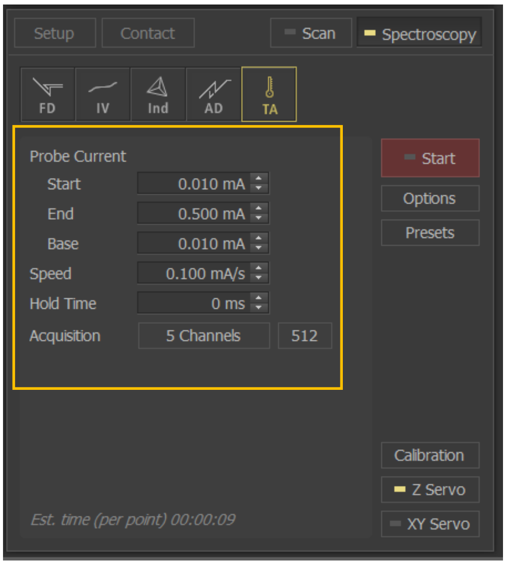


Pixels X 16
Y 16
Size X 5.00 µm
Y 5.00 µm
Offse X -0.50 µm
Y 0.00 µm

(Refer to Section 9-2 Spectroscopy Positions View in the attached SmartScan manual for more information)

9) Set the parameters in the TA tab to obtain optimum data measurement. *(Refer to Section 9-9 in the attached SmartScan manual)*

Figure 10-88. Set the Parameters in the TA spectroscopy

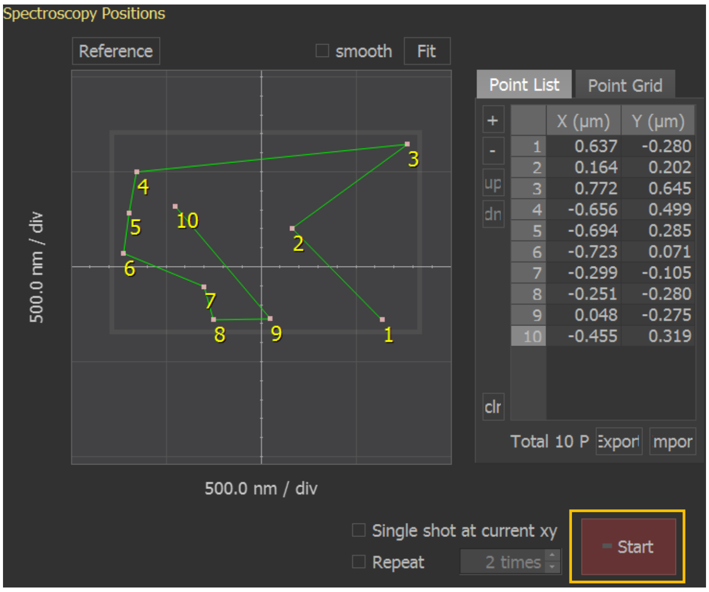


Probe Current
Start 0.010 mA
End 0.500 mA
Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512

Est. time (per point) 00:00:09

10) Acquire TA Spectroscopy data by clicking the ***Start*** button. If the points of interest are designated using the Point list or Map, click the ***Start*** button found in the Spectroscopy Control Workspace.

Figure 10-89. Acquire TA spectroscopy data



	X (µm)	Y (µm)
1	0.637	-0.280
2	0.164	0.202
3	0.772	0.645
4	-0.656	0.499
5	-0.694	0.285
6	-0.723	0.071
7	-0.299	-0.105
8	-0.251	-0.280
9	0.048	-0.275
10	-0.455	0.319

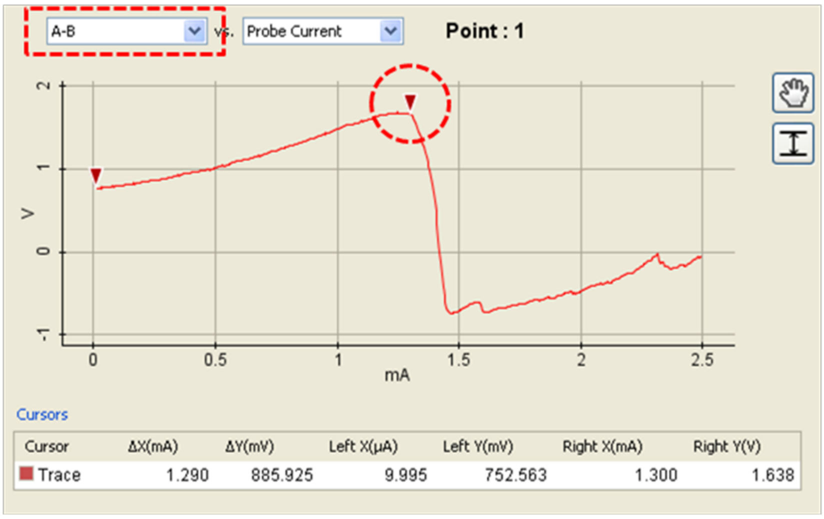
Total 10 P

Once all of the measurement are complete, perform analysis by right-clicking on the file in the buffer window and select “***Select to XEI***”.

(Refer to XEI manual for more information)

Place a cursor pairs where A-B value changes dramatically on A-B vs Probe Current curve.

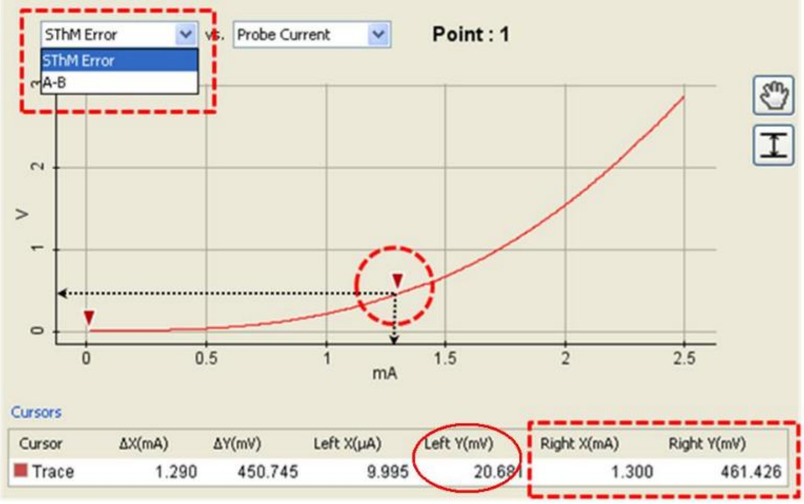
Figure 10-90. A-B vs Probe Current



Cursor	ΔX(mA)	ΔY(mV)	Left X(µA)	Left Y(mV)	Right X(mA)	Right Y(V)
🟥 Trace	1.290	885.925	9.995	752.563	1.300	1.638

Change Y axis as SThM Error on SThM Error vs Probe Current curve, then acquire X axis value (Probe Current value), and Y axis (SThM Error value).

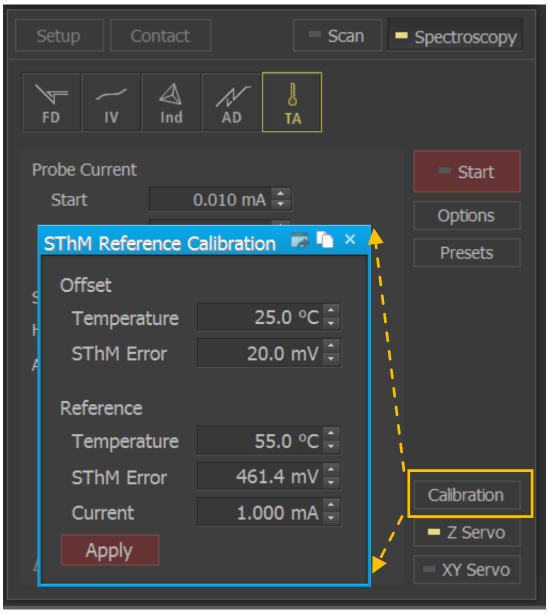
Figure 10-91. SThM Error vs Probe Current



Cursor	ΔX(mA)	ΔY(mV)	Left X(µA)	Left Y(mV)	Right X(mA)	Right Y(mV)
🟥 Trace	1.290	450.745	9.995	20.681	1.300	461.426

11) Open SThM reference calibration window as shown below and input the calibration value. Click the ***Apply*** button to start calibration.

Figure 10-92. SThM reference calibration



Probe Current
Start 0.010 mA

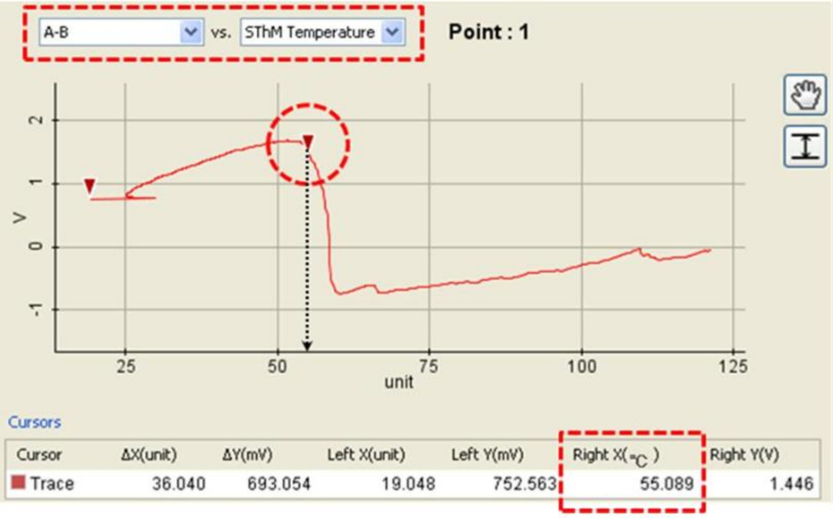
SThM Reference Calibration

Offset
Temperature 25.0 °C
SThM Error 20.0 mV

Reference
Temperature 55.0 °C
SThM Error 461.4 mV
Current 1.000 mA

12) Check the melting point with A-B vs SThM Temperature curve in XEI, after the temperature of nano thermal probe decreases. For better calibration, repeat procedure 14 to 16 more than three times. In repeating the measurement, the user must select another location since the surface condition of the previous location has melted during calibration. Figure below shows A-B vs SThM Temperature curve after thermal calibration using standard sample with melting temperature at 55°C.

Figure 10-93. A-B vs SThM Temperature



Cursor	ΔX(unit)	ΔY(mV)	Left X(unit)	Left Y(mV)	Right X(°C)	Right Y(V)
🟥 Trace	36.040	693.054	19.048	752.563	55.089	1.446

Chapter 11. Q Control Mode

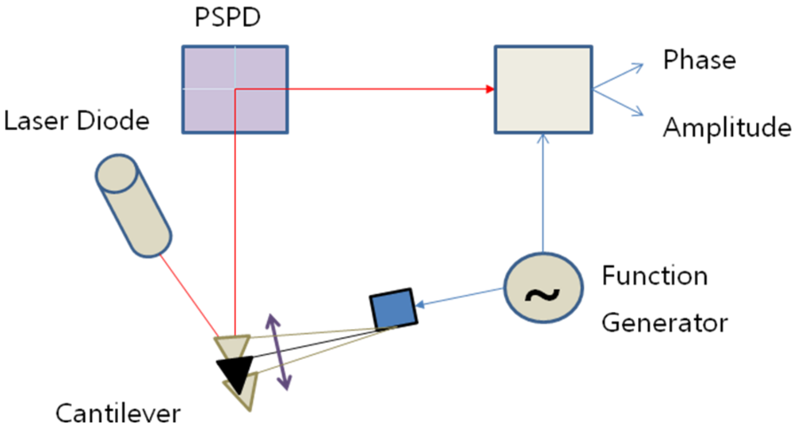
The Q Control Mode enables the control of the quality factor of the cantilever while operating in Non Contact Mode and Tapping mode. The quality factor of the cantilever is inversely proportional to the viscous drag (damping) acting on the cantilever. Like the spring constant, the quality factor is also an important parameter of the cantilever. However, quality factor depends not only on the cantilever but also on the environment in which the cantilever oscillates. For example, in liquid conditions, the resonance frequency peak of the cantilever is dampened and broadened, and the quality factor may decrease compared to the quality factor in air.

Basically, the Q control is an appropriately tuned feedback system where the sensor signal (output of the cantilever) is fed back to the excitation signal (input of the cantilever). Since the feedback can be either positive or negative, we can realize Q enhancing and Q reducing operation of the Q control mode. In Q enhancing mode, the differential tip-sample force will be bigger than without Q control and the sensitivity will be better and the image quality may be better in some cases but the tip response time (settling time) will be longer which may limit the scan speed.

11-1. Principle of Q Control Mode

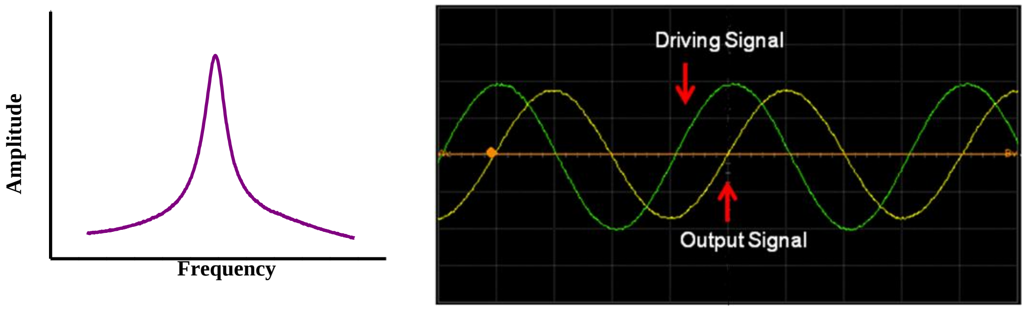
In Non Contact Mode and Tapping mode, the cantilever is modulated with constant amplitude at the resonant frequency using a function generator. This cantilever modulation is detected by PSPD and is divided into a phase signal and amplitude signal through the Lock in Amplifier. The amplitude signal is used for feedback to get the sample topography. Figure 11-1 below shows a schematic diagram of Non Contact mode in NX AFM System.

Figure 11-1. Schematic diagram of Non Contact Mode



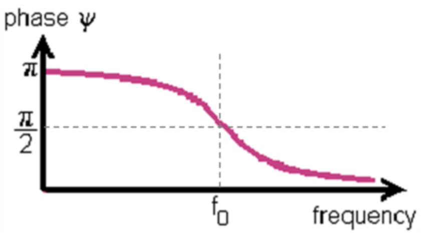
When the cantilever is vibrated at the resonance frequency, a +90 degree phase difference between the driving signal (green) and output signal (yellow, VERTICAL (AC) signal occurs. Please see Figure 11-2.

Figure 11-2. Phase shift between driving signal and output signal



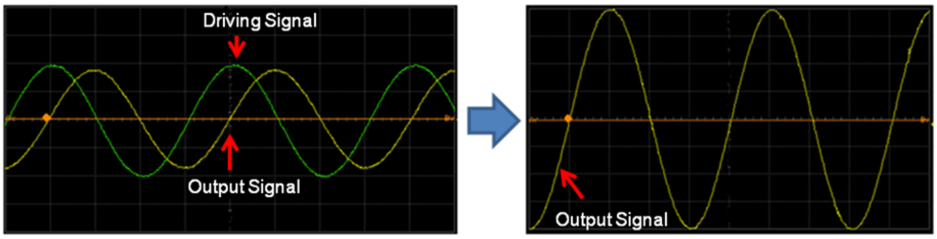
At this point, the phase changed is as shown in Figure 11-3. F_0 is the resonance frequency in the graph.

Figure 11-3. Phase change

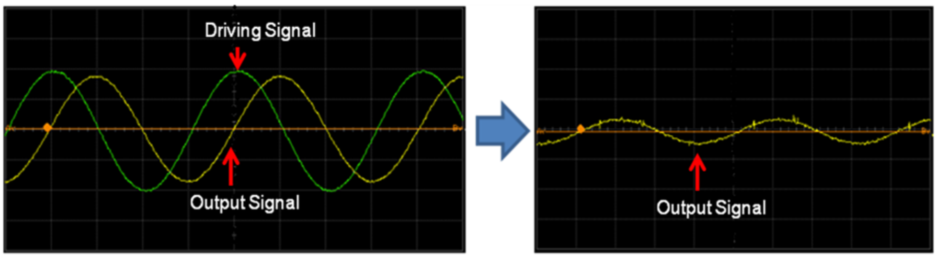


Q Control Mode can make the output signal shift -90 degrees, adding to the driving signal. Then, the driving signal of the cantilever modulation will be amplified. This calls the "Phase Shifter". The "Phase shifter" makes the phase shift through a time delay. In the NX system, input signal for cantilever modulation is a Sine function and output signal through VERTICAL signal is a Cosine function. Therefore, if the output signal is shifted to -90 degree and added to the input signal, the cantilever modulation is amplified about 10^3 in air. Figure 11-4 shows the cantilever modulation signal according to the phase shift. (a) Output signal is amplified when the output signal is shifted to -90 degree in phase and (b) Output signal is decreased when the output signal is shifted to 90 degree in phase.

Figure 11-4. Output signal after phase shift



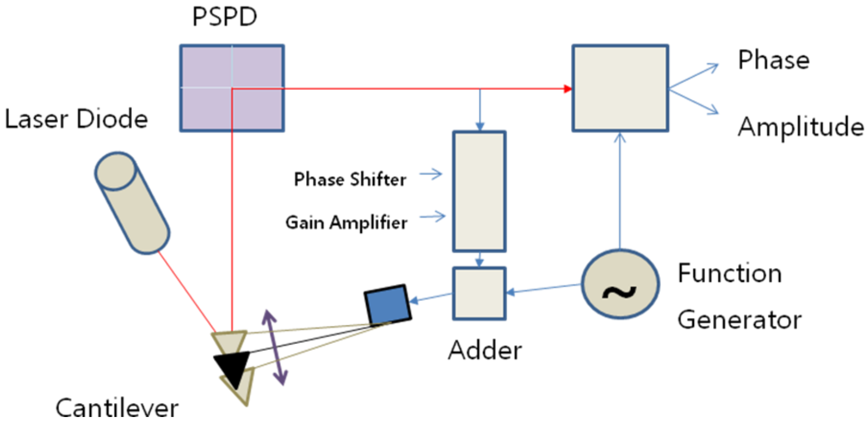
(a) After increasing Q factor (-90 degree phase shift)



(B) After decreasing Q factor (90 degree phase shift)

After passing through the phase shifter, the signal can be amplified again when given an appropriate gain. This additional feedback circuit is called a “Gain Amplifier”. Figure 11-5 shows a schematic diagram of Non Contact mode with Q Control. The output signal, the AC signal from PSPD, passes through the Phase Shifter and Gain Amplifier and is then sent to the Adder. Finally, it is added to the driving signal for cantilever motion.

Figure 11-5. Schematic diagram in Non Contact Mode with Q Control



When the external driving force is applied in Non-Contact mode, the simple harmonic oscillation is expressed by the following equation.

$$m\ddot{x}(t) + \gamma\dot{x}(t) + kx(t) = F_0 e^{i\omega t}$$

m, γ, k, and $F_0 e^{i\omega t}$ he cantilever mass, damping constant, spring constant of the cantilever, and driving signal from NX-electronics respectively.

When the Q control mode is enabled, the equation is as follows:

$$m\ddot{x}(t) + \gamma\dot{x}(t) + kx(t) = F_0 e^{i\omega t} + Ge^{i\pi/2}x(t)$$

G is the Q Control Gain and X(t) is the cantilever's motion when time changes. is $Ge^{i\pi/2}x(t)$ control term. If the driving signal is added to the cantilever modulation, , the equation of the cantilever motion is changed as shown.

$$m\ddot{x}(t) + \gamma_{\text{eff}}\dot{x}(t) + kx(t) = F_0 e^{i\omega t}$$

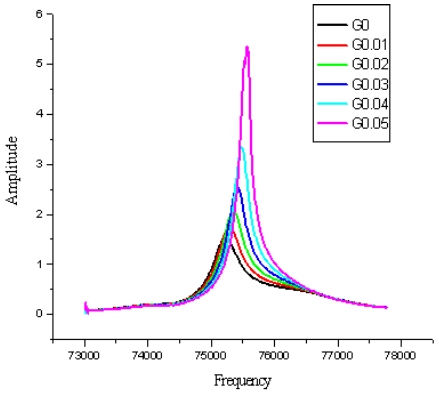
$$\gamma_{\text{eff}} = \gamma - \frac{G}{\omega} \qquad Q_{\text{eff}} = \frac{m\omega}{\gamma_{\text{eff}}}$$

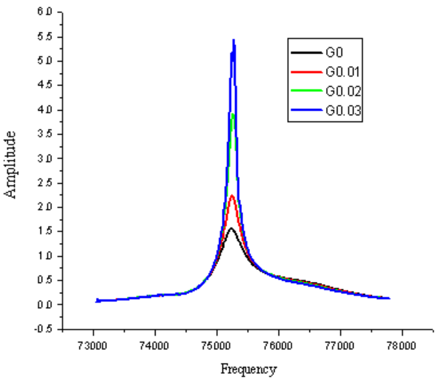
Therefore, the effective damping is changed by Q control gain, and the effective quality factor is changed.

However, the resonant frequency is shifted because of electronics, drive frequency, cantilever and so on. Therefore, when the phase is set to -90°+ α, the resonance frequency does not change during Q control. In other words, the input value of the phase shifter is (+or-90°+ α). The process to find the α is called the "Initial Phase Calibration" in the SmartScan™ program.

Figure 11-6 shows the modulation amplitude change while increasing the Q control gain (Left: before initial phase calibration, Right:after initial phase calibration). When the gain is increased after initial phase calibration, the modulation amplitude is increased without a resonance frequency shift.

Figure 11-6. Modulation Amplitude Change according to gain (Left: Before Initial Calibration, Right: After Initial Calibration)

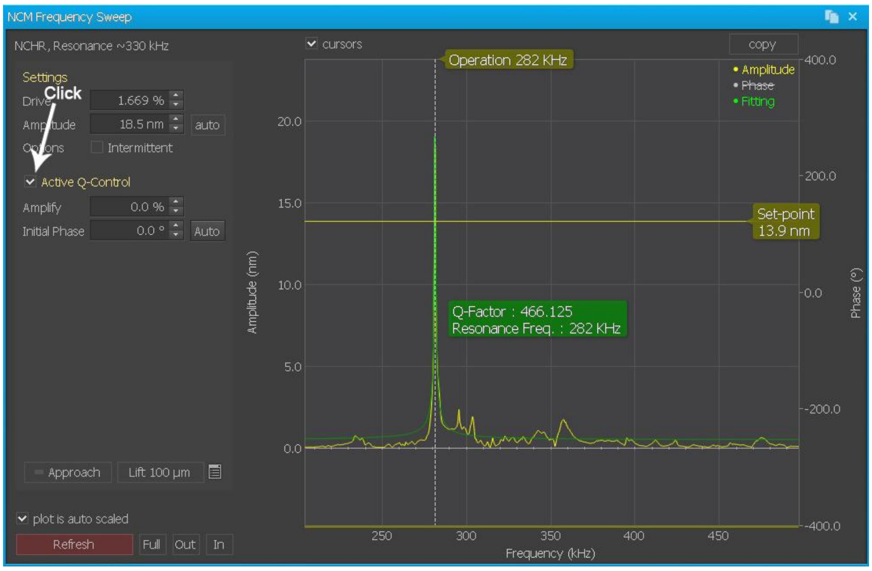




11-2. Q Control User Interface

Clicking the ‘To Q Control” button on the Frequency Sweep Window will change the button to the ‘To Control’ button and change the UI of the Frequency Sweep Window. See Figure 11-7. In this window, you can control the Q value easily.

Figure 11-7. Frequency Sweep Window with Q Control


NCHR, Resonance ~330 kHz

Drive 1.669 %

Amplitude 18.5 nm

Amplify 0.0 %

Initial Phase 0.0 °

Operation 282 KHz

Set-point 13.9 nm

Q-Factor : 466.125
Resonance Freq. : 282 KHz

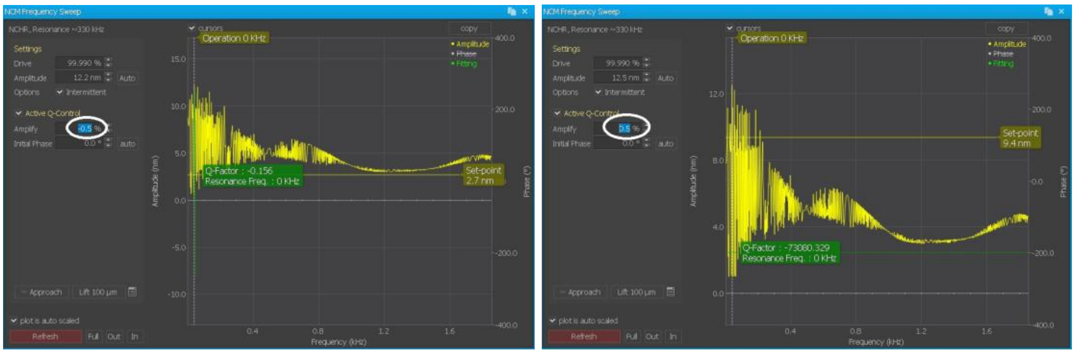
■ Q Amplify

This absolute Q Amplify value applies to the gain amplifier of Q control.

Q Amplify	Gain	Phase
0	0 (Deactivate Q Control)	-
0~1	IQ amplify input Valuel	Initial Phase-90
-1~0	IQ amplify Input Valuel	Initial Phase+90

The negative input changes the Q value in the direction of decreasing Q. The positive input changes the Q value in the direction to increase Q. When you input '0' on the text field on Q Amplify, the Q control mode is deactivated. Figure 11-7 shows that the Q value changes when Q amplify is set to -0.05(Left) and 0.05(Right) after the initial phase calibration is done. You can input -1 to 1 in this text field.

Figure 11-8. Q Control using Q amplify test field(Left: -0.05, Right: 0.05)

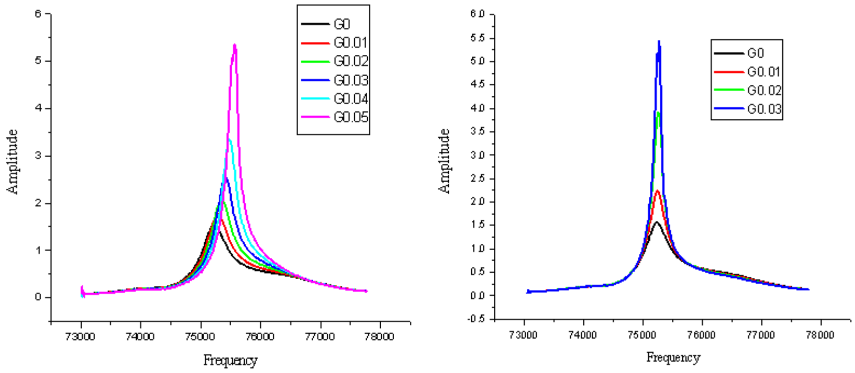

NCM Frequency Sweep
NCHR, Resonance ~330 kHz
Drive 99.990 %
Amplitude 12.2 nm
Options ✓ Intermittent
✓ Active Q-Control
Amplify -0.5 %
Initial Phase 0.0 °
Q-Factor : -0.156
Resonance Freq. : 0 KHz
Set-point 2.7 nm
✓ plot is auto scaled

NCM Frequency Sweep
NCHR, Resonance ~330 kHz
Drive 99.990 %
Amplitude 12.5 nm
Options ✓ Intermittent
✓ Active Q-Control
Amplify 0.5 %
Initial Phase 0.0 °
Q-Factor : -73080.329
Resonance Freq. : 0 KHz
Set-point 9.4 nm
✓ plot is auto scaled

■ **Initial Phase**

In principle, resonant frequency is unchanged when the phase is shifted -90° degrees in the NX System. However, in fact, the resonant frequency is shifted because of electronics, drive frequency, cantilever and so on. Therefore, when the phase is set to -90°+ α, the resonance frequency is not changed during Q control. This 'α' is called the initial phase. In other words, the input value of the phase shifter is (+or-90°+initial phase). Clicking the 'Auto Calib.' button automatically changes the phase little by little to find the initial phase without a resonance frequency shift. This process is called "Initial Calibration". Figure 11-9 shows the modulation amplitude change by increasing the gain. Left is before initial phase calibration and Right is after initial phase calibration. When gain is increased, the modulation amplitude is increased without resonance frequency shift.

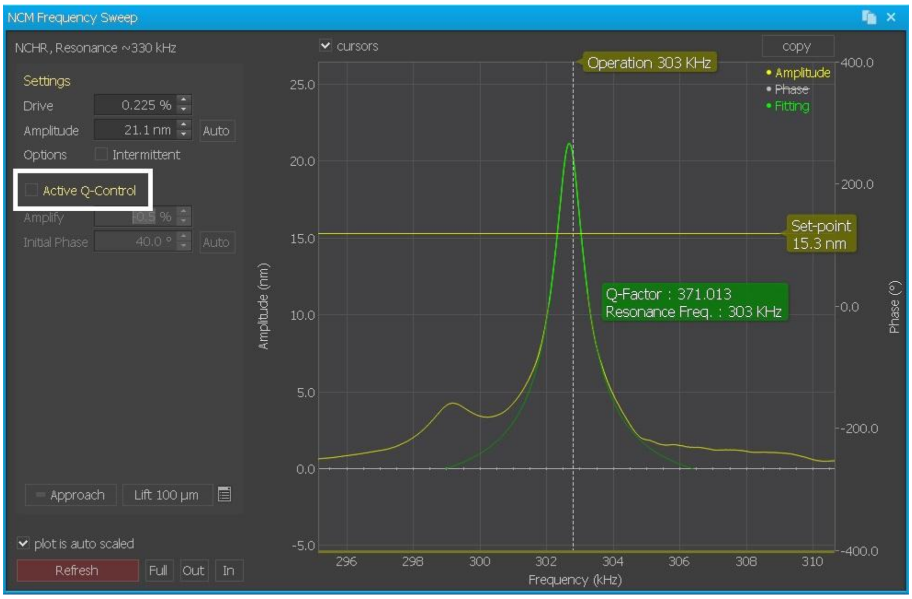
Figure 11-9. Modulation Amplitude Change according to gain (Left: Before Initial Calibration, Right: After Initial Calibration)



■ **Deactivate**

Q control mode is deactivated when the 'Deactivate' button is clicked. It means that the Q amplify value becomes 0. Figure 11-10 is shown when the 'Deactivate' button is clicked.

Figure 11-10. Deactivate Q Control


NCM Frequency Sweep

NCHR, Resonance ~330 kHz

Settings
Drive 0.225 %
Amplitude 21.1 nm
Options ☐ Intermittent
☐ Active Q-Control
Amplify 0.5 %
Initial Phase 40.0 °

☑ cursors

Operation 303 KHz

Set-point 15.3 nm

Q-Factor : 371.013
Resonance Freq. : 303 KHz

☑ plot is auto scaled

11-3. Q Control Procedure

1. Change to the maintenance mode by clicking [Mode->Maintenance Mode]
2. Open the Frequency Sweep Window.
3. Click 'To Q Control" to change the UI of Frequency Sweep Window.
4. Input the adequate value to the Q Amplify field. It is recommended to try to set it to "0.05" first. The input range is -1 to 1.
5. Click 'Auto Calib.' to find the initial phase and wait until the calibration is done. If you hear a noise from the system, stop and go back to step 4 to decrease the Q am

plify value.

6. Input the desired Q amplify value.

Chapter 12. Magnetic Force Microscopy (MFM)

This document is an operating manual for Magnetic Force Microscopy, one of the many application modes for the NX series SPM from Park Systems. MFM is a technique used to map magnetic properties of a sample surface by measuring the magnetic force between the magnetized tip and magnetic surface. MFM images contain information about magnetic properties such as distribution of magnetic domain.

This manual assumes that you are familiar with the NX series SPM and SmartScan™ Data Acquisition program. If not please refer to your user's manual for the NX series SPM and software manual for the SmartScan™ software.

12-1. Principle of Magnetic Force Microscopy

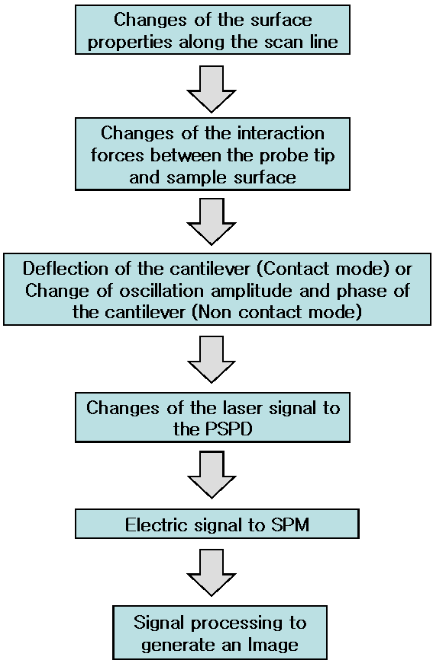
Almost every surface property measured by SPM is acquired by the following process.

MFM measurements follow the same procedure. For MFM, the surface properties would be magnetic properties and the interaction force will be the magnetic force between the magnetized tip and magnetic sample.

However, in addition to the magnetic forces, Van der Waals forces always exist between the tip and sample. These Van der Waals forces varies according to the tip-sample distance and therefore are used to measure the surface height.

Hence, in MFM, the signal contains both information of surface height (called 'Height' signal) and surface magnetic property (called 'MFM signal') generated by Van der Waals and magnetic forces, respectively. The key to successful MFM imaging lies in separating the signal which contains magnetic information from the entire obtained signal.

Figure 12-1. Process of the SPM imaging


Changes of the surface properties along the scan line
Changes of the interaction forces between the probe tip and sample surface
Deflection of the cantilever (Contact mode) or Change of oscillation amplitude and phase of the cantilever (Non contact mode)
Changes of the laser signal to the PSPD
Electric signal to SPM
Signal processing to generate an Image

While the Van der Waals forces present in height imaging are inversely proportional to distance to the power of 7, magnetic signals are long range forces inversely proportional to the second power of distance. This is why NX SPM MFM mode scans a sample twice, in order to separate the signals. Height is measured within a range where Van der Waals forces are dominant, and then the tip is moved further away from the sample in order to measure the effects of magnetic forces.

In the MFM mode of the NX SPM, sample is scanned twice to separate the signal. In first scan the tip scans the surface as in NC-AFM and the surface height of the sample is obtained. In the second scan, the tip-sample distance is increased and the tip is scanned along the surface height line obtained from the first scan as shown in Figure 12-2.

The surface height line is the line of the constant tip sample distance, which equals the line of the constant Van der Waals force. So, when the tip follows the surface height line in the second scan of 'MFM mode', the Van der Waals forces acting on the tip are kept constant. Thus, the only change in force affecting the signal is the change of the magnetic force. So, from the second scan, a surface height free signal can be obtained from which the MFM image is obtained.

Figure 12-2. Scanning process in MFM mode

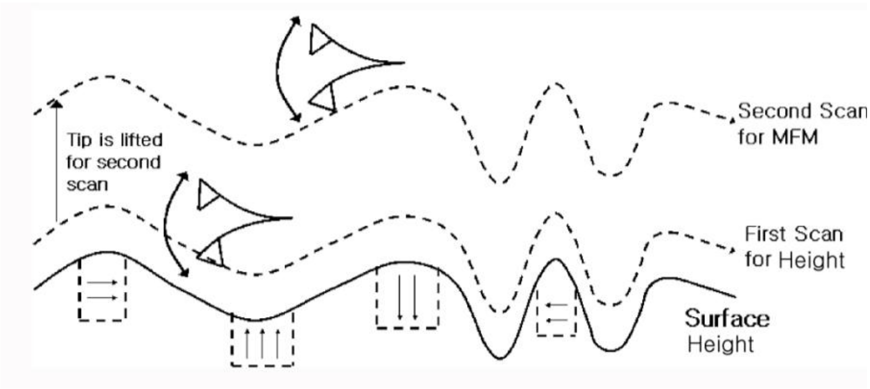
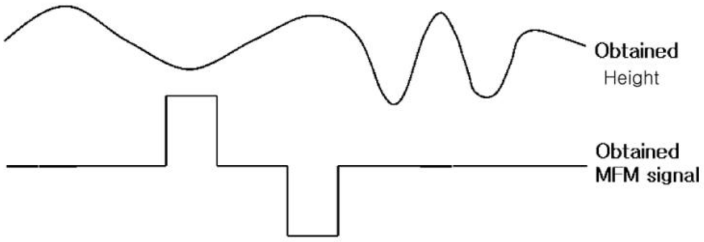


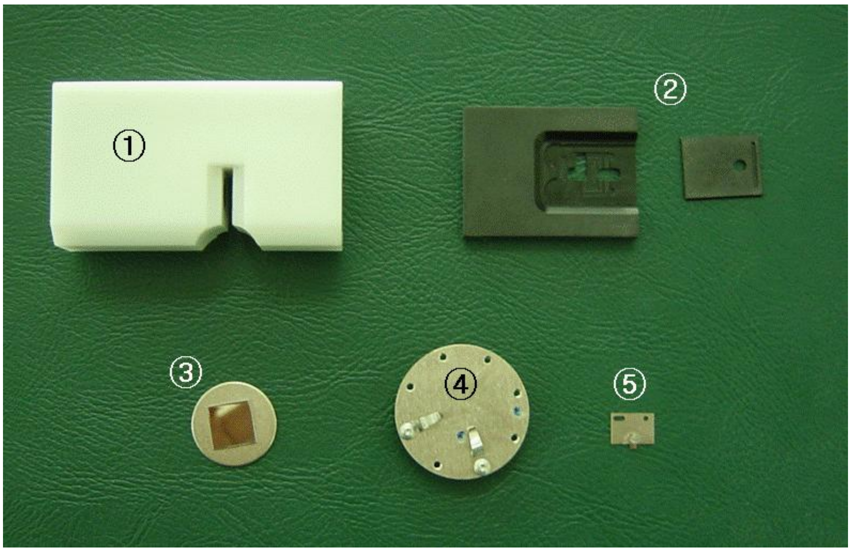
Figure 12-3 Obtained signals in MFM mode



12-2. Components

Required components for the MFM imaging are shown in the Figure 12-4

Figure 12-4. Required Components



1. Magnetizer
2. Magnetizer Clip
3. Standard Sample (a piece of hard disk)
4. Non magnetic sample holder
5. MFM Cantilevers (coated with magnetic materials such as Co-Cr, FeCoNi).

If you are planning to apply external magnetic field as you take image, magnetic field generator is also required. Please see section 'Magnetic Field Generator' for detailed infor mation about magnetic field generator.

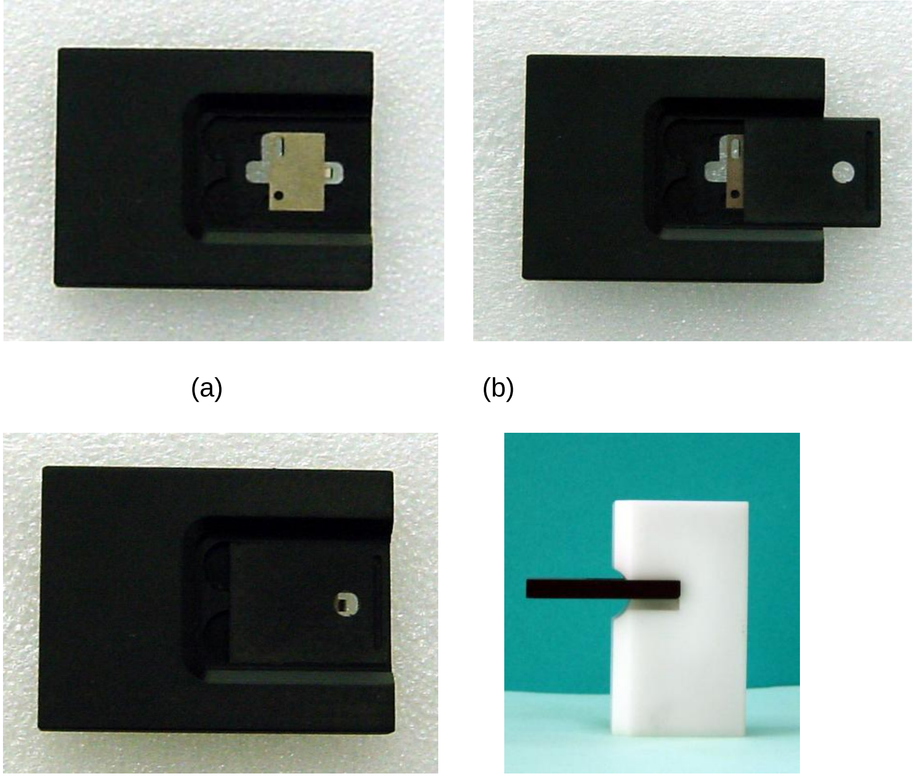
12-3. Setup.

A. Magnetizing the tip

1. Hold the chip carrier with tweezers. Place the chip carrier on the magnetizer clip with the chip facing down into rectangular cutout. See Figure 12-5 (a).

2. Slide in the cover of the magnetizer clip with the groove facing up and to the edge of the magnetizer clip as shown in Figure 12-5 (a). Attach the cantilever chip carrier to the magnetizer clip, taking care to ensure that the chip faces downward, then fasten the magnetizer clip. When the cover is closed, the cantilever chip should be visible through the circular hold of the cover as show in Figure 12-5 (c).

Figure 12-5. Magnetizing the MFM tip



(a) (b)

(c) (d)

3. Insert the magnetizer clip in the magnetizer for 5 ~ 10 seconds as shown in Figure 4 (d). Insert the magnetic chip according to desired tip magnetization direction, following N and S pole indicators as labeled on the magnetizer.

4. Take magnetizer clip out and remove the cover.

5. Remove the chip carrier from the magnetizer clip with tweezers. Hold the clip in the air to prevent the damage of the cantilever by touching the floor as you remove the chip carrier from the clip. It is also possible to obtain MFM signals without going through the tip magnetization procedure if you are using a magnetically coated tip, but the magnetizer is still useful to control the magnetization direction of the tip.

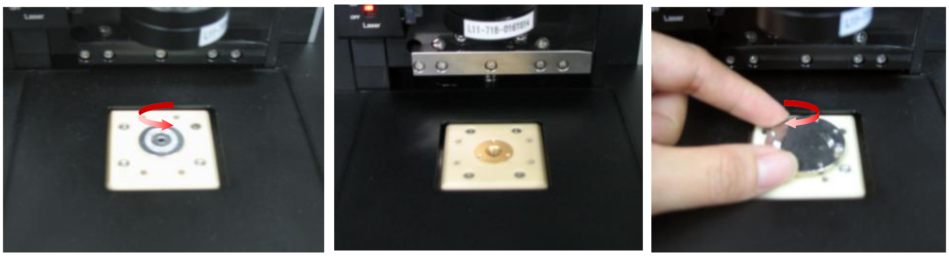
Caution!

The cantilever is very small and fragile. It can be broken easily even by a small force such as touching the edge of a clip. Thus, during the whole tip magnetizing process, be careful not to damage the cantilever. We recommend using a cantilever purchased within the past 3 months, as MFM cantilevers may no longer be usable in obtaining MFM signals despite magnetization after 3 months depending on storage conditions.

B. Preparing the Sample

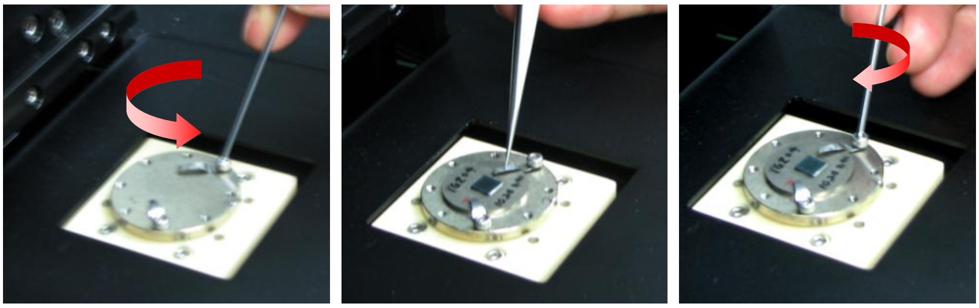
1. The magnetic sample holder cannot be used for MFM because its magnetic field affects the MFM image. Remove the magnetic sample holder by unscrewing it from the sample chuck, and replace it by screwing the non magnetic sample holder into the sample chuck as shown in the figure below.

Figure 12-6. Exchanging the Sample Holder



2. Mount the sample on the non magnetic sample holder by using the holder clips.
   I. Loose the screws holding clips.
   II. Place the clips on the sample.
   III. Tighten the screws to fix the sample well.

Figure 12-7. Sample Loading



If your sample is large enough not to be mounted using the holder clips. Attach the sample to the sample disk using adhesive.

12-4. Operation

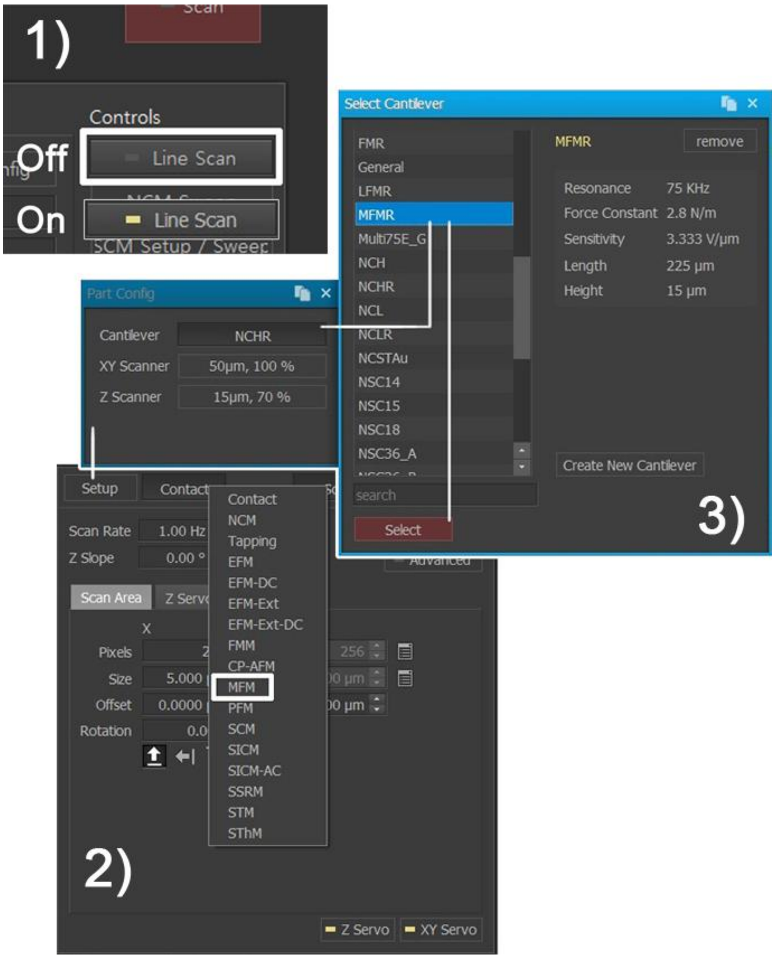
1. First, prepare the tip and sample properly as described in the ‘Setting Up’ section.

2. Mount the cantilever onto the head and install the head to the system.

3. Align the laser beam on the cantilever. For detailed procedures, refer to the NX user’s manual.

4. 1) The ‘Line Scan Off’ button in the toolbar. Select 2) the “MFM” head mode and choose your 3) cantilever type, ‘MFMR’.

Figure 12-8. Selecting the Head Mode and cantilever type



Part Config

Cantilever NCHR

XY Scanner 50µm, 100 %

Z Scanner 15µm, 70 %

Scan Rate 1.00 Hz

Z Slope 0.00 °

Select Cantilever

MFMR

Resonance 75 KHz

Force Constant 2.8 N/m

Sensitivity 3.333 V/µm

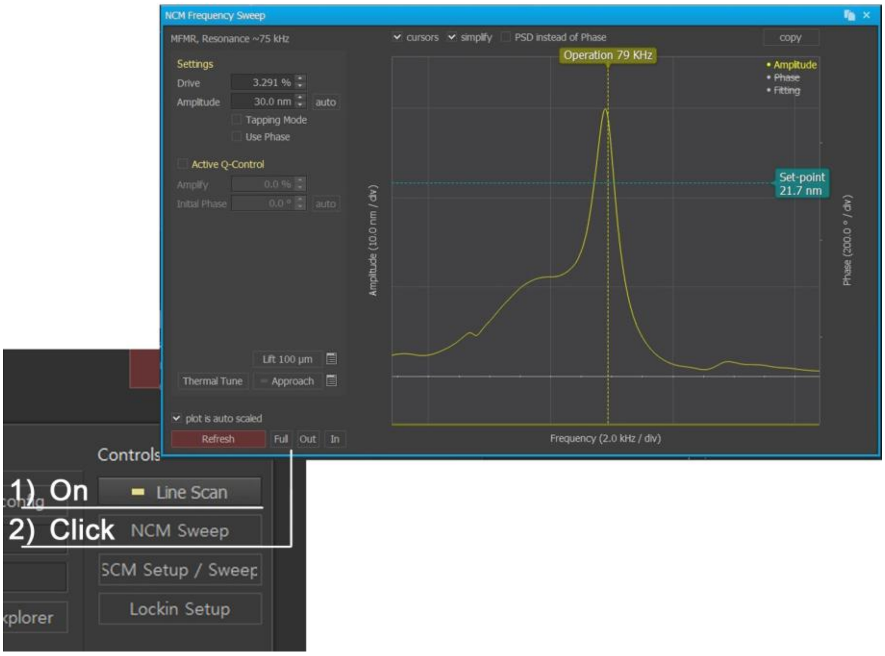
Length 225 µm

Height 15 µm

5. After selecting the MFM mode, 1) the ‘Line Scan on’ On/Off button in the toolbar.

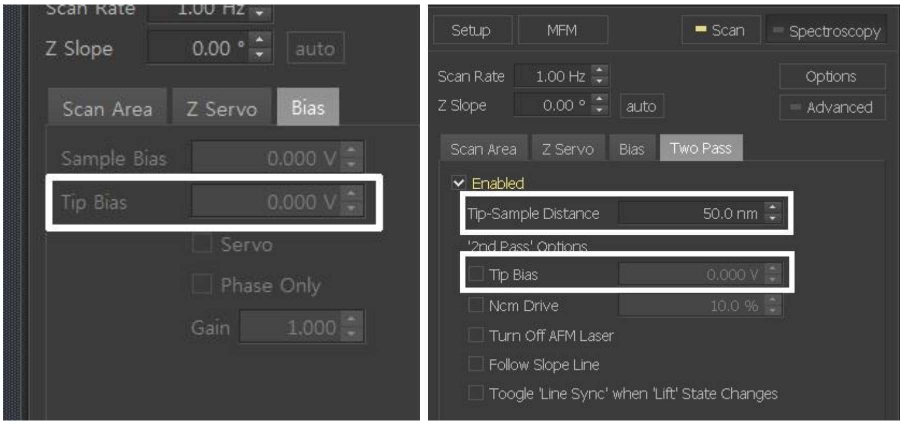
2) 'NCM Sweep' window, which is similar to the ones encountered in NC-AFM will appear. Set the cantilever's resonant frequency, set point, and drive % as it is usually done in NC-AFM.

Figure 12-9. Select the NCM Sweep



6. Figure 12-9 shows the parameter view. There are many scan control parameters, however this manual will introduce only those required for MFM mode. Please refer to the SmartScan™ manual for a description of all other scan parameters in the parameter view

Figure 12-10. Scan Control window of MFM mode



- **Tip bias**

When imaging in the MFM mode, tip automatically scans the sample surface twice.

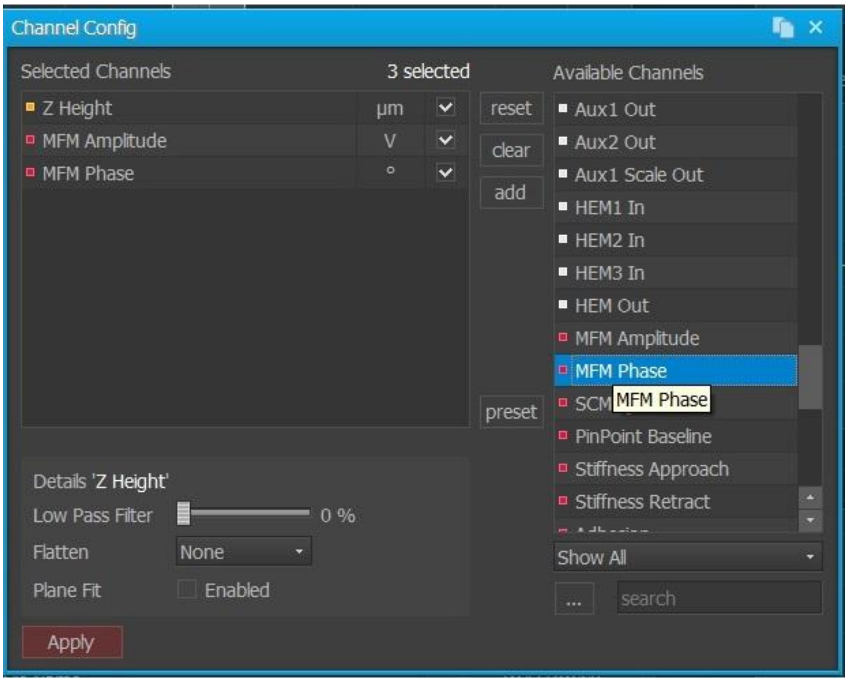
First scan is done for height image and second scan is done following the surface height line for MFM image. “Tip bias” is a voltage applied to the tip when the system performs the first scan.

- **MFM tip bias**

The MFM tip bias is a voltage applied to the tip when the system performs the second scan of the MFM mode to generate the MFM image. For some samples, according to the materials which it is made of, applying the MFM bias has effect of improving image quality.

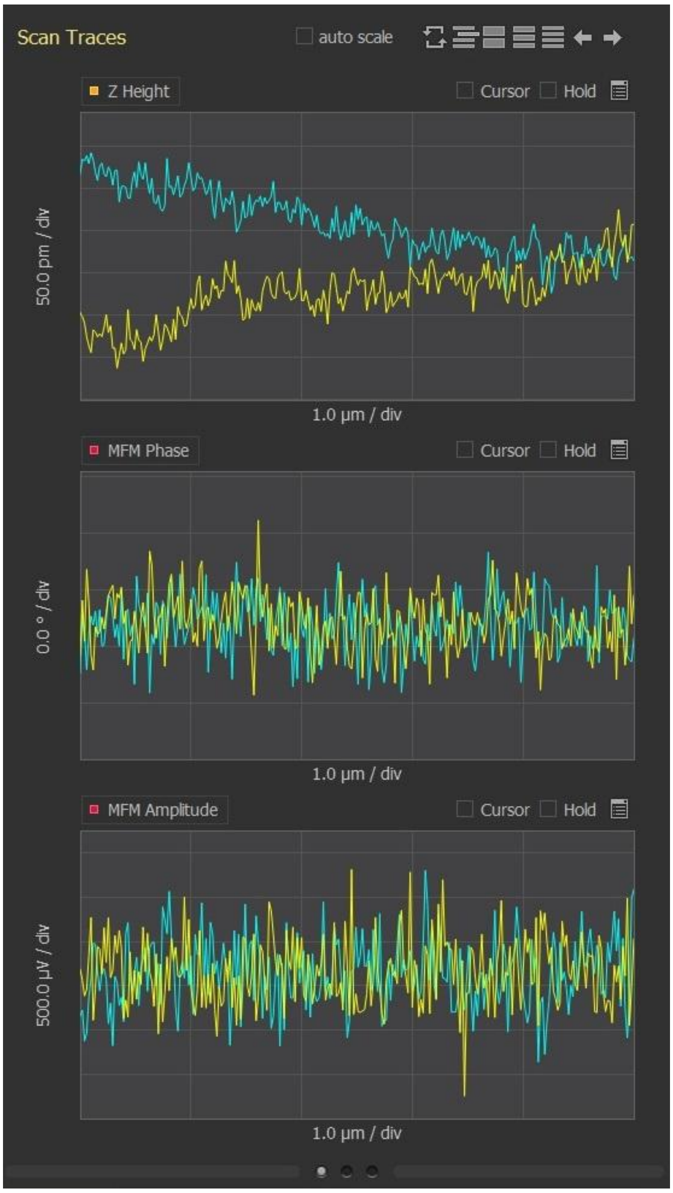
7. Select “Z Height”, “Error Signal”, “MFM Amplitude”, and “MFM Phase’” from the Input configuration window. It is possible to easily adjust settings for recommended channels by selecting MFM from presets located at the bottom of Channel Config.

Figure 12-11. Selecting the Input Signal



8. Select “Height”, “MFM Amplitude” and “MFM Phase” at the signal name list of each trace control window. Add trace control windows using the trace control icon if necessary.

Figure 12-12. Selecting the monitoring signal in trace control window



9. Approach the tip to the sample as it is done in NC-AFM. For detailed procedure, refer to the NX user's manual.

i. After the approach is made, change the scan control parameters (Scan size, Slope, Scan rate, Z servo gain, Set point) to obtain an optimal surface height trace.

ii. After getting a height image, if it is unchecked, check the "Tip-sample dist" check box. Specify the tip-sample distance by entering the value in the Tip-sample distance text field. Now the system will automatically perform the first scan to get the surface height and then the second scan will travel along the surface height line while maintaining the tip sample distance.

iii. While observing the trace line of MFM Amplitude and MFM Phase, change the “Tip-sample distance” and other scan parameters for the optimal MFM image. Adjust Tip-sample distance settings to minimize atomic force effects and find maximal MFM signal strength.

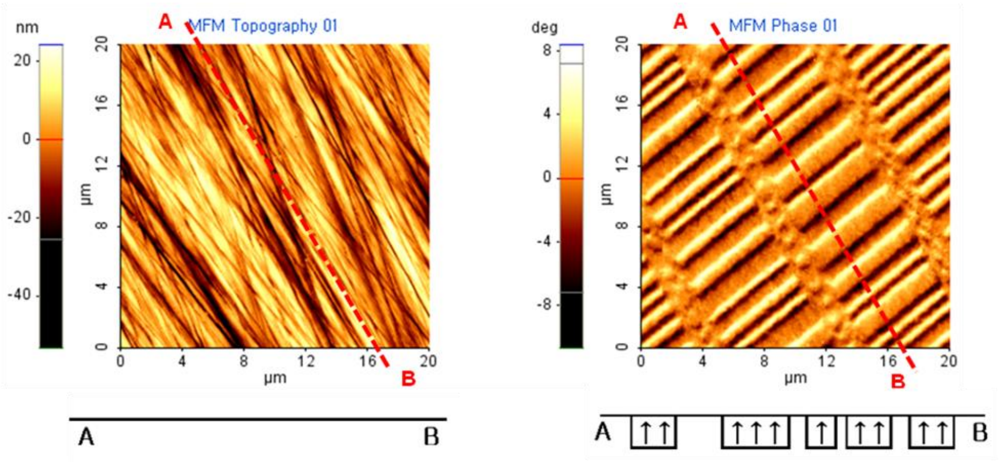
12-5. Practice

Park Systems offers a standard MFM test sample with MFM mode. Users can test their MFM and practice imaging skill by obtaining the MFM image of the standard sample and comparing it with the expected image. This section presents a typical image of a standard sample and expected result.

Standard test sample

The standard sample shown in Figure. 12-7 is a piece of hard disk glued on a sample disk. Its surface is flat a bit whereas in the same region, magnetic domains with each domain representing a single data bit are engraved. Direction of the trench and magnetic domain lines are perpendicular. The actually obtained surface height and magnetic domain of the hard disk is shown in Figure 12-12.

Figure 12-13. Surface Height and Magnetic domain of the standard sample (20µm x 20 µm scan size)



Surface Height

(a)

Magnetic Domain

(b)

12-6. Advanced Application

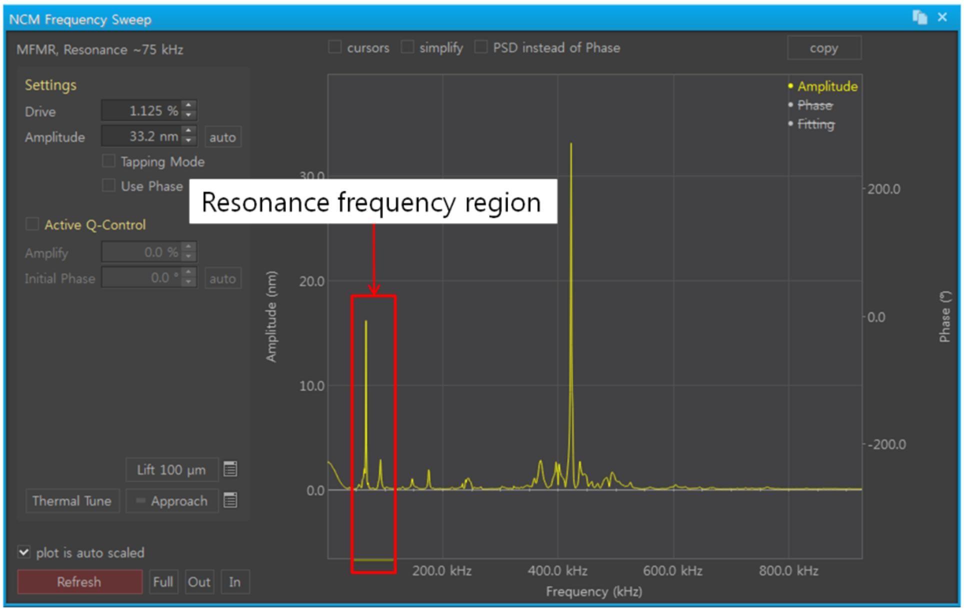
Notes on MFM Imaging

- **Adjust scan parameters to obtain good Height image**

A bad Height image indicates that the distance between the sample and the tip is not constant, and MFM signals obtained when this is the case cannot be considered reasonable data.

- **Cantilever resonance frequency**

Because MFM mode uses the resonance frequency of the selected cantilever in NCM scanning, selecting a peak outside of the cantilever's resonance frequency range can result in failure to obtain an MFM signal. If there are multiple peaks within the resonance frequency range, scan for each peak until one yields a clear signal.



MFMR, Resonance ~75 kHz

Drive 1.125 %

Amplitude 33.2 nm

☐ Tapping Mode

☐ Use Phase

☐ Active Q-Control

Amplify 0.0 %

Initial Phase 0.0 °

Lift 100 µm

☑ plot is auto scaled

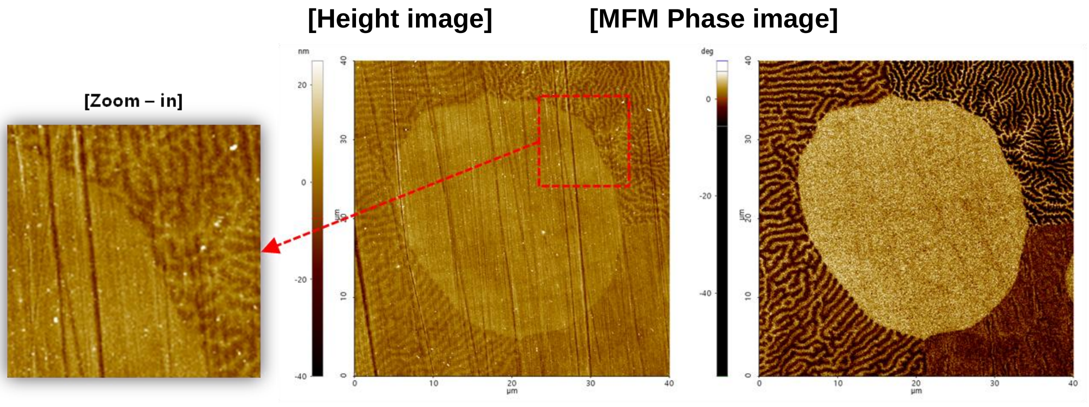
☐ cursors ☐ simplify ☐ PSD instead of Phase

Figure 12-14. PPP-MFMR NCM Frequency Sweep data

For example, Figure12-14 shows NCM Frequency Sweep results using a PPP-LM-MFMR cantilever. A high amplitude peak appears both inside the resonance frequency range and at above 350 kHz. Here, the peak within the resonance frequency range should be selected.

- **MFM Signal Interference with Height signal**

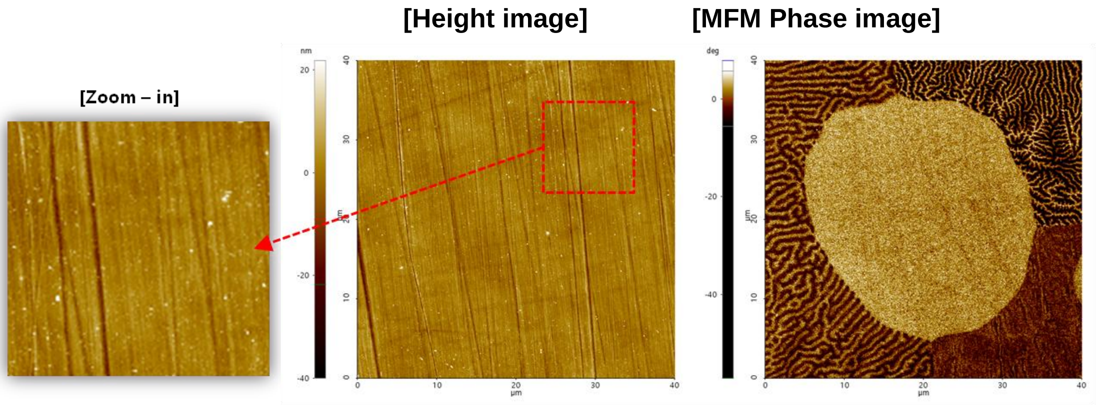
  Example



[Height image] **[MFM Phase image]**

[Zoom – in]

Figure 12-15. Example of MFM signal interference in Height image



[Height image] **[MFM Phase image]**

[Zoom – in]

Figure 12-16. Sample from Figure2, improved scan result

As illustrated in Figure 12-15, the MFM signal can interfere with the Height signal when a sample has a strong magnetic force. One way to eliminate this effect is to adjust the set point to bring tip and sample close enough for the Van der Waals force to overcome the magnetic force. Note, adjusting the set point so low that tip and sample come into contact can result in damage to either or both.

Another way to cope with a sample with a strong magnetic force is to switch out the cantilever type to match. For example, if the PPP-MFMR is producing MFM images such as that in Figure 12-15, changing the cantilever to the PPP-LM-MFMR can eliminate the effect as in Figure 12-16.

- **Height signal interference with MFM signal**

  Example

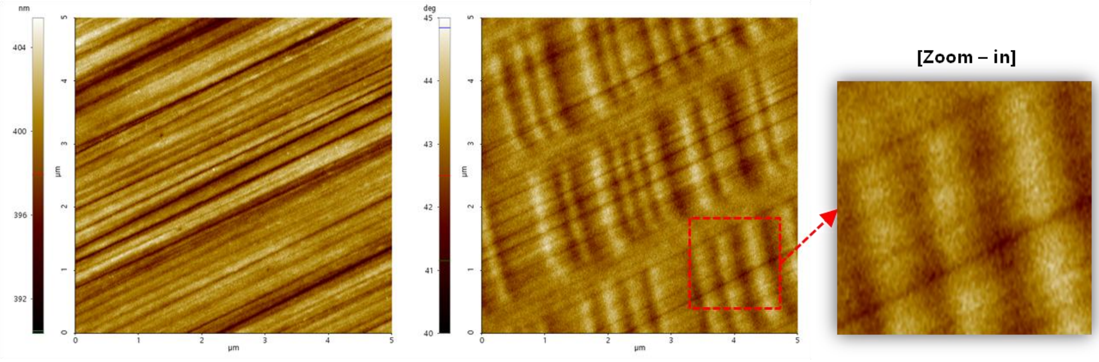

[Height image] **[MFM Phase image]**

Figure 12-17. Example of Height signal interference in MFM image

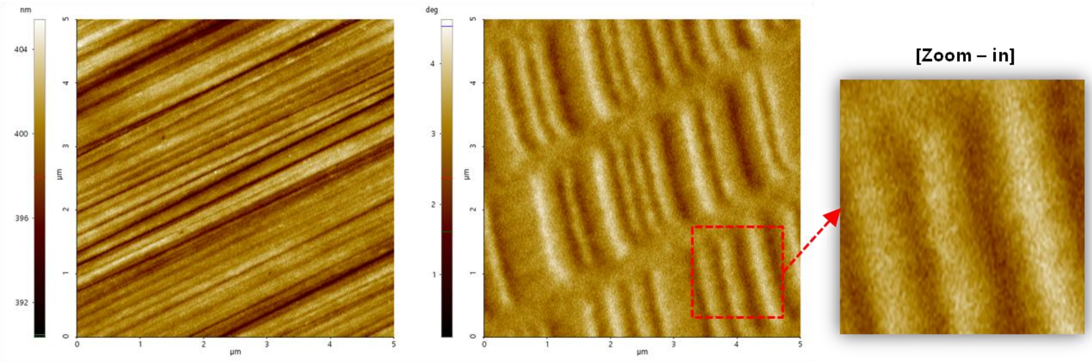

[Height image] **[MFM Phase image]**

Figure 12-18. Sample from Figure4, improved scan result

When obtaining MFM signals, the tip-sample distance is widened in order to separate magnetic and Van der Waals forces while scanning - when the two forces are not completely separated, the Height image distorts the MFM signal (as illustrated in Figure 12-17). In this instance, the tip-sample distance must be widened enough that the MFM signal is unaffected by Van der Waals forces. Completely separating the two forces results in an undistorted MFM Phase image (as in Figure 12-18).

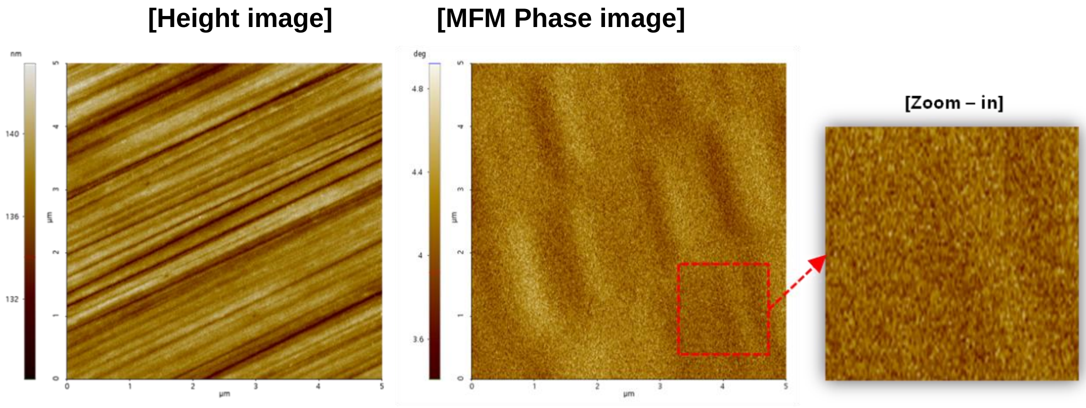


Figure 12-19. Sample with weak magnetic force

The tip-sample distance must be increased in order to prevent Height signal interference with MFM imaging (as illustrated in Figure 12-17), but there are instances when a sample's magnetic force is too weak to detect at that range (as illustrated in Figure 12-19). In this case, it is advisable to switch the cantilever to one sensitive to magnetic force. For example, if the PPP-MFMR yields blurry MFM images (as in Figure 12-19), changing the cantilever to the PPP-LC-MFMR would yield clear MFM images (as in Figure 12-18).

Chapter 13. Force Modulation Microscopy (FMM)

This document is an operating manual for FMM (Force Modulation Microscopy) mode for Park Systems' NX series SPM. FMM is used for investigating samples' mechanical properties.

During FMM measurements, the system scans the sample in contact mode while oscillating the tip. The resulting movement of the cantilever is analyzed to obtain FMM and topographic images. FMM images can provide information related to the mechanical properties of a sample, such as elasticity, adhesion force, and friction. FMM images can also distinguish variations in the composition of a sample.

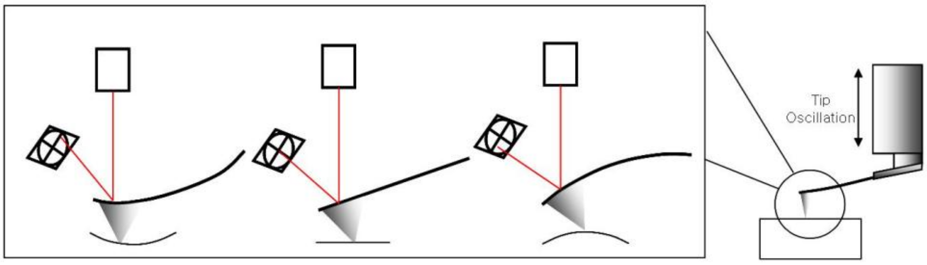
This manual describes the theory behind FMM imaging and the FMM imaging procedure. This manual assumes that you are familiar with your NX SPM system and the SmartScan™ software.

13-1. Principle of Force Modulation Microscopy

FMM operates in contact atomic force microscopy (C-AFM) mode and is used to detect variations in the mechanical properties of a surface, such as surface elasticity, adhesion, and friction.

During FMM measurements, the tip is scanned in contact with the sample surface. At the same time, the tip is oscillated in the vertical direction by a bimorph piezo at the end of probe arm. As a result, deflection of the cantilever continuously oscillates as the tip scans the surface, generating an oscillating signal at the PSPD. This oscillating deflection signal is separated into two parts, DC deflection signal and AC deflection signal.

Figure 13-1. Oscillating deflection of the cantilever



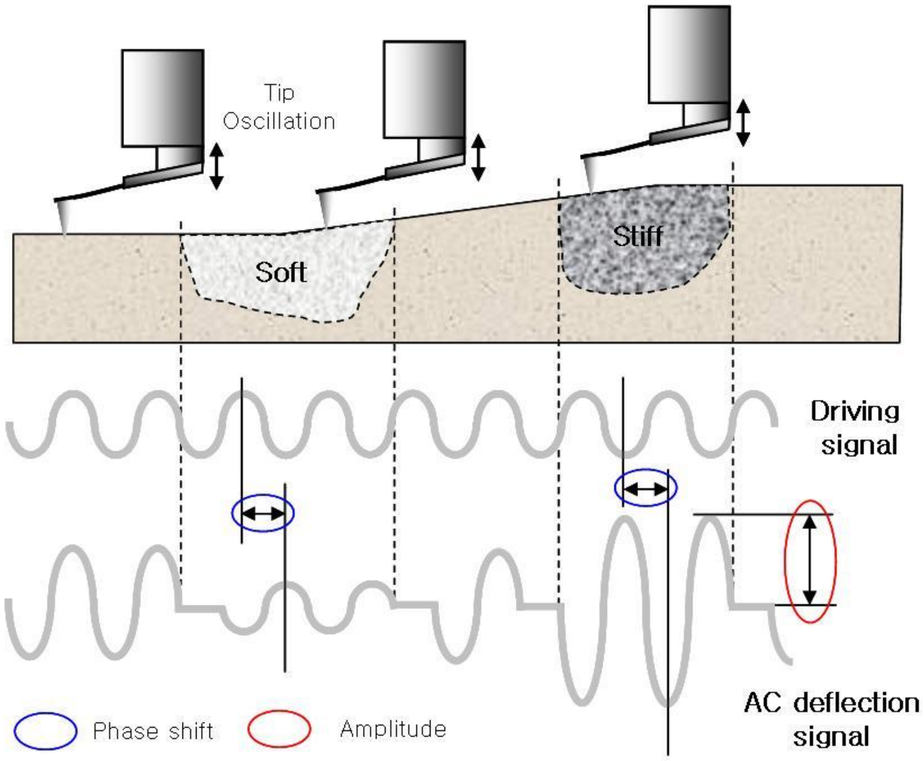
The DC deflection signal represents average deflection of the tip, which depends on the force exerted on the sample. The Z feedback loop maintains the DC deflection signal and generates a topographic image.

The AC deflection signal is analyzed in terms of FMM amplitude and FMM phase. Both signals are sensitive to elastic properties of the sample surface and are used to generate FMM images.

FMM amplitude is amplitude of tip oscillation. When the tip is oscillated in contact with the sample surface, hard sample surface reflects the oscillation, resulting in a large FMM amplitude signal. On the other hand, a soft surface will absorb the oscillation, resulting small FMM amplitude signal.

FMM phase is the phase difference between the driving signal that oscillates the bimorph and resulting AC deflection signal. Often, FMM Phase is more sensitive to the elastic properties of the surface than FMM Amplitude. Hence, FMM phase imaging provides an additional contrast mechanism within a region of homogeneous hardness.

Figure 13-2. FMM Amplitude and FMM Phase Signal



13-2. Operation

No additional NX hardware components are required for FMM imaging. Only the additional SmartScan™ software module for FMM needs to be installed to support the FMM mode. Setting up your NX SPM for FMM is same as that of the standard Contact AFM. Please refer to NX user's manual for detailed instructions about setting up the NX SPM for standard Contact AFM.

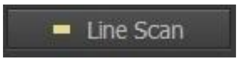
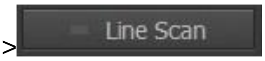
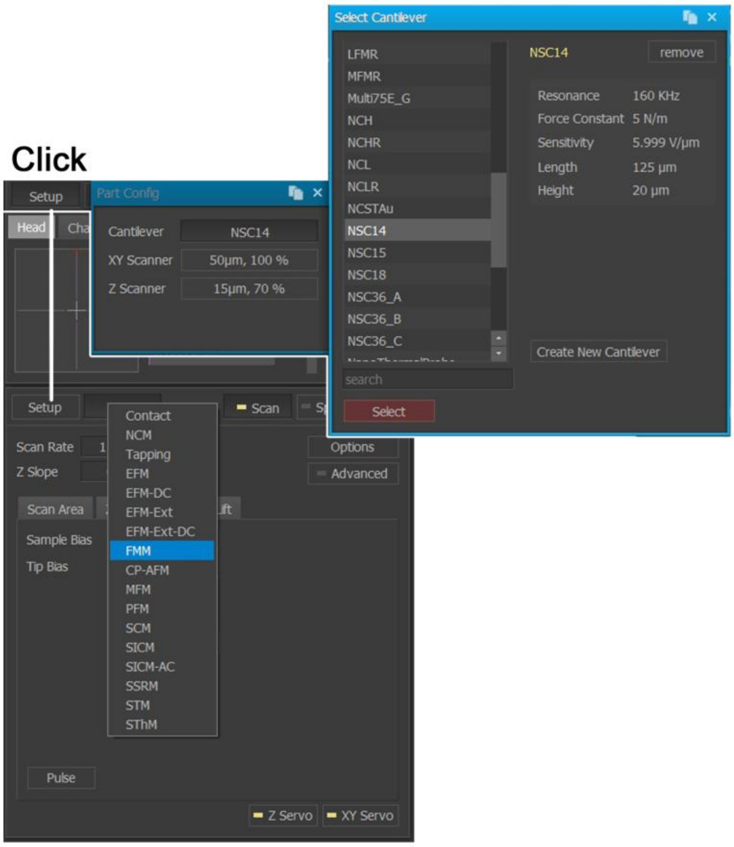
1. Mount the sample and tip and align laser on the cantilever as in C-AFM.
2. Turn off the line scan ( -> ) and Head mode by changing the order of the FMM and then proceed Setup-Select Cantilever-NSC14-Select.

Figure 13-3. Changing the Head mode and select the cantilever

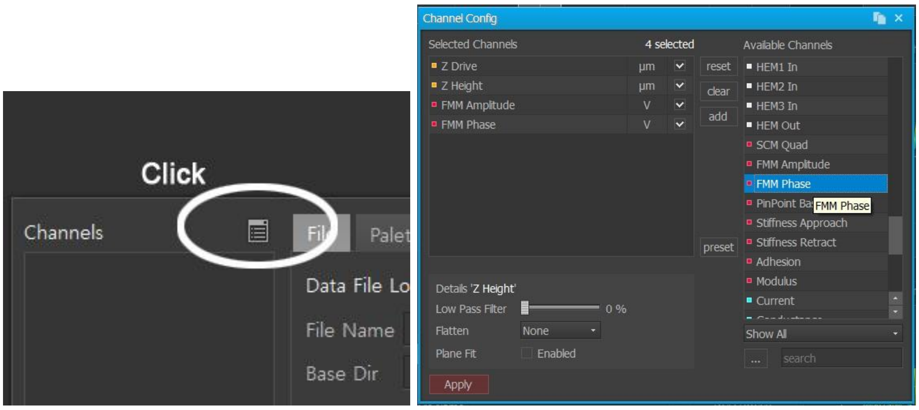


Cantilever NSC14
XY Scanner 50µm, 100 %
Z Scanner 15µm, 70 %

NSC14
Resonance 160 KHz
Force Constant 5 N/m
Sensitivity 5.999 V/µm
Length 125 µm
Height 20 µm

3. Open Input Config by selecting 'Channel Config' from the Setup menu. Select Z Drive, Z Height, FMM Amplitude, and FMM Phase input signals.

Figure 13-4. Select the Channel Config



4 selected
Z Drive µm
Z Height µm
FMM Amplitude V
FMM Phase V

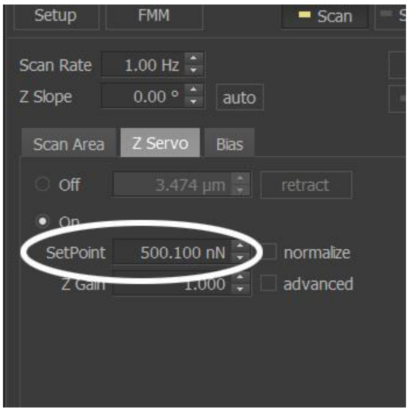
Details 'Z Height'
Low Pass Filter 0 %
Flatten None
Plane Fit ☐ Enabled

4. There are many scan control parameters in the Scan Control Window; this manual only discusses those parameters particular to FMM. For descriptions of the standard scan parameters, please refer to the SmartScan™ manual.

- **Set point**

The Set Point value for FMM is a force value. This represents the force that the cantilever is pressing down on the sample surface with. This value is maintained during the imaging. A higher value indicates a stronger force with which the cantilever presses on the sample. Too high a value will result in tip and sample damage, and too low a value may result in a weak FMM signal.

Figure 13-5. Adjust to Set point

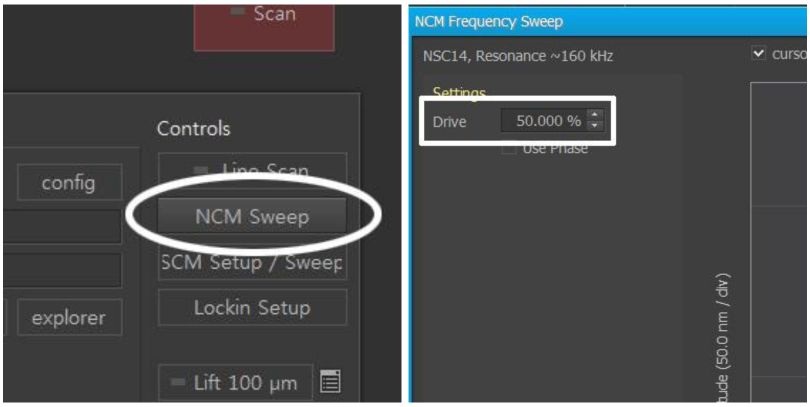


Scan Rate 1.00 Hz
Z Slope 0.00 °
3.474 µm
SetPoint 500.100 nN
Z Gain 1.000

- **Drive**

In FMM, the tip is oscillated in the Z direction. The amplitude of this oscillation is controlled by the drive. 100% indicates the maximum amplitude that the system is capable of applying. As with the Set Point, too high a value may result in damage, and too low a value may result in a weak signal.

Figure 13-6. Adjust to Drive



Drive 50.000 %

5. Set the Drive % and Scan Size to 0.

Warning

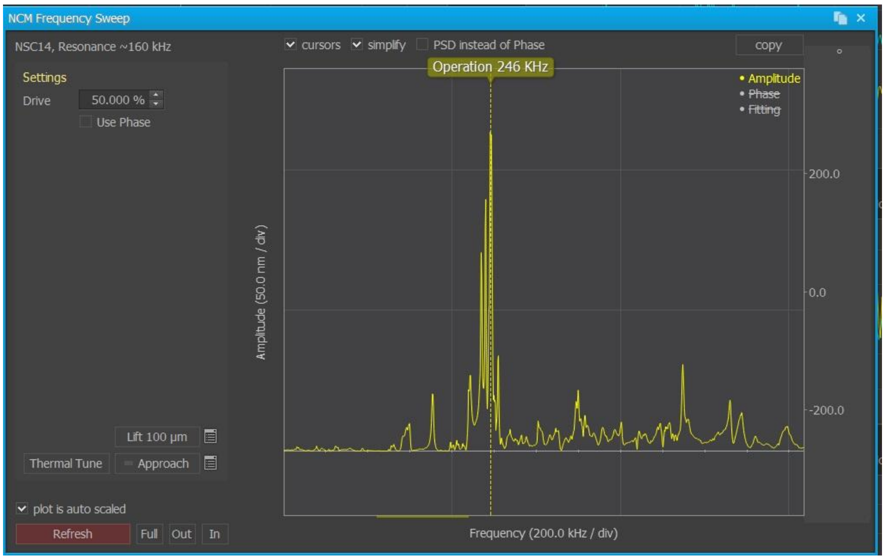
If the Drive % is not 0, you may incur tip and sample damage on Approach.

6. Approach the tip to the sample as with C-AFM.

7. Click the "Frequency sweep and set up" NCM Sweep icon. The Frequency Sweep dialog will appear.

8. Input a Drive % value, and click the Refresh button. A resonance curve will automatically be selected. If this curve is not satisfactory, you can zoom in and out, and select different resonance peaks.

Figure 13-7. NCM Frequency sweep



NCM Frequency Sweep

NSC14, Resonance ~160 kHz

Drive 50.000 %

☐ Use Phase

☑ cursors ☑ simplify ☐ PSD instead of Phase

Lift 100 µm

☑ plot is auto scaled

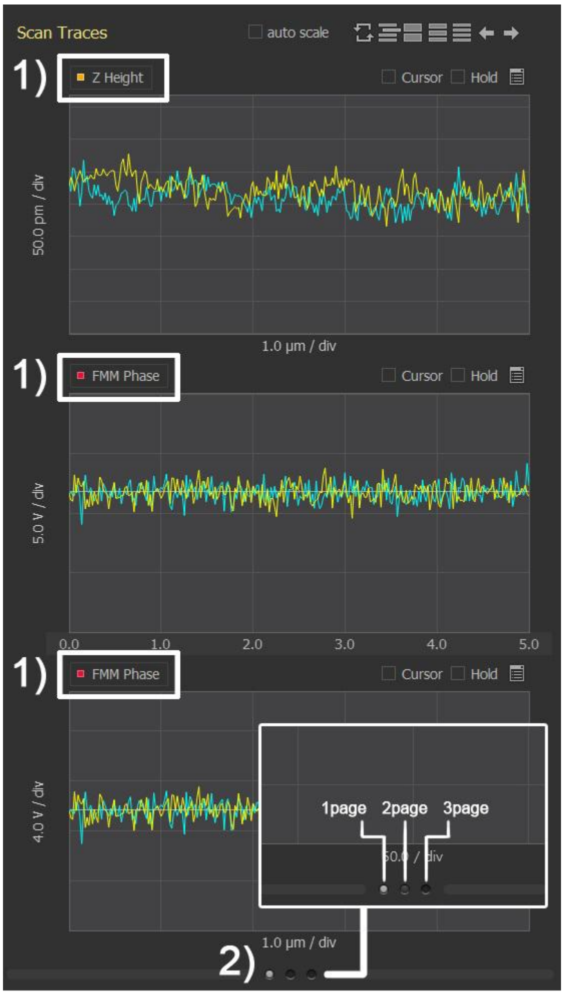
9. Modify the Drive % and selected frequency until satisfactory values are obtained.

<u>Note</u>

The drive % and drive frequency are the parameters that have greatest effect on the FMM signal. Selecting proper value of drive and drive frequency is the key to obtaining good FMM image. Normally, increasing the drive value gives higher contrast image. But if the drive value is increased too much, there can be a damage to sample surface and tip. The driving frequency must be chosen outside a resonance of the system, but high enough to generate a strong dynamic load that can sufficiently indent the sample.

10. Select "FMM Amplitude" and "FMM Phase" in 1) the trace control windows. Add trace control windows using 2) the page button. if necessary.

Figure 13-8. The trace control windows



11. Input a scan size suitable for an image scan. Change the scan control parameters (scan size, scan rate, Z servo gain, setpoint, and drive) to obtain an optimal signal trace. Click the ‘image’ button to get the FMM image.

Some Imaging tips

Contrast of the FMM signal decreases if the Z servo gain is increased.

Contrast of the FMM signal increases if the set point is increased.

Increase drive if FMM amplitude of the FMM signal is too weak.

Rubber and vinyl samples are ideal for practicing obtaining FMM images.

Chapter 14. Electrostatic Force Microscopy (EFM)

This document is an operating manual for Electrostatic Force Microscopy, one of the many application modes for the NX series SPM from Park Systems. EFM is a technique used to map electric properties on a sample surface by measuring the electrostatic force between the surface and a biased AFM cantilever. EFM images contain information about electric properties such as the surface potential and charge distribution of a sample surface.

EFM is largely distinguished as two different modes by the method which the surface morphology information is obtained. These are EFM mode and Dynamic-Contact EFM mode. In addition, EFM mode supports Scanning Kelvin Probe Microscope (SKPM). In this manual, basic principles, sample preparation, and EFM image taking for each mode is explained.

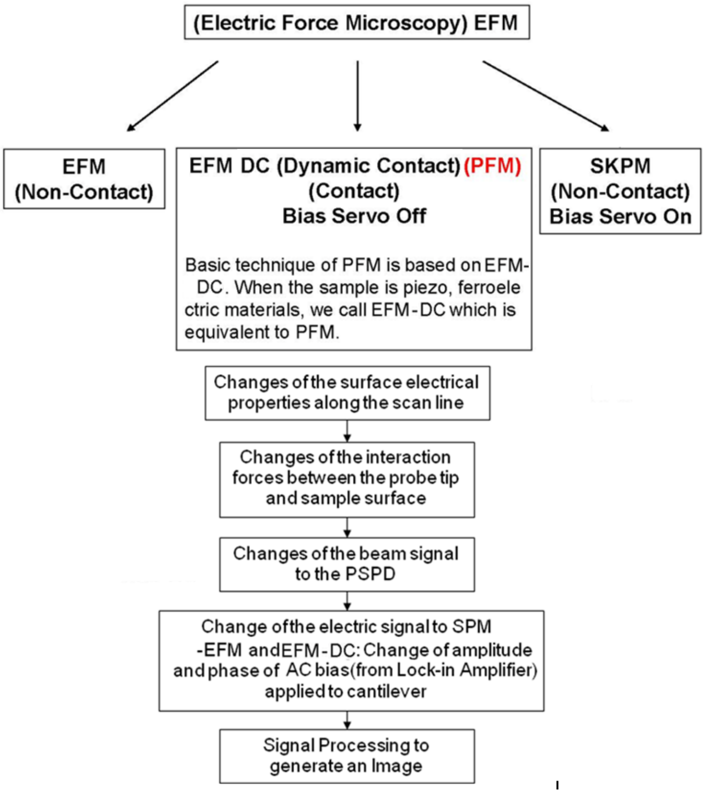
This manual assumes that you have experience taking ordinary AFM images in both contact and non-contact mode with the NX series SPM and the SmartScan™ Data Acquisition program. If not, please refer to your user’s manual for the NX series SPM and SmartScan™ software.

- EFM Applications: Localized charge distribution on the insulator layer, Ferroelectric domain, Local surface potential distribution, Variations in surface work function and so on.

14-1. Principle of Electrostatic Force Microscopy

Surface electrical property measured by EFM is acquired by the following process.

Figure 14-1. Process of the EFM imaging


(Electric Force Microscopy) EFM
EFM (Non-Contact)
EFM DC (Dynamic Contact) (PFM) (Contact) Bias Servo Off
SKPM (Non-Contact) Bias Servo On
Changes of the surface electrical properties along the scan line
Changes of the interaction forces between the probe tip and sample surface
Changes of the beam signal to the PSPD
Change of the electric signal to SPM
Signal Processing to generate an Image

Basic technique of PFM is based on EFM-DC. When the sample is piezo, ferroelectric materials, we call EFM-DC which is equivalent to PFM.

-EFM and EFM-DC: Change of amplitude and phase of AC bias (from Lock-in Amplifier) applied to cantilever

For EFM, the sample surface properties would be electrical properties and the interaction force will be the electrostatic force between the biased tip and sample.

However, in addition to the electrostatic force, the Van der Waals forces between the tip and the sample surface are always present. The magnitude of these Van der Waals forces change according to the tip-sample distance, and are therefore used to measure the surface topography.

Hence, the obtained signal contains both information of surface topography ('Height signal' in SmartScan™) and information of surface electrical property ('EFM signal' in SmartScan™) generated by the Van der Waals and electrostatic forces, respectively. The key to successful EFM imaging lies in the separation of the EFM signal from the entire signal. To separate the EFM signal, Park Systems EFM uses the Lock-in Amplifier imbedded internally in NX electronics.

In EFM, a Lock-in Amplifier is used for two purposes. One purpose is to apply AC bias of frequency ω, in addition to the DC bias applied by the NX controller, to the tip. The other purpose is to separate the frequency ω component from a whole output signal.

In the EFM, the voltage between the tip and the sample can be expressed by the following equation:

$$V(t) = V_{dc} - V_s + V_{ac}\sin(\omega t) \qquad \textbf{(1)}$$

Where V_{dc} is the DC offset potential, V_s is the surface potential on the sample and V_{ac} and ω is the amplitude and frequency of the applied AC voltage signal, respectively.

Equation 1 is appropriate if the geometry of the tip and sample can be approximate using two parallel plates. Other geometries can be assumed as well. Equation 2 can be used to derive an expression for the electrostatic force between the tip and the sample: (Again, parallel-plate geometry is assumed.)

$$F = q \times E = q \times V/d = C \times V^2/d \qquad \textbf{(2)}$$

$$F(t) = (C/d) \times V(t)^2$$

$$= (C/d) \times [(V_{dc} - V_s)^2 + \frac{1}{2}V_{ac}{}^2] \qquad \textbf{(a)}$$

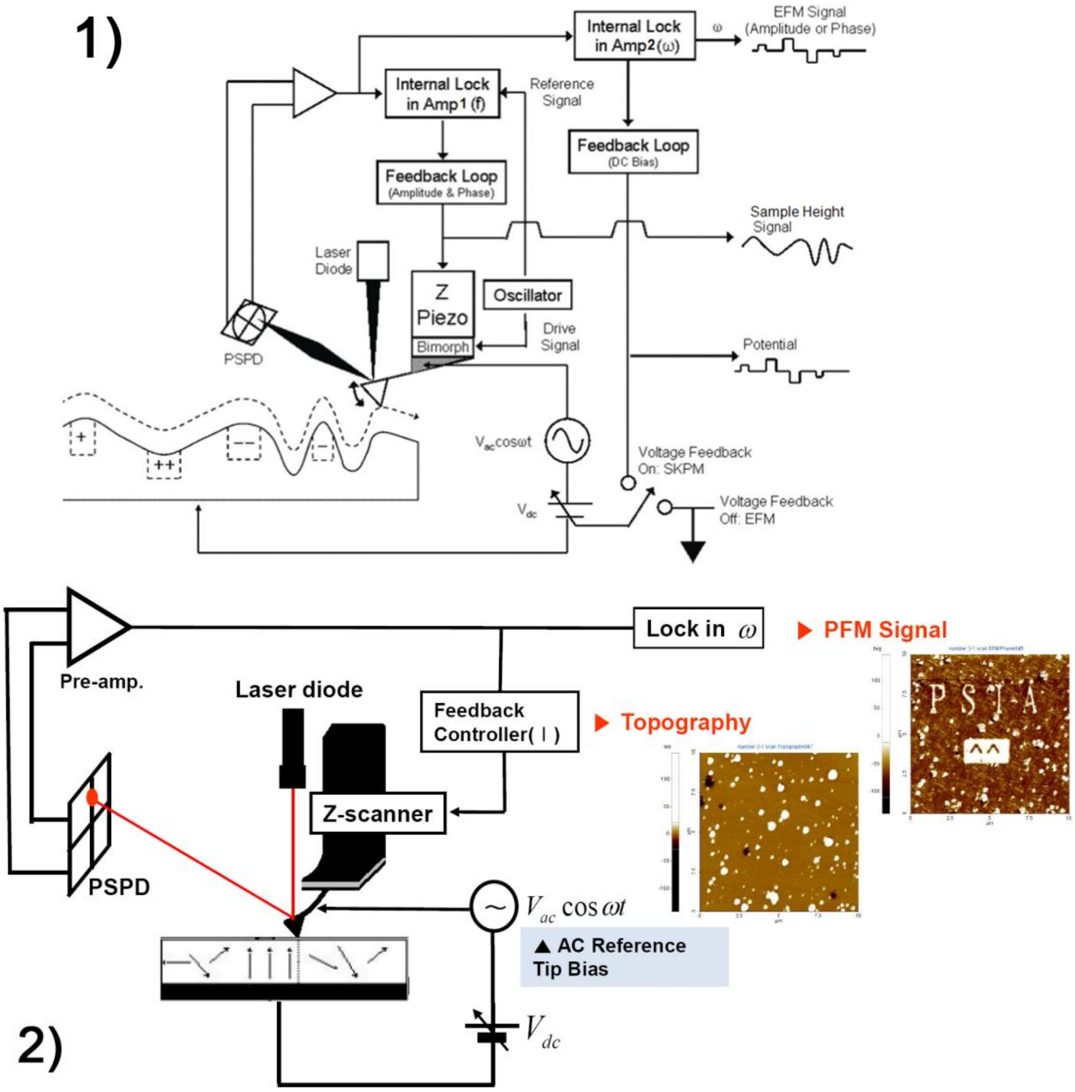
$$+ 2 \times (C/d) \times (V_{dc} - V_s) \times V_{ac}\sin(\omega t) \qquad \textbf{(b)}$$

$$-\frac{1}{2}(C/d) \times V_{ac}{}^2\cos(2\omega t) \qquad \textbf{(c)}$$

Here, F is electrostatic force applied to the tip, q is charge, E is electric field, V is electric potential, C is capacitance, and d is tip to sample spacing. Note that since both AC and DC bias are applied between the tip and the sample, three terms arise in the expression for the force between the tip and the sample. These terms can be referred to as the DC term (a), the ω term (b), and the 2ω term (c), respectively.

The ω and 2ω term contains the electrostatic properties and the capacitive properties of the sample, respectively. Lock-in Amplifier can separate the certain frequency term from the signal. However, change of the signal with a frequency of 2ω is too small to detect and it is hard to detect the capacitive properties of the sample through EFM, and the part of the signal with a frequency of ω is only read through internal Lock-in Amplifier.

Figure 14-2. Diagram of 1) EFM, 2) EFM-DC (PFM)



Images can be generated from any of the above-mentioned signals. Analysis of an image involves understanding the contributions to the signal used to generate the image.

1. EFM

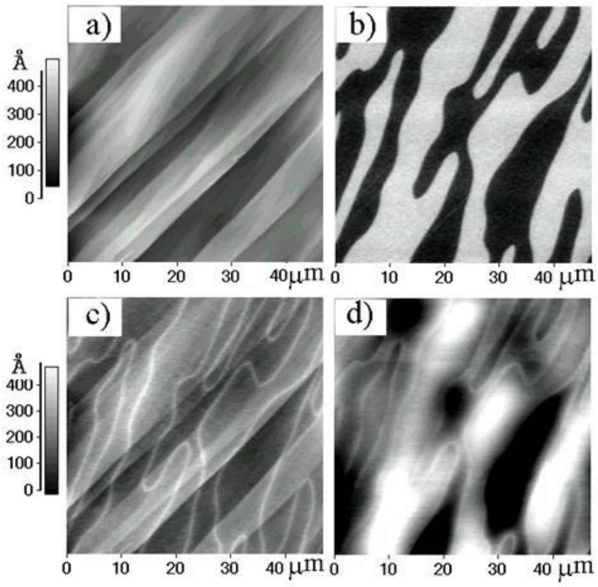
EFM is a mode that operates in Non-Contact mode. In the EFM, tip scans over the surface while oscillating in frequency to obtain the non contact AFM topography image. At the same time, AC bias of frequency ω is applied to the tip via Lock in Amplifier 2. This results the force between the AC biased tip and charged surface. Using the Lock in Amplifier, signal resulting from the tip's motion by the force can be decomposed and analyzed into DC part and frequency ω part. ω part of the signal contains information of surface charge, . and 2ω part of the signal contains information of the gradient of surface capacitance between the tip and the sample (dC/dz). The frequency ω is chosen to be smaller(14~17kHz recommended) enough than the cantilever oscillation frequency(70~330 kHz), so that the two signals do not interfere each other.

2. EFM-DC (Dynamic Contact EFM)

EFM-DC is a mode that operates in Contact mode. EFM-DC uses same method as EFM but is operated in contact mode to give the more improved spatial resolution and clear detection. Figure 14-3. makes the comparison of surface height and surface charge image of TGS single crystal by EFM-DC (upper) and conventional EFM (lower). Image taken by conventional EFM shows strong coupling of the topography to the image while the image taken.

Basic technique of PFM is based on EFM-DC. When the sample is piezo, ferroelectric materials, EFM-DC is equivalent to PFM.

Figure 14-3. (a) Surface height, (b) Surface charge image of TGS single crystal by EFM-DC, (c) Surface height, (d) Surface charge image by conventional EFM

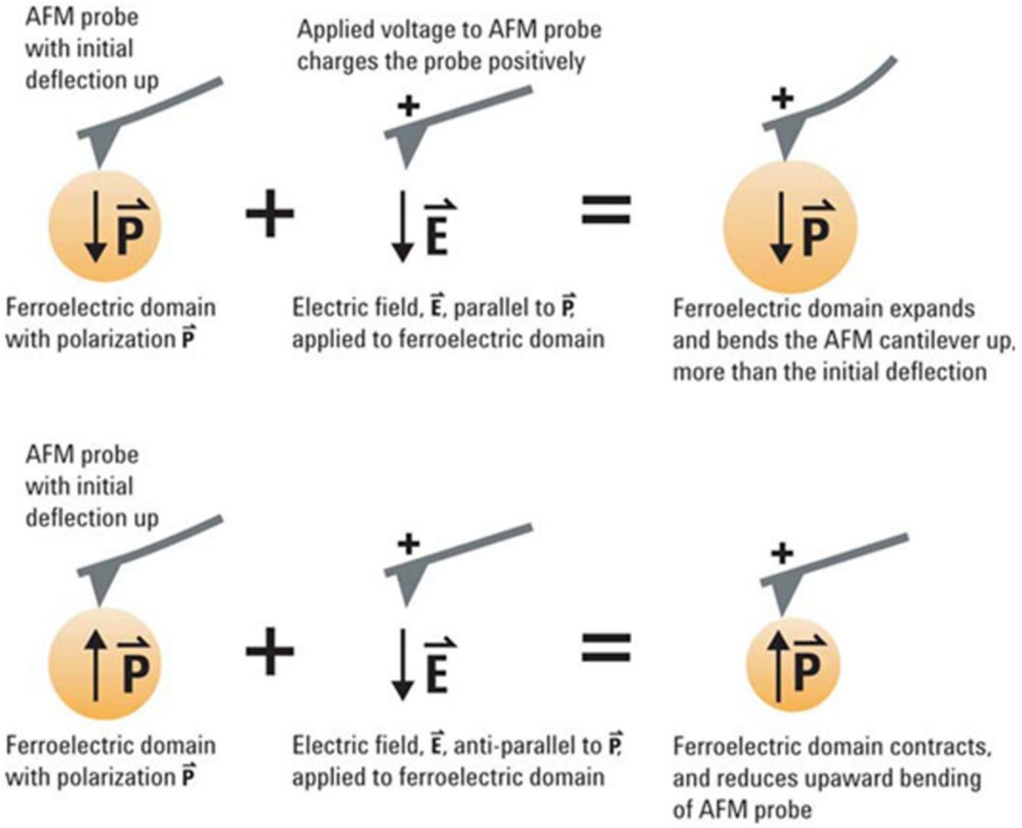


Surface Height **Surface Charge**

3. PFM (Piezoelectric Force Microscopy)

PFM is to obtain characteristics of material in piezoelectric property. Materials which contain ferro-electricity can be determined the distribution of intrinsic remnant polarization by scanning 2D image. Also, size and direction of polarization can be estimated at one point by spectroscopy. In addition, **Reverse Piezoelectric Effect** (the internal generation of a mechanical force resulting from an applied electrical field) of piezoelectric materials can be measured. To observe a response of reverse piezoelectric effect more effectively, we recommend AC bias method by internal lock-in2.

In PFM operation, a conductive AFM tip is brought into contact with the surface of the studied ferroelectric or piezoelectric materials, and a pre-set voltage is applied between the sample surface and the AFM tip, establishing an external electric field within the sample. Due to the electrostriction, or “inversed piezoelectric” effects of such ferroelectric or piezoelectric materials, the sample would locally expand or contract according to the electric field. For example, if the initial polarization of the electrical domain of the measured sample is perpendicular to the sample surface, and parallel to the applied electric field, the domains would experience a vertical expansion. Since the AFM tip is in contact with the sample surface, such domain expansion would bend the AFM cantilever upwards, and result in an increased deflection compared to the status before applying the electric field. Conversely, if the initial domain polarization is anti-parallel to the applied electric field, the domain would contract and in turn result in a decreased cantilever deflection (Figure 1). The amount of cantilever deflection change, in such situation, is directly related to the amount of expansion or contraction of the sample electric domains, and hence proportional to the applied electric field.


AFM probe with initial deflection up
Applied voltage to AFM probe charges the probe positively
+
P
+
E
=
+
P
Ferroelectric domain with polarization P
Electric field, E, parallel to P, applied to ferroelectric domain
Ferroelectric domain expands and bends the AFM cantilever up, more than the initial deflection
AFM probe with initial deflection up
+
P
+
E
=
+
P
Ferroelectric domain with polarization P
Electric field, E, anti-parallel to P, applied to ferroelectric domain
Ferroelectric domain contracts, and reduces upaward bending of AFM probe

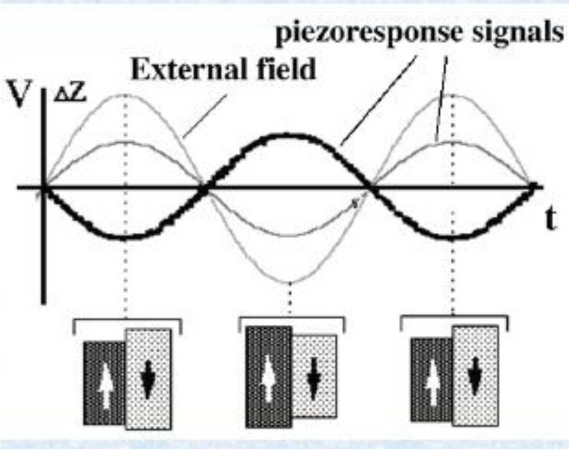
If the applied voltage contains a small AC component, the inversed piezoelectric response from the sample would result in sample surface oscillation in the same frequency as the applied AC voltage. In the case that the sample is an ideal piezoelectric crystal, its polarization $\vec{P}$ would be related to applied mechanical stress $\vec{s}$ by the following equation:

$$P_i = d_{ijk}\sigma_{jk},$$

in which d_{ijk} is the rank-3 peizoelectric tensor of the material. For such materials with tetragonal crystal structures, this piezoelectric tensor can be reduced to the following form:

$$\begin{pmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{pmatrix}$$

in which case, under the applied AC modulation voltage $V = V_0 cos(\omega t)$, sample surface vibration would take the form $\Delta Z = \Delta Z_0 cos(\omega t + \varphi)$, with the vibration amplitude $\Delta Z_0 = d_{33} V_0$, and phase $\varphi = 0$ if the sample domain polarization is oriented parallel to the applied electric field, and out of $\varphi = 180°$ if it is oriented anti-parallel to the applied electric field (Figure 2). Such oscillation would be directly reflected in the amplitude and phase signal of the AFM probe contacting the surface, and can be read out using a lock-in amplifier.



In typical PFM imaging, the applied AC voltage is set to be much lower than the coercive bias for sample domain switching, to avoid alternation of the local domain structure of the studied sample. If such criterion is met, the phase contrast generated in PFM imaging would reflect the domain polarity in different sample locations, while from the magnitude of the amplitude signal local piezocoefficient of the sample can be extracted, as discussed in the former paragraph.

For more complicated sample domain orientation containing not only components perpendicular to the surface in contact with the AFM tip, but also components along different directions within the surface plane, vector PFM with one vertical and two lateral channels can provide more complete information. For example, to obtain the d_{15} component of the piezoelectric tensor in tetragonal piezoelectric crystals, we need to measure lateral components of AFM tip vibration proportional to the in-plane sample surface displacement (Figure 6), which would take the form would take the form $\Delta L = \Delta L_0 cos(\omega t + \varphi)$, with the vibration amplitude $\Delta L_0 = d_{15} V_0$ Notice if a DC bias is applied between the tip and the sample in conjunction with the AC voltage, both the in-plane and out-of-plane electromechanical response of the sample are also functions of this applied DC voltage.

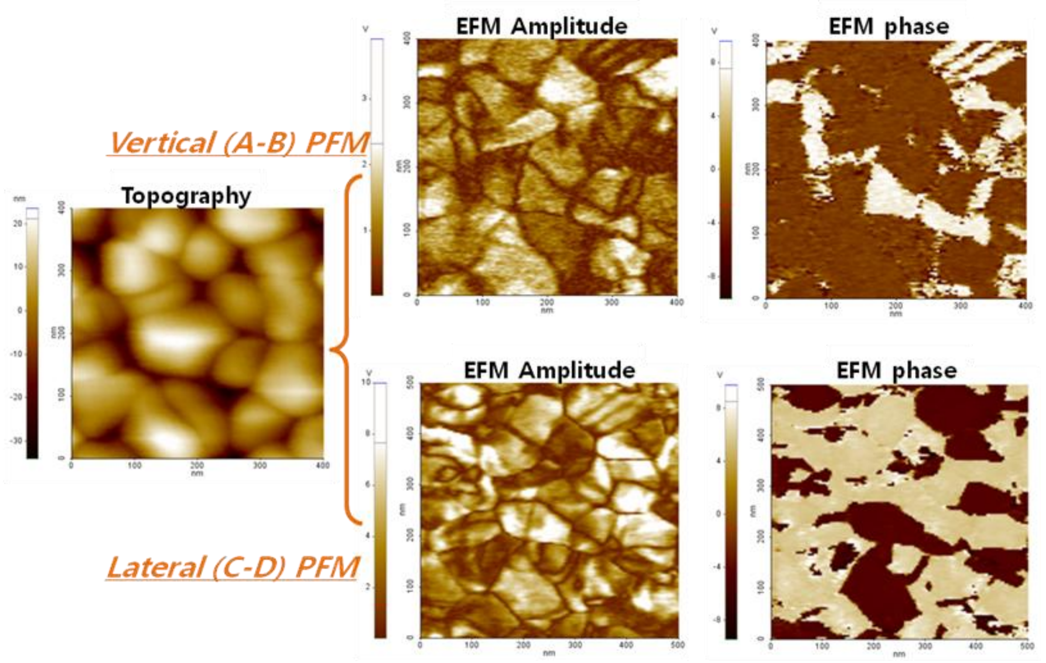


Figure 6. The in-plane sample surface displacement

In most of the real cases, the studied sample contains random-oriented polycrystalline grain structure, often with non-zero lateral components in its piezoelectric tensor. In this case, the detected vertical PFM signal is no longer only proportional to d_{33}, but also dependent on the d_{31} and d_{15} components. E.g., the vertical PFM amplitude would no longer be $\Delta Z_0 = d_{33} V_0$; instead, it would take the form

$$\Delta Z_0 = d_{zz} V_0 = [(d_{31} + d_{15}) sin^2\theta cos\theta + d_{33} cos^3\theta] V_0$$

in which θ is part of the local orientation map (θ, ϕ, ψ) between the lab coordinate system and the crystal coordinate system of the sample. Nevertheless, if both the vertical and two lateral components of PFM signal are obtained on the sample location, either the intrinsic sample piezoelectric constants d_{ij} or the local orientation map (θ, ϕ, ψ) can be extracted from such data. In a word, 3D PFM has opened the possibility of a complete 3D reconstruction of the polarization vector of the studied sample at nanometer scale.

4. Scanning Kelvin Probe Microscopy (SKPM)

As presented in previous section, the ω signal from Lock-in Amplifier can be expressed as following equation.

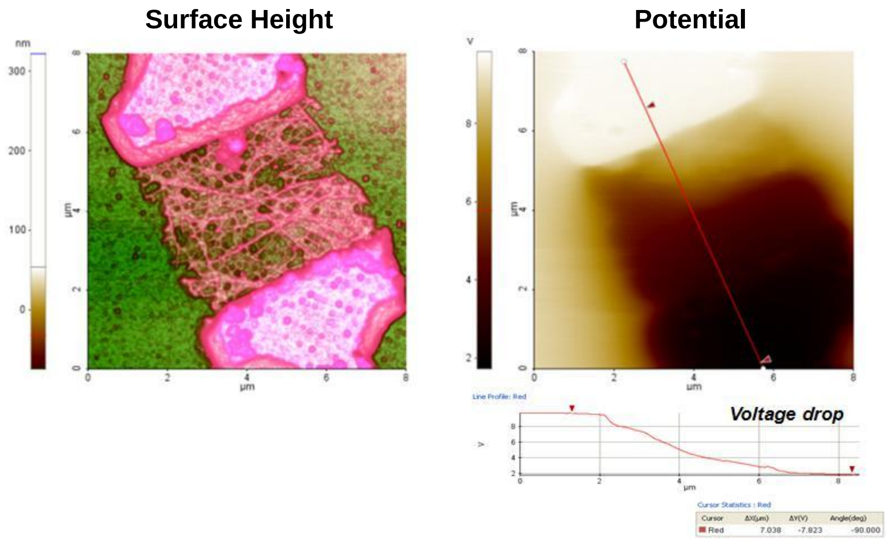
$$2 \times (C/d) \times (V_{dc} - V_s) \times V_{ac} \sin(\omega t)$$

From the same configuration of the EFM, this ω signal is related with the electrostatic properties of the sample. The ω signal goes to zero when $V_{dc} = V_s$ in the equation, or the DC bias applied to the cantilever is equal to the surface potential. Using the way,

NX series SKPM measures the surface potential. The DC bias applied to the cantilever is controlled and acquired so that the ω signal from Lock-in Amplifier is maintained to zero during the imaging. In other words, by reading the ω signal from the Lock-in Amplifier and feeding back the signal to V_{dc}, the surface potential map is acquired from the feedback signal, V_{dc}.

Figure 14-4 shows the 2D image of the potential distribution of Nanowire Bundle between electrodes.

Figure 14-4. (Left)Surface Height, (Right)Surface Potential



Surface Height

Potential

Cursor	ΔX(μm)	ΔY(V)	Angle(deg)
🟥 Red	7.038	-7.823	-90.000

14-2. Setup

1. Devices

Set up your NX system as you would for the ordinary Contact/Non Contact AFM. For detailed instructions, refer to your NX user’s manual.

Caution!

You must set 0V for AC Amplitude before tip approaches to sample. After approach, set the AC Amplitude to 0~3V range. Otherwise, tip can be damaged during approach process.

Note!

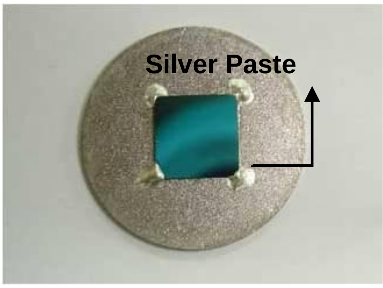
To obtain the highest quality EFM images, be sure to familiarize yourself with the operation of the Lock-in Amplifier you are using.

2. Preparing the Tip and Sample

Sample

1. Attach the sample to the sample disk by using an electro-conductive adhesive such as silver paste.
2. Mount the sample disk on the magnetic sample holder.

Figure 14-5. Sample Preparation



Tips!

Sample bias will be applied through the sample holder and can be controlled by changing the 'Sample bias' value in the SmartScan software. Setting the sample bias value to zero will have same effect as grounding the sample. But if needed, connect the ground wire or the proper external voltage line to the sample.

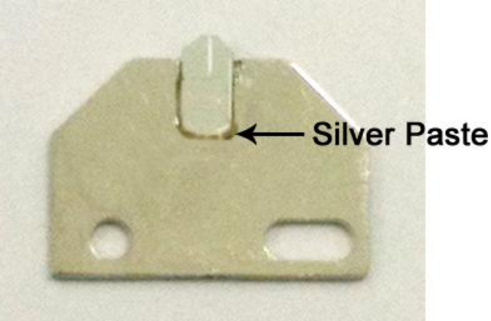
If you have connected the ground wire or external voltage line to the sample, connect the other end of the wire or line to the proper grounding or voltage source, respectively. Any conducting part on the SPM body or the acoustic enclosure bolts can be used as grounding.

Cantilever Tip

You must use conductive tip for the EFM measurement. If you use the metal chip carrier to hold cantilever tip, please follow the steps below.

1. Attach the cantilever chip to the chip carrier using adhesive.
2. Connect them electrically by an electro-conductive adhesive such as silver paste. You can check if they are electrically connected with multi-meter.

Figure 14-6. Cantilever Preparation



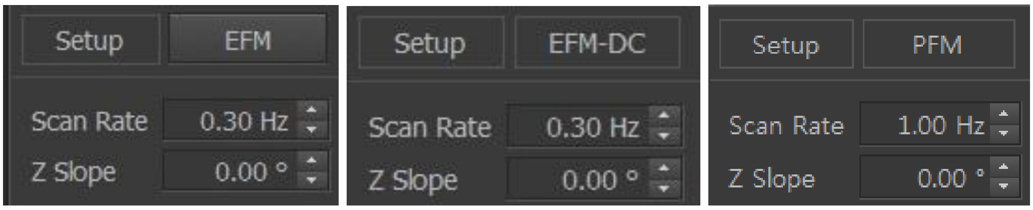
14-3. Software UI

The EFM modes can be classified by the method to acquire the sample height and result some difference in software UI. Please note that to improve the product, software UI can be changed without notice.

1. Scan Control Window UI

Figure 14-7 shows the Scan control window for the EFM mode in Non-contact mode base(Left) and in Contact mode base(Right). There are many scan control parameters, but in this section, only the parameters which are introduced in EFM modes are explained. Please refer to the SmartScan™ manual for all other scanning parameters.

Figure 14-7. Scan Control Window (Left: EFM, Center: EFM-DC, Right: PFM)



Scan Rate 0.30 Hz
Z Slope 0.00 °

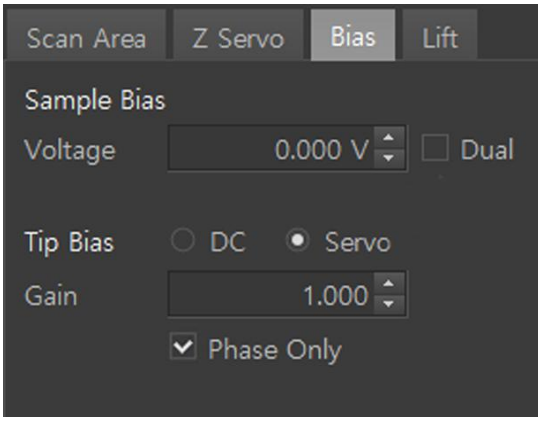
Scan Rate 0.30 Hz
Z Slope 0.00 °

Scan Rate 1.00 Hz
Z Slope 0.00 °

■ Tip Bias Servo

Checking the Tip Bias Servo enables feedback control of the potential difference between the tip and the sample by adjusting the tip bias. When the tip bias servo is on, the system adjusts the tip bias to minimize the difference in potential between tip and sample. **Please check this option only in SKPM.** Checking Tip bias servo, Gain is activated to can changing the tip bias servo gain. Tip bias is a voltage applied to the tip. In two pass scan option, this tip bias value is to apply the tip bias only in first scan. Since the effect of electrostatic force needs to be minimized in first scan, tip bias is generally set to zero.

Figure 14-8. Tip Bias Servo



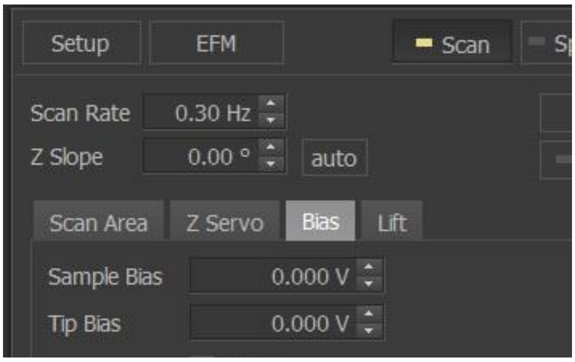
Sample Bias
Voltage 0.000 V ☐ Dual
Tip Bias ○ DC ● Servo
Gain 1.000
☑ Phase Only

■ Tip Bias Servo Gain

The Tip Bias Servo Gain controls the sensitivity of SKPM feedback control. As this value is higher, the SKPM feedback will be better and the trace/retrace signal of Potential will be matched better. However, if this value is too high, the noise can be shown at Potential signal on the trace window such as Z servo gain parameter in NCM. Tip bias servo gain is recommended to set less than '1' as usual.

■ EFM tip bias

Figure 14-9. Tip Bias



Scan Rate 0.30 Hz
Z Slope 0.00 °
Sample Bias 0.000 V
Tip Bias 0.000 V

EFM tip bias is a voltage applied to the tip when the system performs the second scan to get the EFM image. It is activated when Tip-sample distance is checked. EFM tip bias is a voltage applied to the tip when the system performs the second scan of the EFM mode to get the EFM image.

3. Signals

- EFM Signals

Height	Sample surface morphology
EFM Amplitude	Magnitude of electric force from potential difference. SKPM feedback system works to keep the (EFM Amplitude+EFM phase) signal zero.
EFM Phase	Polarity of electric force from potential difference. SKPM feedback system works to keep the (EFM Amplitude+EFM phase) signal zero as default. If you select 'Phase only' option, the EFM Phase will be only considered for SKPM feedback loop.
SKPM Potential	SKPM Potential on the sample surface.

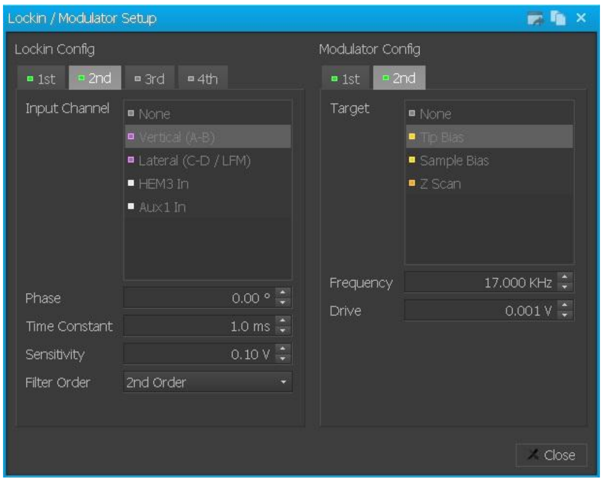
-PFM Signals

Z Height	Sample surface morphology
PFM Amplitude	Magnitude of electric force from potential difference. SKPM feedback system works to keep the (PFM Amplitude+PFM phase) signal zero.
PFM Phase	Polarity of electric force from potential difference. SKPM feedback system works to keep the (PFM Amplitude+PFM phase) signal zero as default. If you select ‘Phase only’ option, the PFM Phase will be only considered for SKPM feedback loop.
PFM Quad	Quadrature Signal of Lock in 2

3. Lock-in Setup Window UI

Figure 14-10 shows the Lock-in Setup Window, displayed when [View->Lock-in Setup Window] on the Menus is selected.

Figure 14-10. Lock-in Window



Phase 0.00 °
Time Constant 1.0 ms
Sensitivity 0.10 V
Filter Order 2nd Order
Frequency 17.000 KHz
Drive 0.001 V

3-1. Lockin Config

There is an independent lock-in channel for each lock-in(1/2/3/4)

- 1st: For NCM Feedback
- 2nd: For Optional Mode Feedback or Monitoring
- 3rd, 4th: Reserved For Later Use

■ Input Channel

Choose the Input Channel. Currently the A-B(AC), LFM (AC), HEM1, HEM2, HEM3, AUX1, AUX2, AUX3 and None are available. However, the operation mode may select the source for Lock-in automatically..

- Source for Lock-in 1: ‘A-B’ and ‘None’ automatically selected in EFM and SCM and EFM-DC, respectively.
- Source for Lock-in 2: ‘A-B’ and ‘HEM3’ automatically selected in EFM modes and SCM, respectively.

■ Phase

When modulating the signal, its phase becomes the reference phase value as a default. This reference phase is shifted so as to choose your preferred phase value by controlling this [Phase] value. The Phase can be controlled from -180 degrees to 180 degrees in 0.01 resolution and one should monitor the Output phase signal (SCM phase in SCM mode and EFM phase in EFM mode) value to receive the optimal value.

■ Time Constant

Set time constant on internal Lockin post filter which is a kind of ‘low pass filter’. Therefore, the filter order is set to ‘None’, and the time constant value will not contribute the signal since the low pass filter is not applied. It is recommended to set approximately 1~3msec for the time constant to acquire the available signal with 0.2~1Hz. As the time constant value increases, the output signal is smoother. If it increases too much the signal may become blurry. To avoid this, be monitoring/setting the output signal at all times.

■ Sensitivity

The output signal coming from interaction between the tip and sample is amplified, divided by same amplified amount to avoid the underflow of measuring signal, and finally displayed on the trace window in SmartScan. As this amplified amount called as ‘Output Gain’ increases, the maximum detectable bias decreases since the detectable bias in NX series is fixed(-10~10V). To know the maximum detectable bias directly and the amplified amount, it suggests to adjust the ‘Sensitivity’ which is 10V/’Output Gain’. For example, one adjusts ‘Sensitivity’ from 0.1V to 10V, the maximum detectable bias changes from 0.1V to 10V but the Output Gain decreases from 100 to 1. Please note that ‘Sensitivity’ is set too low, the detected signal can become too noisy.

Guideline for Sensitivity Setting			
Raw Signal Level	100uV ~ 1mV	1mV ~ 10mV	Higher than10mV
Sensitivity	0.1~1V	1 ~ 10V	10V

■ **Filter Order**

Set the filter order(in other words, rate of 'frequency roll off') on internal Lockin post filter which is a kind of 'low pass filter'. Currently, one among 'None', '1' and '2' is selectable. When 'None' is selected, the low pass filter is not applied. As increasing the filter order steeper attenuates higher frequencies than cut off frequency, and can cause the output signal smoother.

3-2. Modulator Config

There is an independent Modulator channel for each Modulator (1/2)

- 1st: For NCM Feedback
- 2nd: For Optional Mode Feedback or Monitoring

■ **Target**

Choose the desired channel for modulation. The selectable channels depend on the lock-in channel and the measurement head mode may select the Target automatically.

- Target Control Source for Lock-in 1: Selectable between 'NCM Modulator' or 'Off'. 'Off' is automatically selected in contact based modes such as SCM, EFM-DC.
- Target Source for Lock-in 2: Selectable various control sources such as 'Tip Bias', 'Sample Bias', 'Z Scan' and 'Off'.
  The Tip Bias is automatically selected in EFM modes. The Sample Bias in SCM and lastly the Z Scanner (SCAN) in the SICM (AC).

■ **Frequency**

Frequency for modulation and source to Lockin amplifier is selectable. In case of EFM, in order to differentiate the NCM, you must select the frequency lower than one in NCM modulation (generally, (100-300 kHz) used for NCM modulation). Also, the SCM uses the radio frequency(MHz) for sensing the capacitance.

Therefore, around 17 kHz is generally used for EFM and SCM to avoid any disturbance.

■ **Drive**

Modulation Drive is selectable. In case of electrical properties measurement, if the Modulation Drive value increases too much, an electric field may form between tip and sample and may affect the sample surface potential. Thus, it is recommended to select lower than 2-3V.

*Modulation Drive and Modulation&Lock-in Frequency are also selectable through the Lock-in1(NCM)/Lock-in 2(EFM, SCM, SICM(AC) Frequency Sweep window in Setup menu.

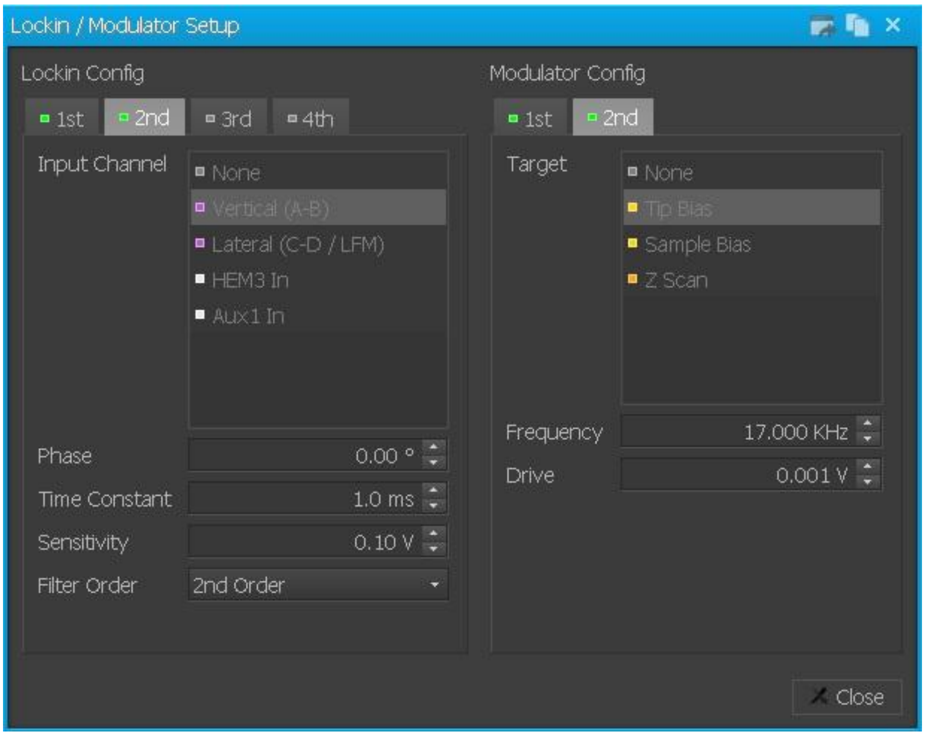
Guideline for Sensitivity Setting			
SCM/EFM Amplitude Level	100uV ~ 1mV	1mV ~ 10mV	Higher than10mV
Sensitivity	0.1~1V	1 ~ 10V	10V

14-4. Operation

1. EFM Measurement

- Base mode: Non-contact mode
- Default setup for lock-in 1st, lock-in 2nd

Figure 14-11. Lock-in Setup in EFM



Phase 0.00 °

Time Constant 1.0 ms

Sensitivity 0.10 V

Filter Order 2nd Order

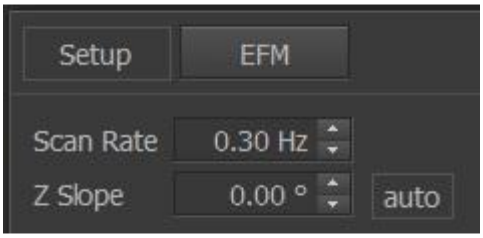
Frequency 17.000 KHz

Drive 0.001 V

*Note that to improve the product, software UI can be changed without notice.

① **Head Mode: Select as ‘EFM’.**

Figure 14-12. Head Mode Setup



Scan Rate 0.30 Hz

Z Slope 0.00 °

② **Channel Config:**

Choose signals to be imaged. Recommend to set ‘Z Height’, ‘EFM Amplitude’, ‘EFM Phase’.

③ **Trace Window:**

Choose signals to be monitored in real time. Recommended to set ‘Height’, ‘EFM Amplitude’, ‘EFM Phase’.

④ **NCM parameter setting:**

As generally done in NCM. Click ‘Approach’ button to approach the tip to the sample surface. If the approach is successful, the upper half of the Z scanner bar will turn green and the green light at the Stage Control Window will stop blinking. Control the scan parameters and obtain optimized height line profile. Before you begin Lock in setup To get the 'Heght' to complete the Parameter Setting.

*Note after checking cantilever specification, choose optimal drive frequency, Amplitude. For specific description, go to Non-contact mode page in User’s manual.

⑤ **Lock-in setting for EFM Measurement:**

When you select a mode, the EFM Lockin 2 is activated. After that the Input channel is automatically vertical, Target is fixed at Tip Bias. In order for optimized EFM Amplitude/Phase to appear, control the parameters such as Time Constant, Sensitivity and so on.

(For more information about Parameter setting , please refer to 14-6.)

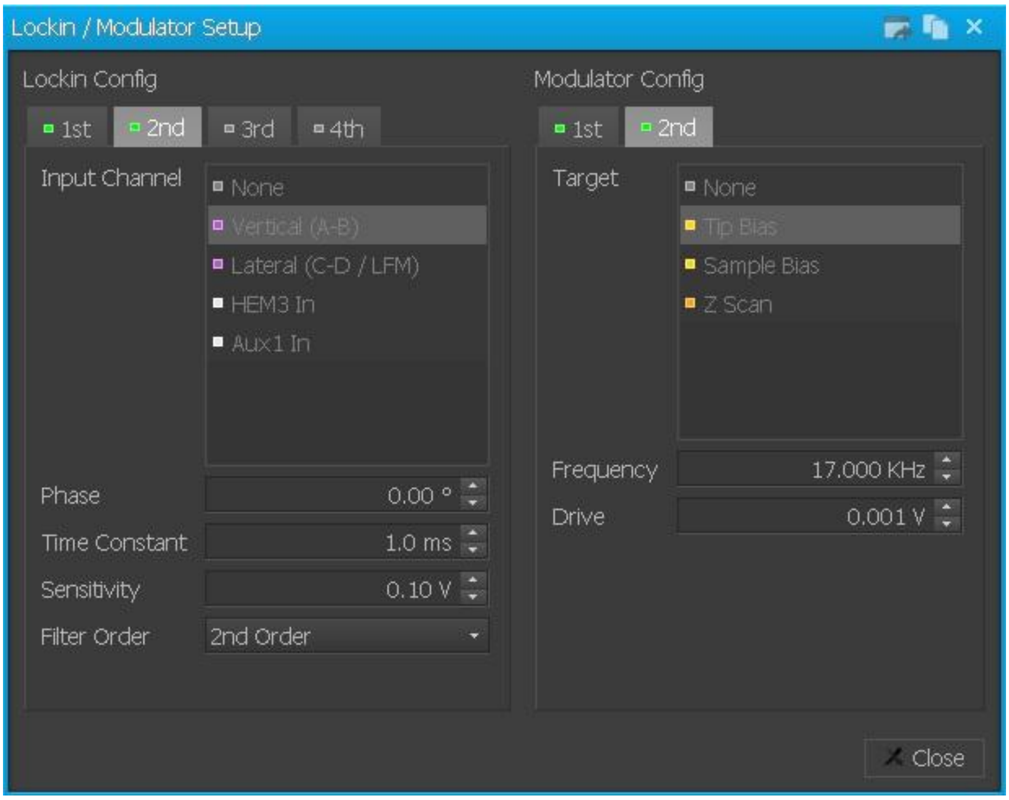
Caution!

Before approach, please make sure that the modulator amplitude is set to zero so as to avoid any damage to the tip.

2. EFM-DC Measurement

- Base mode: Contact mode
- Default Set Up For Lock-in 1, Lock-in 2

Figure 14-13. Lock-in Setup in EFM-DC



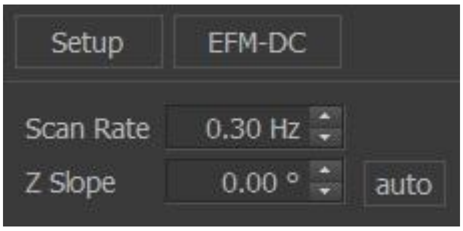
Input Channel: Vertical (A-B)
Phase: 0.00 °
Time Constant: 1.0 ms
Sensitivity: 0.10 V
Filter Order: 2nd Order
Target: Tip Bias
Frequency: 17.000 KHz
Drive: 0.001 V

*Note that to improve the product, software UI can be changed without notice.

① **Part Configuration:**

Head Mode-EFM-DC, Cantilever-loaded cantilever

Figure 14-14. Head Mode Setup



EFM-DC
Scan Rate: 0.30 Hz
Z Slope: 0.00 °

Note that when installed cantilever is not there, choose a similar spec cantilever and create a cantilever DB. To do so, please refer to the cantilever page in User's manual.

② **Channel Config:**

Choose signals to be imaged. Recommend to set 'Z Height', 'EFM Amplitude', 'EFM Phase'.

③ **Trace Window:**
Choose signals to be monitored in real time. Recommended to set 'Height', 'EFM Amplitude', 'EFM Phase'. Before you begin Lock in setup To get the 'Heght' to complete the Parameter Setting.

④ **Parameter setting:**
As generally done in Contact. Click 'Approach' button to approach the tip to the sample surface. If the approach is successful, the upper half of the Z scanner bar will turn green and the green light at the Stage Control Window will stop blinking. Control the scan parameters and obtain optimized height line profile. Before you begin Lock in setup To get the 'Heght' to complete the Parameter Setting.

⑤ **Lock-in setting for EFM Measurement:** When you select a mode, the EFM Lockin 2 is activated. After that the Input channel is automatically vertical, Target is fixed at Tip Bias. In order for optimized EFM Amplitude/Phase to appear, control the parameters such as Time Constant, Sensitivity and so on.
(For more information about Parameter setting , please refer to 14-6.)

Caution!

If the set point is increased too much, force exerted on the tip will becomes too high. This will result in tip breaking or the damage to the sample surface. Also if the set point is increased too much, the tip can come to ohmic contact with sample surface resulting in shorts and excessive current between tip and sample even thgough sample is an insulator since it may have the defect region.

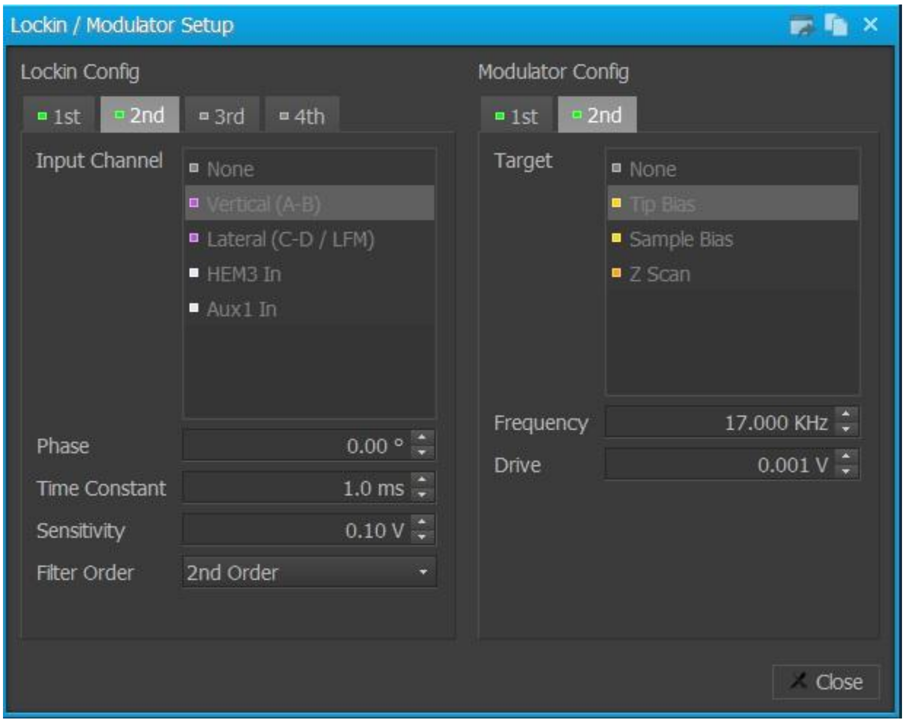
Caution!

Before approach, please make sure that the modulator2 amplitude is set to zero so as to avoid any damage to the tip.

3. PFM Measurement

- Base mode: Contact mode

- Default Set Up For Lock-in 1, Lock-in 2



Lockin / Modulator Setup

Lockin Config

Input Channel: Vertical (A-B)

Phase: 0.00 °

Time Constant: 1.0 ms

Sensitivity: 0.10 V

Filter Order: 2nd Order

Modulator Config

Target: Tip Bias

Frequency: 17.000 KHz

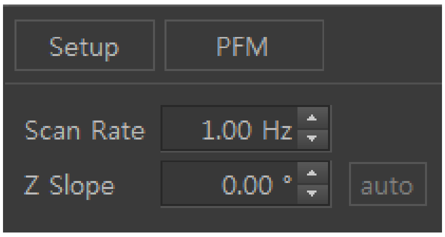
Drive: 0.001 V

Figure 14. Lock-in Setup for PFM

*Note that to improve the product, software UI can be changed without notice.

④ **Part Configuration:**

⑤ Head Mode-PFM, Cantilever-loaded cantilever



Scan Rate: 1.00 Hz

Z Slope: 0.00 °

Figure 15. Head Mode Setup

Note that when installed cantilever is not there, choose a similar spec cantilever and create a cantilever DB. To do so, please refer to the cantilever page in User's manual.

⑥ **Channel Config:**

Choose signals to be imaged. Recommend to set 'Z Height', 'PFM Amplitude', 'PFM Phase', 'PFM Quad'.

⑦ **Trace Window:** Choose signals to be monitored in real time. Recommended to set ‘Z Height’, ‘PFM Amplitude’, ‘PFM Phase’.Before you begin Lock in setup To get the 'Z Height' to complete the Parameter Setting.

⑥ **Parameter setting:** As generally done in Contact. Click ‘Approach’ button to approach the tip to the sample surface. If the approach is successful, the upper half of the Z scanner bar will turn green and the green light at the Stage Control Window will stop blinking. Control the scan parameters and obtain optimized height line profile. Before you begin Lock in setup To get the 'Heght' to complete the Parameter Setting.

⑦ **Lock-in setting for EFM Measurement:**

When you select a mode, the PFM Lockin 2 is activated. After that the Input channel is automatically vertical, Target is fixed at Tip Bias. In order for optimized PFM Amplitude/Phase to appear, control the parameters such as Time Constant, Sensitivity and so on.

(For more information about Parameter setting , please refer to 14-6.)

Caution!

If the set point is increased too much, force exerted on the tip will becomes too high. This will result in tip breaking or the damage to the sample surface. Also if the set point is increased too much, the tip can come to ohmic contact with sample surface resulting in shorts and excessive current between tip and sample even thgough sample is an insulator since it may have the defect region.

4. SKPM(Scanning Kelvin Probe Microscope) Measurement

SKPM measurement procedure is same as for the EFM or EFM-DC. The tip DC voltage is controlled by feedback to keep the potential difference between the tip and the sample at zero. Then, value of the absolute surface potential can be obtained by using the SKPM.

① Follow steps 1 to 9 of EFM or EFM-DC.

② Input channel & Trace Window: **Add "Potential" signal.**

③ Scan Control Window: Change the scan parameters as follows

−**Scan size: 0**

−**Sample bias: 0**

④ Title Bar&**Trace Mode**: **Perform the Potential Sweep.**

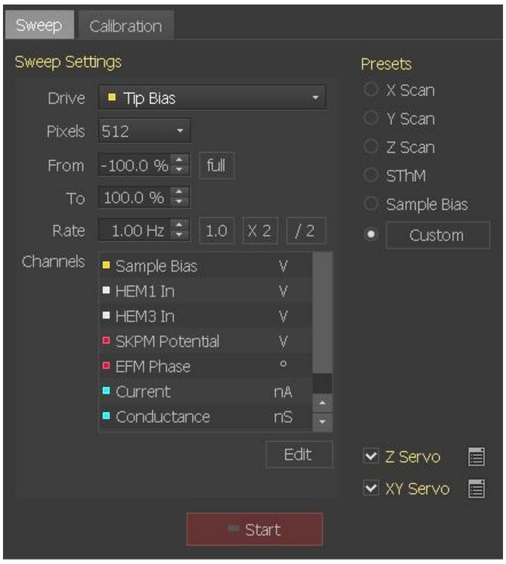
i. Click the "Trace Mode(maintenace on the tap.)" on the toolbar, and select "Potential(sample bias)" at the driving source combo box.

Warning!

> Make sure that Potential is selected for driving source. If you select other parameters, NX system and/or the sample can be severely damaged.

ii. Trace Mode (mauntenace): When the XY Scanner is changed off, then "Sweep(Start)" button is enabled.

Figure 14-18. Trace mode

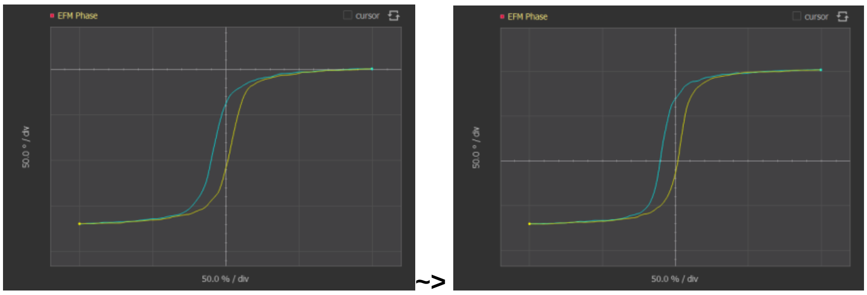


Drive: Tip Bias
Pixels: 512
From: -100.0 %
To: 100.0 %
Rate: 1.00 Hz
Presets: ● Custom
☑ Z Servo
☑ XY Servo

iii. Trace Mode&Lock-in Setup Window:Click the "Sweep" button.

Then, DC bias to the sample will be applied from -10V to 10V. The EFM phase curve versus potential is plotted. Adjust the "Phase" of the output signal on the Lock-In Amplifier control panel to center the curve in the window.

Figure 14-19. Centering the Trace Curve



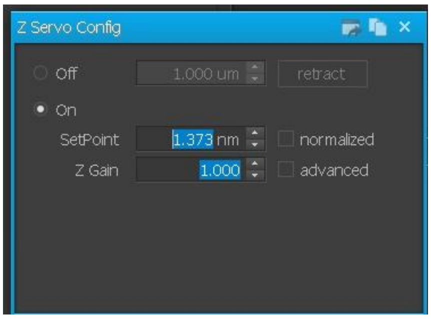
EFM phase is used for SKPM feedback. This value includes polarity of sample and Y offset from system in fact. Therefore, we need to set the signal above by adjusting phase shift on the Lock-in Amplifier in order to distinguish the polarity of the sample potential.

iv. Click the "Stop" button, and return to the 'Scan Mode Control' by clicking the "Scan Mode" button in the main toolbar.

⑥ Scan Control Window: Set the scan parameters to scan the sample properly and confirm if the signals are acquiring correctly.

⑦ Check the "Tip Bias Servo" button

Figure 14-20. Tip Bias Servo



Z Servo Config

○ Off 1.000 um retract

● On

SetPoint 1.373 nm ☐ normalized

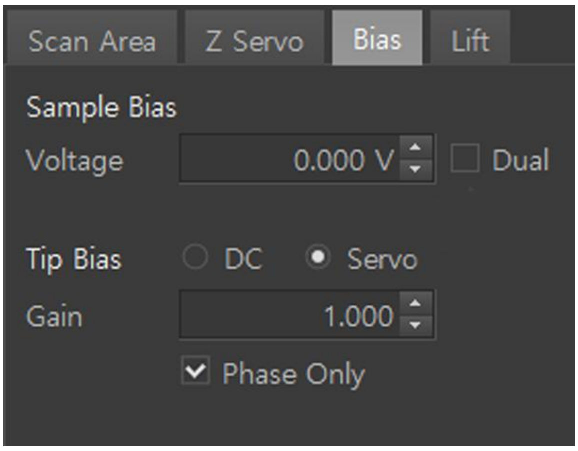
Z Gain 1.000 ☐ advanced

Then, tip bias will be applied to make ω component from Lock-in Amplifier zero.

***Use Phase Only in Tip Bias Servo**

Both EFM Amplitude and EFM Phase [R_0sineθ_0-R_1sine$\theta_{1,}$ (R_0: Modulator2 amplitude from Lock-in Amplifier setting, $\theta_{0:}$Modulator2 phase from Lock-in Amplifier setting, A_1:Current EFM amplitude, ө1:Current EFM Phase) will be used for SKPM tip bias feedback. Checking this button make EFM Phase used only in SKPM feedback loop system. Therefore, tip bias is applied to make EFM phase difference [sineθ_0-sineθ_1] zero this option is located in [Manual->bias].

Figure 14-21. Use Phase Only in Tip Bias Servo



Sample Bias

Voltage 0.000 V ☐ Dual

Tip Bias ○ DC ● Servo

Gain 1.000

☑ Phase Only

⑧ Trace Window: Monitor the “Potential” signal. The potential curve is a representation of the surface voltage profile.

⑨ Adjust the Lock-in Amplifier parameters (Time constant, Sensitivity and etc.) and the Tip bias servo gain on SmartScan™ to optimize the Potential signal.

14-5. Practice

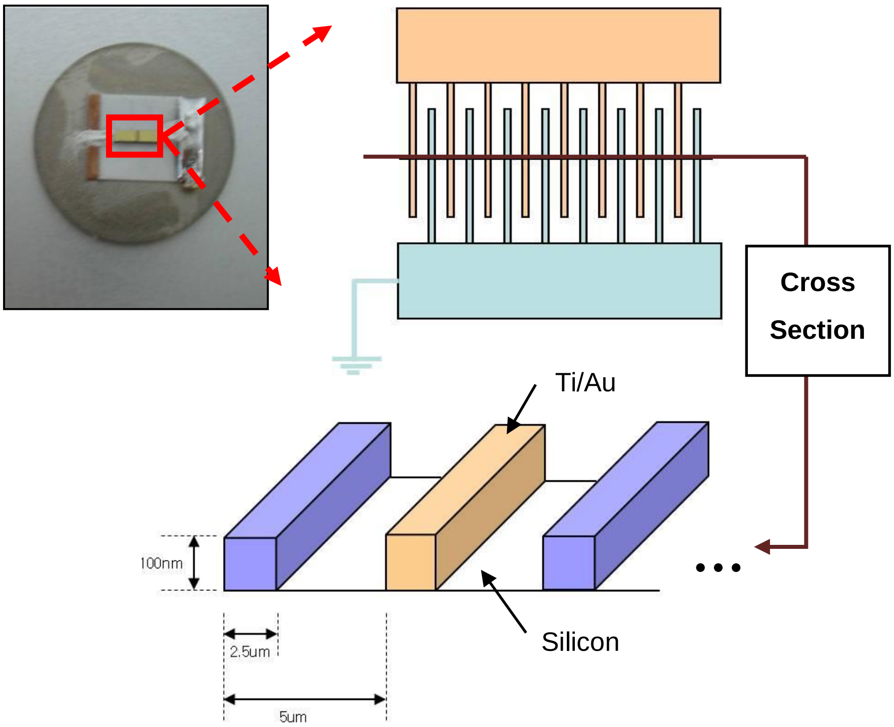
Park Systems offers the EFM test sample with EFM mode. You can test your EFM and imaging skills by obtaining an EFM image of the test sample and comparing it with the expected image. This section describes the test sample and expected results.

1. EFM

A. Test Sample

Figure 14-22. shows the standard test sample and its magnified view. The test sample consists of two comb shaped Ti/Au electrodes with each tooth of one electrode lying between teeth of the other. One electrode is electrically connected to the metal plate, the sample holder, and thus can be biased through NX electronics. The other electrode is connected to the wire slot. If the wire is connected between this slot and the ground, it will be grounded.

Figure 14-22. EFM Test Sample



Sample bias will be applied through the sample holder and can be controlled by changing the 'Sample bias' value in the SmartScan™ software.

For grounding, any conducting part on the SPM body or the acoustic enclosure bolts can be used.

B. Obtaining an EFM Image of the Test sample

1. **Test Sample Installation:**
   a. Mount the test sample on the sample holder.
   b. Connect the ground wire between ground slot and the grounding.

2. **Head Mode:** EFM, SKPM

3. **Recommended Scan Parameters:**
   a. Scan size: 20 µm
   b. Tip bias: 0 Volts
   c. Sample bias: ± 1V
   d. Frequency: 17kHz
   e. Drive: 1V
   f. Phase: 40 Degree
   g. Time Constant: 2ms
   h. Filter: 2nd order
   i. Sensitivity: 1V

4. **Results:**

Figure 14-23 shows the expected EFM and surface height signals and Figure 14-24 shows the actual EFM and height image of the test sample. Since all the neighboring teeth of the comb shaped electrode are the same height, the surface height signal is in the shape of a square wave. However, since the neighboring electrodes differ in potential, every other height peak is missing in the EFM image.

Figure 14-23. Expected results of the test sample

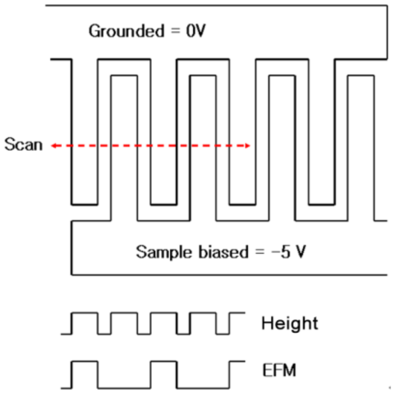
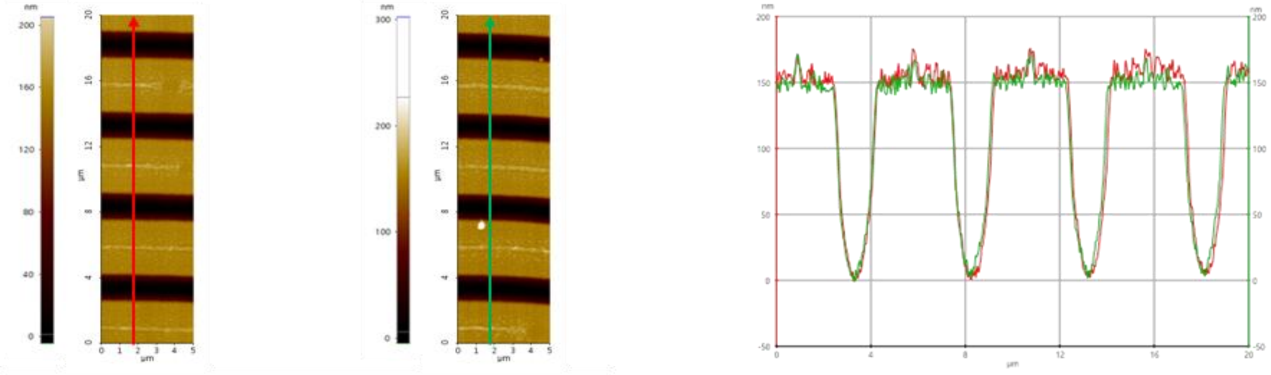


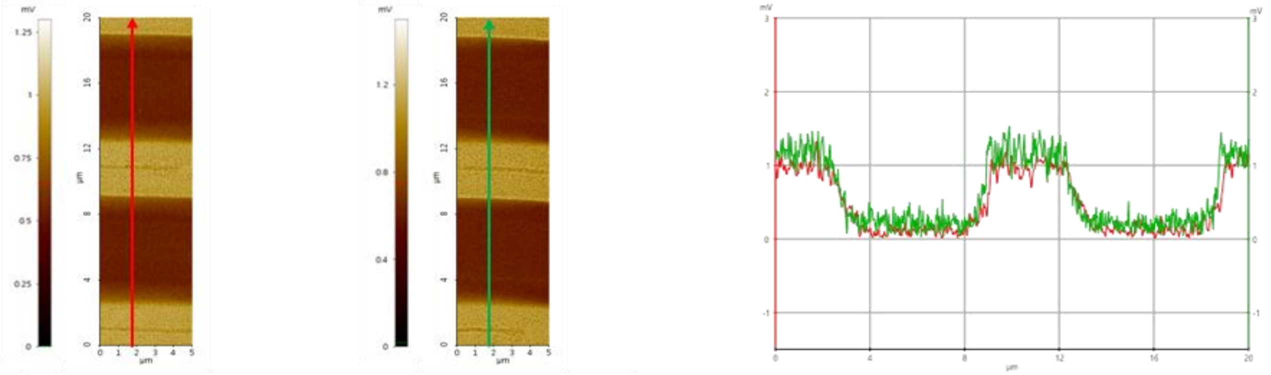
Figure 14-24. Actual Height and EFM image of the test sample

[Height Image] [Height line profile]



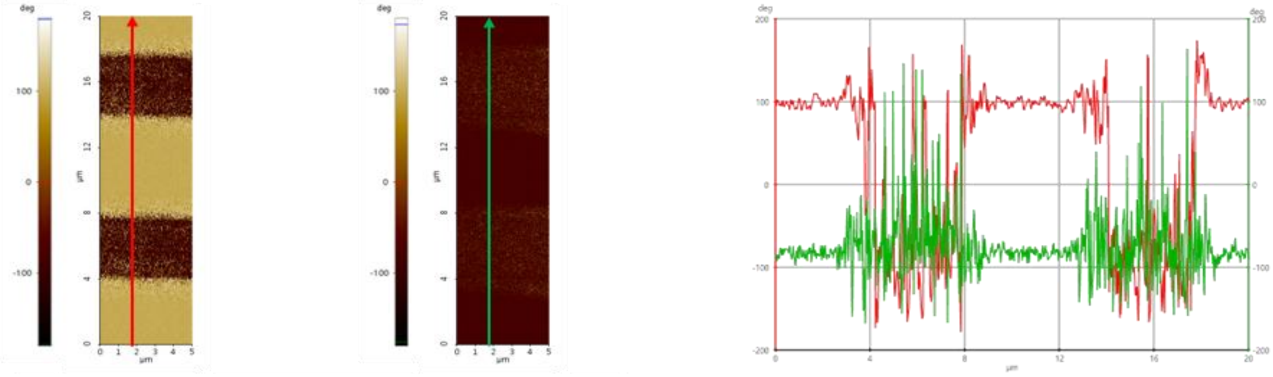
Sample bias = -1V Sample bias = 1V

[EFM Amplitude Image] [EFM Amplitude line profile]



Sample bias = -1V Sample bias = 1V

[EFM Phase Image] [EFM Phase line profile]



Sample bias = -1V Sample bias = 1V

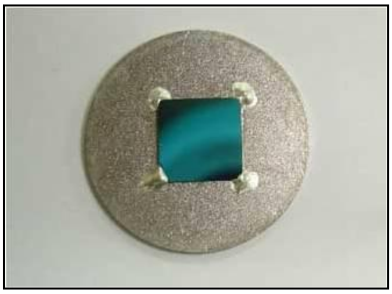
2. PFM (EFM-DC)

A. Test Sample

PFM (EFM-DC) provides ferroelectric piezo material for the test sample.

The thickness of piezo material(Zr/Ti composition) is approximately 150nm and the substrate is Ti/Pt on SiO_2 /Si wafer. The test sample Figure below shows the test sample electrically connected to the metal plate.

Figure 14-25. EFM-DC Test Sample



B. Obtaining an PFM Image of the Test sample

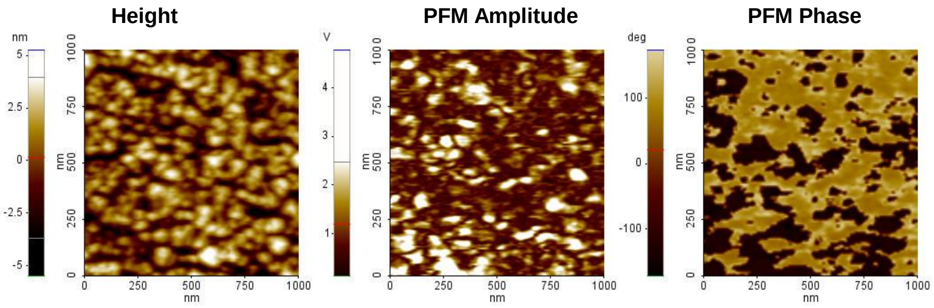
1. **Test Sample Installation:**
   Mount the test sample on the sample holder.

2. **Head Mode:** PFM mode

3. **Recommended Scan Parameters:**
   a. Scan size: 1 µm
   b. Tip bias: 0 Volts
   c. Sample bias: 0 Volts
   d. Frequency: 17kHz
   e. Drive: 1V
   f. Phase: 40 Degree
   g. Time Constant: 2ms
   h. Filter: 2^{nd} order
   i. Sensitivity: 5V

4. **Results:**
   This piezo material has the ferroelectric property and possess a spontaneous electric polarization. Therefore, the sample affects the electric field between tip and sample and we can get the PFM image below.

Figure 14-26. PFM Image of Test Sample


Height

PFM Amplitude

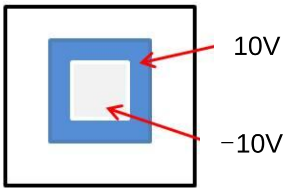
PFM Phase

C. Obtaining an PFM Image of the Test sample after Domain Switching

This electric polarization of this piezo matrial can be reversed by external electric field. We can confirm it through PFM after applying the +/- voltage to the tip.

1. **Test Sample Installation:**

   Mount the test sample on the sample holder.
2. **Head Mode:** EFM-DC mode or PFM mode
3. **Recommended Measurement Procedure:**



   a. Scan the sample with Scan size: 8um, Tip Bias: -10V
   b. Scan the sample with Scan size: 5um, Tip Bias: 10V
   c. Acquire the EFM image with Scan size: 10um, Tip Bias: 0 V

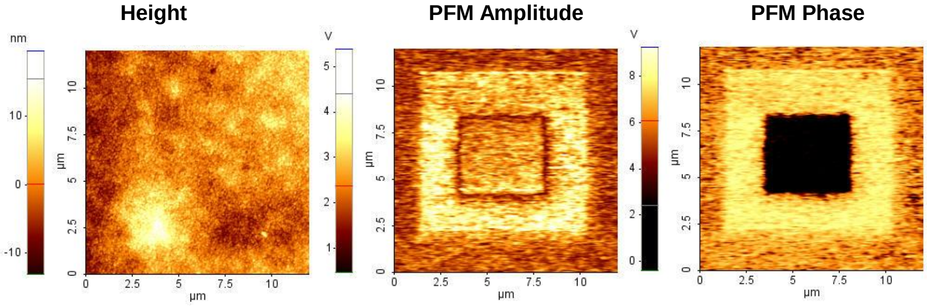
Note!

Scan XY offset of (a, b) should be same.

4. **Results:**

   Scanned area of 8 µm has electric domain by -10 V tip bias. After that, tip charged +10V scanned 5um scan area with same offset. Therefore, the electric polarization of 5um scanned area is reversed. Therefore, PFM phase should have opposite direction each other. We can confirm it with PFM.

Figure 14-27. PFM Image of Test Sample domain switching


Height

PFM Amplitude

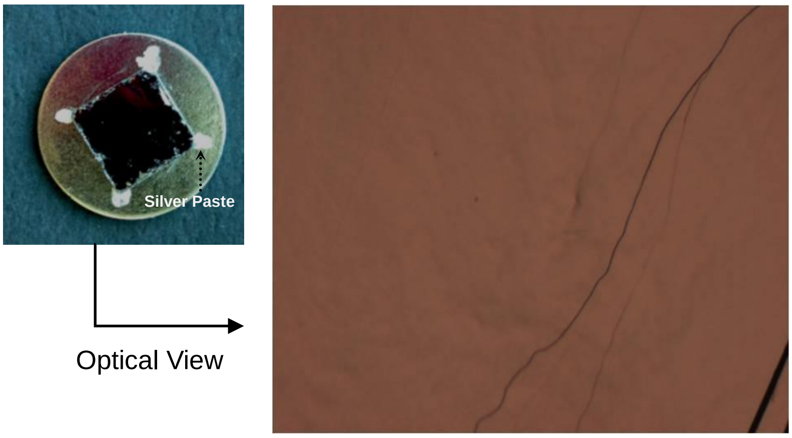
PFM Phase

3. SKPM

A. Test Sample

The HOPG(Highly Oriented Pirolytical Graphite), a material that consists of many atomic layers of carbon. is provided as the SKPM test sample. It is used a lot of applications by its atomic flatness, cleanness and conductivity. The parallelism of atomic layer is characterized by “mosaic spread angle” and the HOPG provided in SKPM has 0.7 degree high quality in it and 10 x 10 mm^2 in size, 1.2 mm(±0.2) in thickness. Figure 24 shows the provided sample and its magnified view. This test sample electrically connected to the metal plate by electro-conductive adhesive. The metal plate is attached onto the sample holder, and thus the sample can be biased through NX electronics.

Figure 14-28. HOPG



B. Obtaining an SKPM Image of the Test sample

5. **Test Sample Installation:**
    a. Mount the HOPG test sample on the sample holder.
6. **Head Mode:** EFM

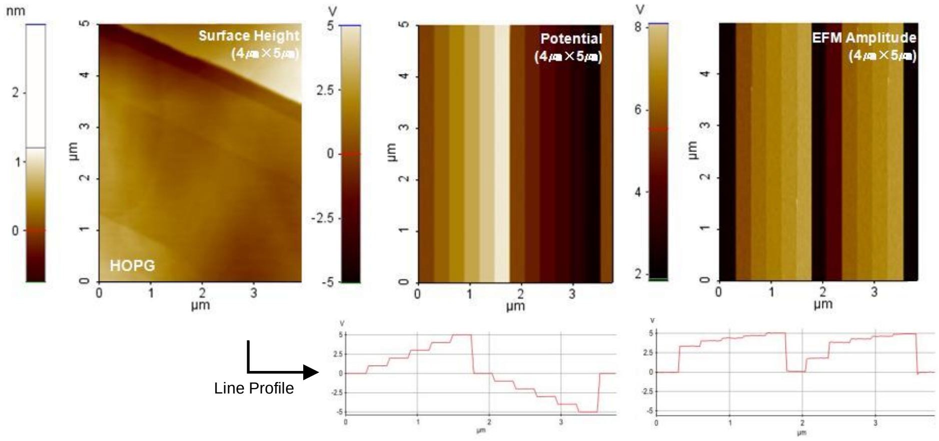
7. **Recommended Scan Parameters:**
    a. Tip bias: 0 Volts
    b. Sample bias: Change the ‘Sample Bias’ during scanning.
    c. Frequency: 17kHz
    d. Drive: 0.5V
    e. Phase: 40 Degree
    f. Time Constant: 2ms
    g. Filter: 2nd order
    h. Sensitivity: 0.1V

8. **Results:**

The potential value according to the applied sample bias will be observed by SKPM. Figure 25 shows Potential image by SKPM and EFM image by EFM during scanning the HOPG sample(scan size: 4μm x 5μm) and applying the sample bias as (0V→+1V→+2V→+3V→+4V→+5V→0V→-1V→-2V→-3V→-4V→-5V→0V).

As you see in each line profile, unlike EFM amplitude, the Potential value was measured equally with the applied sample bias. In other words, the SKPM can distinguish the real potential difference.

Figure 14-29. Expected results of the test sample



14-6. Advanced Application

Notes on EFM Imaging

- **Scan parameter setting (Height)**

A bad Height image indicates that the distance between the sample and the tip is not constant – EFM signals obtained when this is the case cannot be considered reasonable data.

In order to make EFM imaging exact, scan parameters (scan rate, set point, z-servo gain) must be adjusted so the distance between tip and sample is always constant and yields Height Image of good quality. A bad Height Image indicates that the sample-tip distance is not being maintained at a constant, and EFM data obtained when this is the case cannot be considered reasonable data.

- **Lock-In Amplifier Parameter Setting (EFM Image)**

In order to obtain EFM data, Lock-In Amplifier Parameters must be adjusted appropriately for each situation. There are 6 Lock-In Amplifier Parameters: Frequency, Drive voltage, Phase, Time constant, Sensitivity, Filter order.

- **Frequency;** Use of 17kHz is effective for obtaining good results.
- **Drive voltage;** The larger the Drive voltage, the higher the magnitude of response to surface potential, and when this value is too large it can act as DC bias on the sample, so we recommend usage with this value within 3V.
- **Phase;** The EFM phase can determine whether the surface potential value of the sample is + or –. This parameter modulates the offset of the EFM Phase signal.
- **Time constant;** The Time constant is used in reading the averaged data

received for the duration of time set as the Time constant in Lock-In Amplifier. This parameter is highly relevant to scan rate. For example, if scan rate is 0.5 Hz and pixel count is 512 then pixel-to-pixel travel time is 2ms, but if the Time constant is 4ms then the data for 2 pixels are averaged into 1 EFM data point input and resulting images may be blurry. Or, if the time constant is too short, resulting images may be blurry.

- **Sensitivity;** This parameter determines EFM Amplitude signal detection range. You can set this parameter in accordance with the below table while monitoring the EFM Amplitude signal value.

Guideline for Sensitivity Setting				
EFM Amplitude	<10mV	<100mV	<1V	>1V
Sensitivity	0.01V	0.1V	1V	10V

- **Filter order;** This is a Low pass filter function and we recommend use of 2nd order.

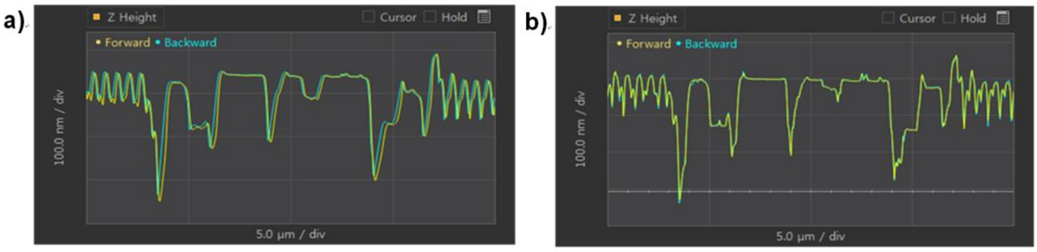
When the above Lock-In Amplifier Parameter Settings are unsuitable, Height image output may be inaccurate and EFM image output may be noisy or blurry. This is why EFM data must be obtained after setting Lock-in Amplifier parameters to suitable values using line profiles as guide.

Examples

1. *Influence of Drive voltage on Height*

Drive voltage may be set to a higher value in order to increase the tip’s reaction sensitivity to surface potential. However, setting the Drive voltage to a large value increases the surface potential of the sample and this surface potential pushes the tip away from the sample, resulting in inaccurate imaging of surface morphology. Therefore, Drive voltage increases must be to within a range which does not cause height signal distortion.

Figure 14-30. Z Height line profiles according to Drive voltage; Drive voltage = a) 5V, b) 1V



2. *Influence of Time Constant on EFM Image*

As aforementioned, the Time constant is closely related to the scan rate, and must be adjusted appropriately according to scan rate. Examine EFM signal’s Line profiles for forward/backward consistency, noisiness, or blurriness and adjust the Time constant accordingly prior to imaging.

Figure 14-31. EFM line profiles according to Time constant; Time constant = a) 1ms, b) 3ms, c) 5ms

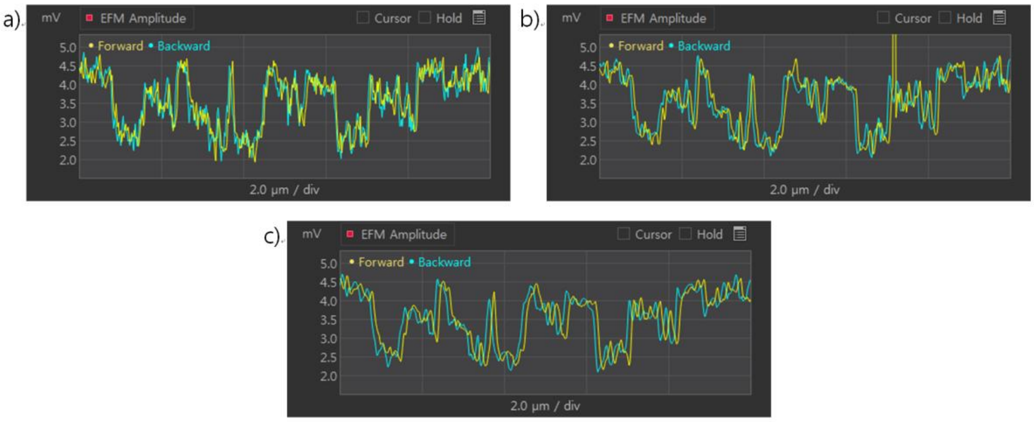


Figure 14-32. EFM Amplitude Image according to Time constant; Time constant = a) 10ms, b) 5ms, c) 1ms

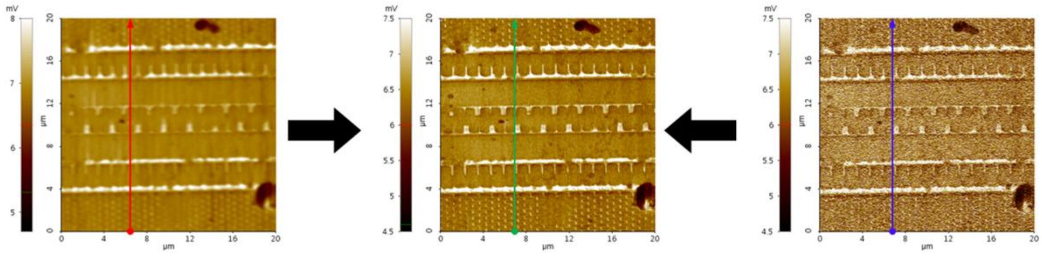
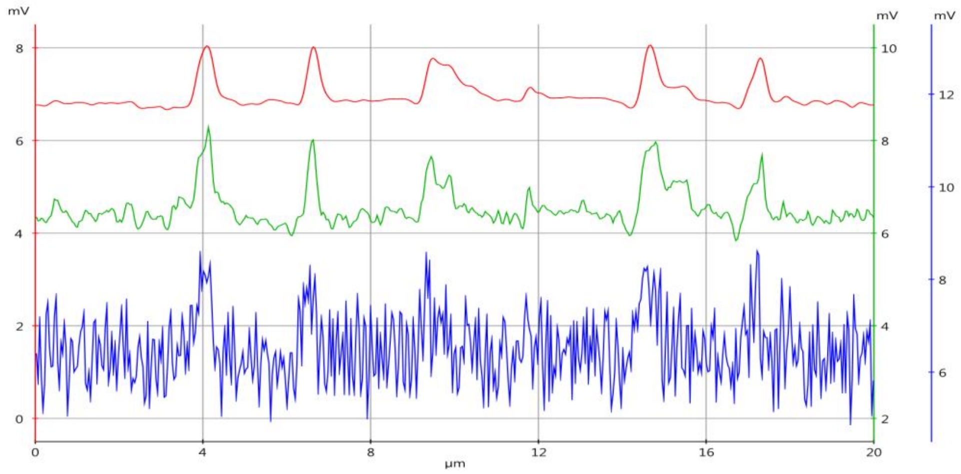


Figure 14-33. Line profiles of Figure 3 EFM Amplitude Image



As seen above in Figure 14-31, Figure 14-32, and Figure 14-33, if the Time constant is long then image and line profile become blurry, while if the Time constant is short then image and line profile become noisy.

- **EFM-DC**

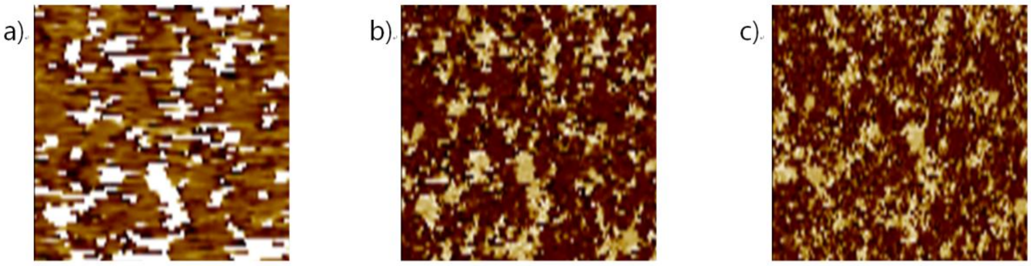
As EFM-DC is distinct only in that standard EFM operation is based on Contact mode, with identical imaging procedures for all other measurements, there should be no difficulties in obtaining images through adjusting the parameter setting as detailed afore in 1, 2. As domain direction may be known through the EFM Phase, EFM-DC is mainly used to obtain Phase image.

❖ Examples

Influence of EFM Image on Time constant

Longer Time constant produces blurry images while shorter Time constant produces noisy images, as with EFM.

Figure 14-33. EFM Phase Image according to Time constant; Time constant = a) 3ms, b) 1ms, c) 0.5ms



- **PE curve**

PE curve is obtained as a good method for examining Piezoelectric properties.To observe the characteristics of Ferroelectric good way is to obtain a PE curve. In order to obtain a good result of PE Curve should be setting as well as to the Time constant of sample bias sweep period, Lock-in setting.

❖ Examples

PE Curve according to Sample Bias Period.

Sample bias sweep period is not enough time is given short sample of this domain is difficult to return to observe the hysteresis.

Figure 14-34. PFM Phase Amplitude according to Sample Bias sweep period; a) 1s, b) 5s, c) 10s

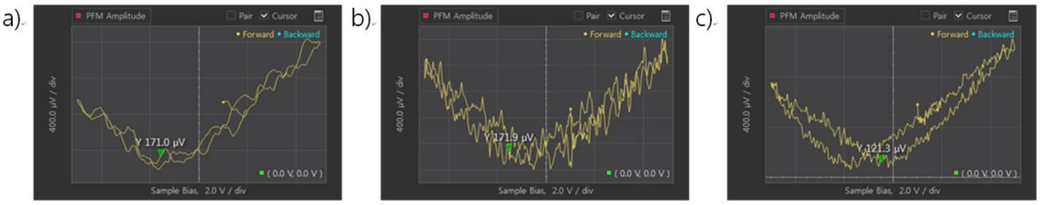
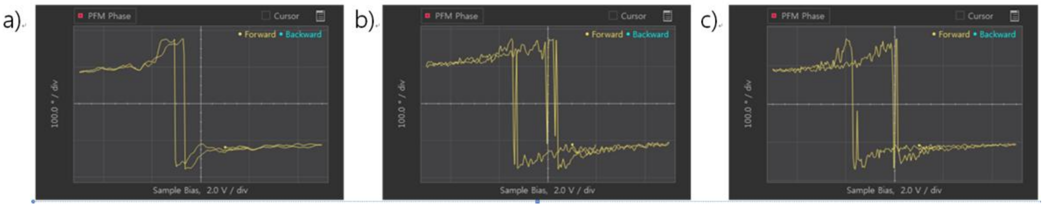


Figure 14-35. PFM Phase according to Sample bias sweep period; a) 1s, b) 5s, c) 10s



PE Curve according to Time constant.

If the time constant in the Lock-in setting is set faster PE curve is noisy, and if the time constant is set to slow PE curve emerges blurry.

Figure 14-36. PFM Amplitude according to Time constant; a) 1ms, b) 5ms, c) 10ms

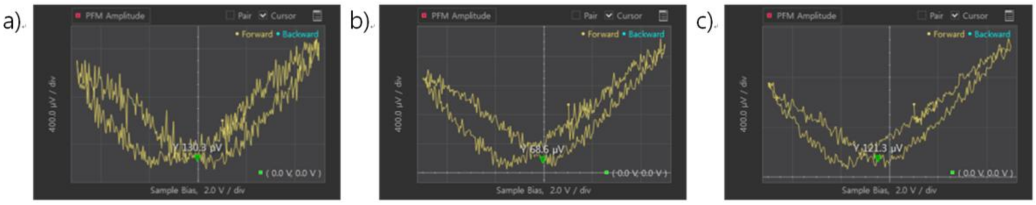
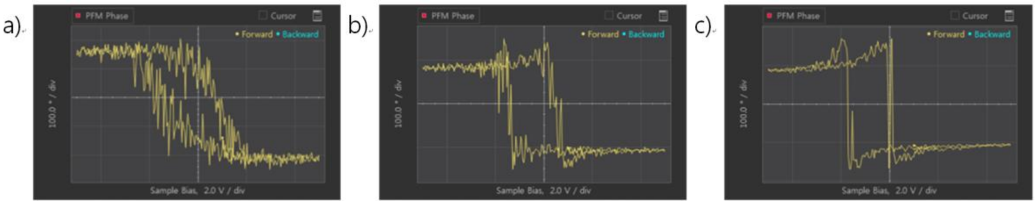


Figure 14-37. PFM Phase according to Time constant; Time co a) 1ms, b) 5ms, c) 10ms



Notes on SKPM Imaging

- **Adjust scan parameters to obtain good Topography results.**

  Bad Topography results indicate that the distance between the sample and the tip is not constant - SKPM signals obtained when this is the case cannot be considered reasonable data.

- **If SKPM Potential Image is blurry or noisy.**

Example

- SKPM Potential Images depending on Tip bias servo gain settings

Figure 14-38-a **Figure 14-38-b** **Figure 14-38-c**

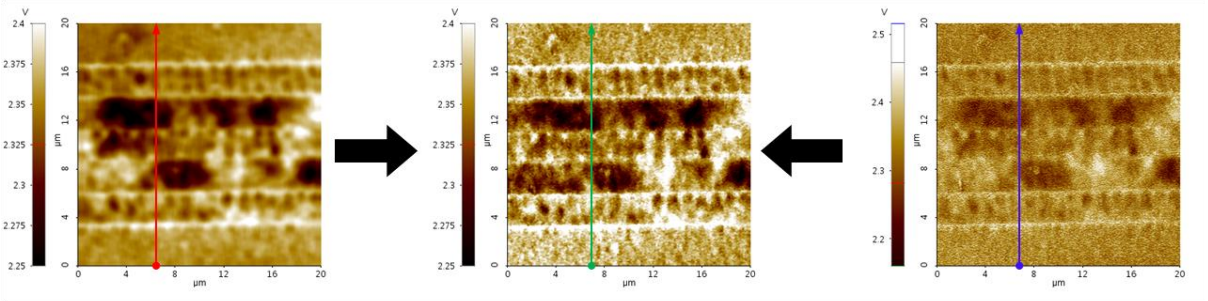
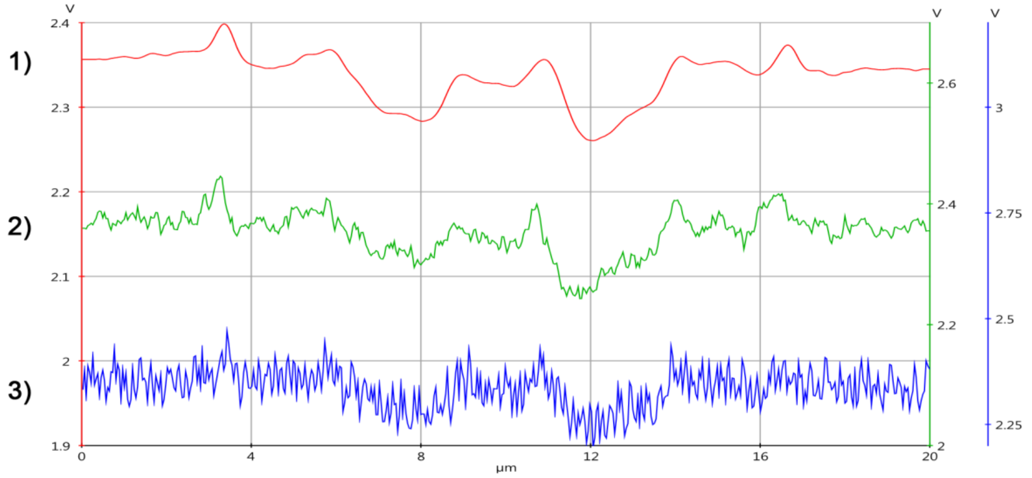


Figure 14-38; a) Tip bias servo gain=0.1, b) Tip bias servo gain=0.3, c) Tip bias servo gain=0.5

Figure 14-39. Line profiles of SKPM Potential Images



line profiles of each image in Figure 14-38.

2): Figure 14-39-a, 1): Figure 14-39-b, 3): Figure 14-39-c

When taking SKPM scans, the SKPM Potential image obtained may be blurry as shown in Figure 14-38-a, or noisy as shown in Figure 14-38-c. In this case, adjusting the Tip bias servo gain can improve the quality of the SKPM Potential image.

Figure 14-38-a shows an image which is blurry due to a small Tip bias servo gain value, while Figure 14-38-c shows an image which is noisy due to a large Tip bias servo gain value. Adjusting the Tip bias servo gain value can yield results such as Figure 14-38-b. In Figure 14-39, the line profiles of each SKPM Potential image in Figure 14-39 show noisier results with larger Tip bias servo gains and blurrier results with smaller Tip bias servo gains. It is important to run line scans to look at line profiles and set the right Tip bias servo gain prior to obtaining SKPM Potential images.

Tip bias servo gain setting

- SKPM Potential line profiles by Tip bias servo gain setting.

Figure 14-40-a. Tip bias servo gain=0.1

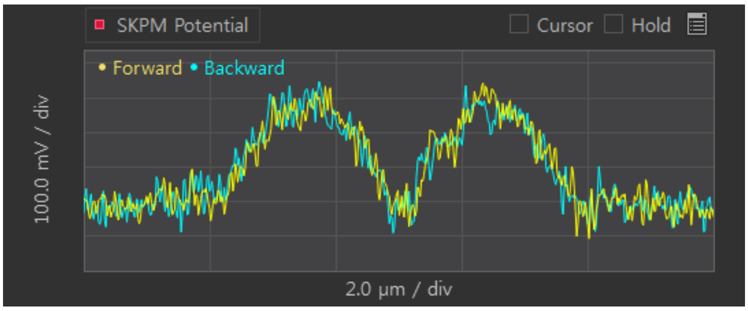


Figure 14-40-b. Tip bias servo gain=0.05

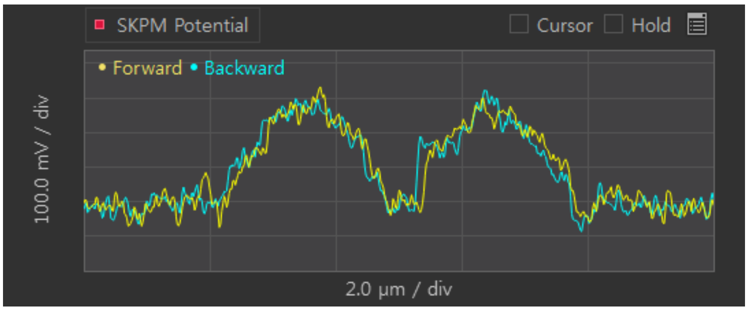


Figure 14-40-c Tip bias servo gain=0.01

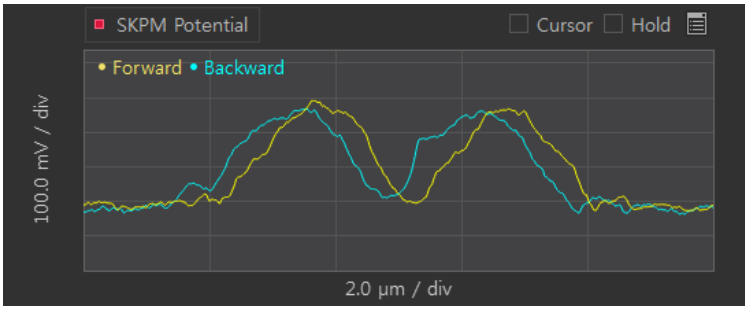


Figure 14-40-a displays a noisy line profile resulting from a large Tip bias servo gain value and Figure 14-40-c displays a blurry line profile resulting from a small Tip bias servo gain value. Adjust the Tip bias servo gain value to minimize line profile noise and synchronize forward/backward lines.

Index

A

VERTICAL, 103

VERTICAL Sensitivity, 63, 65

Acoustic Enclosure, 37, 39, 46, 50

ADC, 33

Adhesion, 134

Adhesion Energy, 134

AFM, 2

Amplitude Change, 111, 130

Approach, 85

Approach Curve, 122, 124, 130, 133

Approach Spectroscopy, 122, 133

B

Beam Alignment Knobs, 20, 80

Beam Path, 8, 82

Beam Switch, 19, 77

Bimorph, 110

BNC Input/Output, 25, 27

C

Calibration, 4, 146

- VERTICAL Sensitivity Calibration, 65
- Auto Calibration, 155
- Cantilever Calibration, 63
- Detector Offset Calibration, 157
- Software Linearized Correction, 162
- XY Scanner Calibration, 146

Cantilever, 2, 53, 69, 77, 78, 79, 80, 82, 98, 114

Cantilever DB, 63

Cantilever Exchanger, 59

Cantilever Vibration, 110

CCD Camera, 9, 23

LATERAL, 103

Chip Carrier, 56, 62, 79

- Clip Type Chip Carrier, 58
- Glue Type Chip Carrier, 56

Closed Loop, 90, 146, 159

Contact Mode AFM, 96

Control Electronics, 10

Cross Coupling, 3, 7

D

Data Export, 94

Dovetail Rail, 19

Dovetail Thumb Locks, 19

Drive Amplitude, 114

Drive Frequency, 110

Tapping mode(TAPPING MODE), 116

E

Effective Spring Constant, 110

EMG, 25

Ethernet, 25

External Sample Bias, 26

External Tip Bias, 26

F

FD Mode, 122, 124

Flexure Hinge, 21

Focus Stage, 76

Force Gradient, 110

Force Volume Image, 135

Frictional Coefficient, 102

Frictional Information, 103

Fuse, 29

H

Head, 15

Head Connector, 77

Height Information, 93

Height Offset Calibration, 159

Hysteresis, 3, 90, 162

I

Image Sync Outputs, 27
  Frame, 27
  Line, 27
  Pixel, 27

Input Configuration, 106

Input Signal
  VERTICAL, 87
  Error Signal, 86
  Force, 87
  Height, 86
  Lateral Force, 87
  NCM Amplitude, 86
  NCM Phase, 87
  Z Drive, 86

Installation, 34

Interatomic Force, 96, 98

Intrinsic Frequency, 55, 110

Intrinsic Spring Constant, 110

J

Jump to Contact(Snap-In), 134

L

Lateral Deflection, 102

Lateral Force Microscopy, 102

Lateral Resolution, 92

Linearized Correction, 162

M

Magnetic Sample Holder, 23

Maintenance, 145

Maintenance Mode, 79

Maximum Load, 134

Motor, 25, 33
  Focus Stage, 23
  XY Stage, 21
  Z Stage, 14

Motor Control, 76

N

Non-contact Mode AFM, 108

Non-linearity, 3, 90, 162

NX-Hivac Main System Cables, 42

O

Objective Lens, 23

Open Loop, 90, 146

Optical Alignment Knobs, 24

Optical Microscope, 23

Optics, 33

Orthogonality, 6

P

Piezoelectric, 3, 90, 162

Power, 28, 33, 36

Principle of
  Contact Mode, 96
  Tapping mode, 116
  Lateral Force Mode, 102
  Non-contact Mode, 108

Probehand, 16, 77

PSPD Alignment, 8, 20, 81

PSPD Alignment Knobs, 20, 81

Pull-Off, 134

Q

Q Control Mode, 136

Quad-cell PSPD, 2, 102

Quality Factor, 136

R

Reflection Angle, 96

Resonant Frequency, 55, 109, 116

Resonant Frequency Setup, 113, 120

Response Rate, 4

S

Sample Chuck, 23

Sample Loading, 69

Set Point, 83, 114, 120

SLD, iii, 8, 33

SLD Detector Chip Carrier, 169

Specifications, 33

SPM, 1

Spring Constant, 55, 98, 115

Standard Sample, 4, 98

Steering Mirror, 8, 20

STM, 1

System Layout, 37

T

Tiff, 94

Tip Bias, 16, 25, 89

Tip Convolution, 55

Tip Oscillation Mode, 122, 130

Topographic Information, 103

V

Van der Waals Force, 96, 108

Vertical Resolution, 92

Vibration Isolation System, 31

X

XEI, 10, 13

SmartScan, 10, 13, 73

SmartScan Parameters

- Offset X, Y, 88
- Repeat, 88
- Rotation, 88
- Scan OFF, 88
- Set Point, 89
- Slope, 88
- Tip Bias, 89
- Two way, 88
- X,Y, 88
- Z Servo, 89
- Z Servo Gain, 89

XY Detector, 146

XY Detector Calibration, 157

XY Scanner, 21, 33, 90, 92, 146

XY Scanner Calibration

- Closed Loop, 151
- Open Loop, 146

XY Servoscan, 90

XY Stage, 21, 33

Z

Z Scanner, 6, 15, 17, 33, 93, 153

Z Servo, 89

Z Stage, 33, 76

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If, during the course of using this manual, you come upon any errors, inaccuracies, or procedural inconsistencies, or if you have other content suggestions, please take the time to forward your comments to us for consideration in future manual revisions.

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Park Systems | The Most Accurate Atomic Force Microscope

Park SmartScan™ Operating Software User's Manual

Version 1.1 RTM13
2020-07-20

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Preface

This document is a reference manual for SmartScan operating software, which controls NX-series AFM instruments from Park Systems. This manual discusses in detail the software features of the SmartScan interface.

Unlike the User's Manual, which explains the operating procedures involved in analyzing a sequence of samples, this document describes, in detail, all features available in the NX data acquisition program. Therefore, users should become familiar with both manuals in order to efficiently the NX system. You may also selectively refer to this manual to clarify points made in the User's Manual.

This manual is organized to allow users to skip directly to items of interest. It begins with an introduction to SmartScan's main categories of operation. Next, the manual covers the overall features of the SmartScan screen. Finally, the manual details all control windows and their functions.

Contents

Chapter 1. Introduction to SmartScan 1

1-1. Introduction to the NX System Operating Software 1

1-2. The NX Data Acquisition Software...1

1-3. Save as TIFF..2

1-3-1. What is TIFF?..2

1-3-2. Why TIFF format?...2

1-4. Installing Park SmartScan Operating Software 3

1-4-1 SmartScan Installation 3

1-4-2. The SmartScan Splash Screen 7

1-4-3 Upgrading SmartScan Software 7

1-4-4. Backing up and Restoring the Database...8

1-4-5. Uninstalling a previous SmartScan version 9

1-5. Input Widgets..11

1-6. Hotkey List..12

1-7. TCP/IP Configuration for AFM Controller...13

1-8. GigE Viewer Installation and Ethernet Card Configuration...................15

1-8-1. Install GigE Viwer and Filter driver...15

1-8-2. Ethernet Card Configuration 16

Chapter 2. SmartScan Overview.. 20

2-1. The SmartScan Main Screen 20

2-2. Interface Functions...21

2-2-1. Title bar..21

2-2-1. Workspace and Mode Tabs...21

2-2-2. Auto Mode Sidebar 22

2-2-3. Sidebar (Toolbar) 23

Chapter 3. The Title bar 25

3-1. Park Systems Logo 25

3-2. SmartScan ▼ 26

3-2-1. Auto 27

3-2-2. Manual Mode 27

3-2-3. Browse Mode 27

3-2-4. Maintenance Mode 27

3-2-5. Login / Maint. Mode 27

3-2-6. Job Status 29

3-2-7. Copy/Capture Plots 29

3-2-8. Preference 30

3-2-9. Language 31

3-2-10. Logging window 31

3-2-11. Information 31

3-2-12. About 31

3-2-13. Exit 32

Chapter 4. The Auto Mode Sidebar 33

4-1. Setup 33

4-1-1. Probe Setup 33

4-1.2. Sample Setup 35

4-2. Position 36

4-3. Image 37

4-4. End 39

Chapter 5. The Sidebar 41

5-1. Z/Focus Stage 42

5-1-1. Z stage pad 42
5-1-2. Focus Stage Pad 42
5-1-3. Z Stage(μm) Digital Panel 43
5-1-4. Focus Stage(μm) Digital Panel 43
5-1-5. Stepwise Control 43
5-1-6. Key (Off/Z/Focus) 44
5-1-7. Reset Stages (Z/Focus) 44
5-1-8. Retract Z All 45
5-1-9. Approach 45
5-2. XY Stage 45
5-2-1. Key Enabled 46
5-2-2. X/Y Position (μm) 47
5-2-3. Stepwise Control 47
5-2-4. Reset 48
5-3. Frequency Sweep 48
5-3-1. Frequency Sweep Plot 49
5-3-2. Settings 51
5-3-3. Active Q-Control 52
5-3-4. Approach 55
5-3-5. Lift Z 55
5-3-6. Other Functions 56
5-4. PowerScript 57
5-5. Internal Lock-In 58
5-5-1. Lock-in Config 58
5-5-2. Modulator Config 59
5-6. StepScan 60
5-6-1. Postions and Methods 61

- 5-6-2. Method ... 62
- 5-7. Current Amplifier ... 64
- 5-7-1. Type ... 64
- 5-7-2. Internal Current Amplifier ... 64
- 5-7-3. Log Amplifier ... 65
- 5-7-4. External Current Amplifer ... 65
- 5-8. Aux DAC ... 66
- 5-9. TC-AE ... 67
- 5-9-1. Control ... 67
- 5-9-2. Data History ... 70
- 5-10. Support ... 70

Chapter 6. Auto Mode ... 73

- 6-1. Expanded Vision View ... 73
- 6-1-1. Current Field of View ... 75
- 6-1-2. PSPD ... 75
- 6-1-3. Vision Settings ... 76
- 6-1-4. Options ... 78
- 6-1-3. Guide ... 78
- 6-1-4. Marker ... 79
- 6-1-4. Ruler ... 79
- 6-1-5. PSPD when expanded ... 80
- 6-1-6. XY Stage ... 80
- 6-1-7. Z, Focus Stage ... 80
- 6-1-8. Light ... 81
- 6-1-9. Setting ... 81
- 6-1-10. Copy ... 81
- 6-1-11. Capture ... 81

    6-1-12. XY Stage Control 81
    6-1-13. Beam Control 82
  6-2. Control Parameters View 82
    6-2-1. Scan Config 82
    6-2-2. Date File Locations 84
    6-2-3. Z Servo 84
    6-2-4. Channels 87
  6-3. Scan Area View 91
  6-4. Scan Traces View 91

Chapter 7 Manual Mode 93

  7-1. Vision View 93
  7-2. Monitor View 95
    7-2-1. Head Tab 95
    7-2-2. Channels Tab 99
  7-3. Parameters View 99
    7-3-1. Setup 100
    7-3-2. Head Mode 100
    7-3.3 Scan and Spectroscopy 100

Chapter 8. Scan Control 101

  8-1. Scan Area View 102
    8-1-1. Scan Position View 103
    8-1-2. Displaying Scan Data 110
  8-2. Scan Traces View 112
    8-2-1. Auto Scale 113
    8-2-2. Rescale 113
    8-2-3. Relocate 113
    8-2-4. Add/Delete Plots 113

8-2-5. Previous/Next 114
8-2-6. Signal Name List 114
8-2-7. Cursor 114
8-2-8. Hold 116
8-2-9. Menu 116
8-3. Setup View 119
8-3-1. Channels 119
8-3-2. File 123
8-3-3. Palette 125
8-3-4. Options 127
8-3-5. Controls 127
8-4. Parameters View on Scan Control 132
8-4-1. Scan Rate 133
8-4-2. Z Slope 133
8-4-3. Scan Area 134
8-4-5. Z Servo 136
8-4-6. Bias 140
8-4-7. Options 142
8-4-8. Advanced 145
8-4-9. FM Mode (Only for NCM Head Mode) 167
8-4-9. Z Servo 168
8-4-10. XY Servo 169
8-4-11. Lift Scan 171
Chapter 9. Spectroscopy Control 173
9-1. Spectroscopy Parameters View 175
9-1-1. Start 177
9-1-2. Options 177

9-1-3. Presets 179

9-1-4. Calibration 179

9-1-5. Z Servo 184

9-1-6. XY Servo 184

9-2. Spectroscopy Positions View 184

9-2-1. Reference and Point List 185

9-2-2. Point Grid 187

9-2-3. Single Shot at Current xy 188

9-2-4. Repeat 188

9-2-5. Start 188

9-3. Data View 188

9-3-1. Axis Menu 189

9-3-2. Cursor 189

9-3-3. Copy Menu 189

9-4. Spectroscopy Data List View 190

9-4-1. Rescale 190

9-4-2. Relocate 190

9-4-3. Axis Menu 190

9-4-4. Copy Menu (Right) 191

9-5. F/d Spectroscopy 191

9-6. I/V Spectroscopy 194

9-7. Piezo Res Spectroscopy 196

9-8. Indent 199

9-8-1. Moving the Y Scanner During Indentation 202

9-9. A/d Spectroscopy 204

9-10. I/d Spectroscopy 206

9-11. ThA Spectroscopy 208

Chapter 10. Program Mode 211

10-1. XY Stage Area View 212

10-1-1. Select Mode 212

10-2. Control View 214

Chapter 11. Data Browsing 217

11-1. Directories and Files View 218

11-1-1. File Systems 218

10-1-2. Current Directory 219

11-1-3. Thumbnails 221

11-2. Image View 222

11-2-1. Displaying an Image in Image View 222

11-2-2. Pallete 223

11-2-3. Line Profile Indicators and Display 226

11-3. Information & Profile 227

11-3-1. Histogram 227

11-3-2. Information 228

11-4. Flattener 232

11-4-1. Flattening Method 232

11-4-2. Save 233

11-5. Histogram Equalization 233

Chapter 12. Maintenance 234

12-1. Vision View 234

12-2. Monitoring View 234

12-3. Setup View 235

12-3-1. Sweep Setup View 235

12-3-2. Calibration Setup View 235

12-4. Sweep Result 245

Chapter 13. Sweep Tests 249

13-1. Sweep Result Workspace 250

13-1-1. Horizontal Axis 251

13-1-2. Rescale 251

13-1-3. Relocate 251

13-1-4. Page Toggle 251

13-1-5. Previous / Next 251

13-1-6. Cursor Check Box 252

13-2. Sweep Control Tab 252

13-2-1. To Perform a Sweep Test 253

Index 259

Figures

Figure 1-1-1. SmartScan and XEI icons.. *1*

Figure 1-2-1. SmartScan interface.. *2*

Figure 1-4-1a to Figure 1-4-1h. SmartScan Installation Setup........................... *5*

Figure 1-4-2. Database (db) installation options.. *6*

Figure 1-4-3. Desktop after SmartScan installation.. *6*

Figure 1-4-4. SmartScan splash screen... *7*

Figure 1-4-5. Backing up the database... *8*

Figure 1-4-6. Restoring the database.. *8*

Figure 1-4-7. Uninstalling SmartScan with the Windows Control Panel........... *10*

Figure 1-4-8. Uninstalling SmartScan using the SmartScan installer............... *10*

Figure 1-7-1. Network and Sharing Center... *13*

Figure 1-7-2. Properties of Local Area Connection... *13*

Figure 1-7-3. Use the following IP address.. *14*

Figure 1-7-4. Rename.. *14*

Figure 1-8-1. Use the following IP address.. *15*

Figure 1-8-2. Fixed IP address, Auto-IP range. Windows................................. *16*

Figure 1-8-3. Intel adapter properties. (Windows 7, Intel Gigabit CT.).............. *17*

Figure 1-8-4. Intel adapter performance options. (Windows 7, Intel Gigabit CT.) *18*

Figure 1-8-4. Camera IP Configuration.. *19*

Figure 1-8-5. Camera IP Configuration.. *19*

Figure 2-1-1. The SmartScan main screen.. *20*

Figure 2-2-1. The SmartScan titlebar... *21*

Figure 2-2-2. Mode tabs... *22*

Figure 2-2-3. The auto mode sidebar.. *23*

Figure 2-2-4. The right sidebar 24

Figure 3-0-1. The titlebar 25

Figure 3-2-1. The SmartScan drop-down menu 26

Figure 3-2-3. Administrator login indicator 28

Figure 3-2-6. Copy and capture screen 30

Figure 4-1-1. The probe setup wizard 33

Figure 4-1-2a and 4-1-2b. Selecting a cantilever 34

Figure 4-1-3. Searching Cantilever, Beam alignment and PSPD adjustment ... 35

Figure 4-1-4. Changing a sample 36

Figure 4-2-1. Optical view of position 37

Figure 4-3-1. Optical view during imaging 38

Figure 4-4-1. Optical view during imaging session end 39

Figure 5-0-1. Frequently used items 41

Figure 5-1-1. Motor control window 42

Figure 5-1-2. Stepwise stage control 43

Figure 5-2-3. XY position display fields 47

Figure 5-2-4. Stepwise stage control 47

Figure 5-3-2. Cursors 50

Figure 5-3-3. Copying the frequency sweep plot 51

Figure 5-3-4. Active Q control settings 53

Figure 5-3-5. Frequency Sweep dialog during Q control Auto Phase 54

Figure 5-3-6. Changing NCM amplitude through the use of Q control 55

Figure 5-5-1 Internal lock-in config window 58

Figure 5-6-3. StepScan Method window 62

Figure 5-6-4. Expanded method sections 63

Figure 5-7-1. Internal Current Amplifier 65

Figure 5-7-2. External Current Amplifier 65

Figure 5-7-3. Aux DAC *66*

Figure 5-9-1. TC-AE Control & Monitor *67*

Figure 5-9-2. Copying TC-AE data *69*

Figure 5-10-1. Remote control confirmation dialog *71*

Figure 5-10-2. Teamviewer support window *71*

Figure 6-0-1. Auto mode workspace *73*

Figure 6-1-1. Current field of view *74*

Figure 6-1-2. Field of view controls *74*

Figure 6-1-4. Vision Settings window *76*

Figure 6-1-5. Presets window *77*

Figure 6-1-6. Options box *78*

Figure 6-1-7. Vision View with/without guides *78*

Figure 6-1-8. Vision View with Marker *79*

Figure 6-1-11. Z and focus stage pads *80*

Figure 6-2-1. Control Parameters View *82*

Figure 6-2-2. Custom pixel resolution *83*

Figure 6-2-3. Z Servo Config *85*

Figure 6-2-4. Advanced check box *87*

Figure 6-2-5. Channel Config window *88*

Figure 6-2-5. Preset Channels Panel *90*

Figure 6-2-6. Channel List and Mode *91*

Figure 7-0-1. Manual Mode Workspace *93*

Figure 7-1-1. Vision View and expanded Vision View *94*

Figure 7-2-1. Monitor View *95*

Figure 7-2-2. Quad-cell PSPD *96*

Figure 7-2-3. Z scanner bar *98*

Figure 7-2-4. Channels tab *99*

Figure 7-3-1. Software and hardware feature toggle buttons 99

Figure 7-3-2. Part Config.. 100

Figure 8-0-1. Scan mode interface.. 101

Figure 8-0-2. Scan Control workspace... 102

Figure 8-1-1. Toggle buttons for Scan Position and Scan Data 102

Figure 8-1-2. Scan Area View 103

Figure 8-1-3. Bounding the scan area.. 104

Figure 8-1-4. Zooming in to the scan area 105

Figure 8-1-5. Increasing (above) and decreasing (below) scan size 106

Figure 8-1-6. Tracker side adjustment.. 106

Figure 8-1-7. Changing scan location in the Scan Area View......................... 107

Figure 8-1-8. Rotating the scan area.. 108

Figure 8-1-9. Data Information window 109

Figure 8-1-10. Scan Data 110

Figure 8-1-11. Channel selector 110

Figure 8-1-12. Scan Trace oscilloscope window...111

Figure 8-1-13. Data thumbnails...111

Figure 8-2-1. Scan Traces View 112

Figure 8-2-2. Removing traces from a view 113

Figure 8-2-3. Input signals.. 114

Figure 8-2-4. Single and paired cursors.. 115

Figure 8-2-5. Scan Trace menu.. 116

Figure 8-2-6. Scan Trace options window... 118

Figure 8-3-1. Setup View.. 119

Figure 8-3-2. Channel Config window... 119

Figure 8-3-3. Preset Channels Panel.. 122

Figure 8-3-4. Channel List and Mode.. 122

Figure 8-3-5. Data File Information window *124*

Figure 8-3-6. Changing the image paletteEquation *125*

Figure 8-3-7. Equation Palette Selector *126*

Figure 8-3-8. Option view *127*

Figure 8-3-9. Approach Config dialog *129*

Figure 8-3-10. Saving Cantilever Postion *132*

Figure 8-3-11. Parameters View on Scan Control *132*

Figure 8-4-1 Concept of the Z servo in NC-AFM *137*

Figure 8-4-2 Concept of the set point in NC-AFM *139*

Figure 8-4-3. Bias tab *141*

Figure 8-4-4. Bias pulse generation *142*

Figure 8-4-5. Scan Options dialog *143*

Figure 8-4-6. Skip scan *145*

Figure 8-4-7. ARS Mode Config *146*

Figure 8-4-8. ARS Mode setup *146*

Figure 8-4-9. QuickStep Scan *147*

Figure 8-4-10. Scan rate feedback *147*

Figure 8-4-12. Error Bound *149*

Figure 8-4-13. PinPoint mode channels on an F/d curve *150*

Figure 8-4-14. PinPoint scanning control window *151*

Figure 8-4-15. Force constant of the three cantilevers and suitable sample modulus range *152*

Figure 8-4-29. PinPoint^{TM} Details Parameters *163*

Figure 8-4-30. Stiffness calculation in F/d curve *165*

Figure8-4-31. PinPointTM Details Parameters *166*

Figure 8-4-35. XY Servo Configuration dialog *169*

Figure 8-4-36. Lift scan *171*

Figure 9-1-1. Spectroscopy Control workspace *173*

Figure 9-1-2. Spectroscopy control workspace 174

Figure 9-1-3. Spectroscopy parameter View 175

Figure 9-1-4. Spectroscopy Options dialog 178

Figure 9-1-5. Spectroscopy calibration menu 180

Figure 9-1-6. Cantilever Sensitivity Calibration window 181

Figure 9-1-7. Cantilever Spring Constant Calibration window 182

Figure 9-1-8. Force Slope Calibration window 183

Figure 9-1-9. NCM Amplitude Calibration window 184

Figure 9-2-1. Spectroscopy Positions 185

Figure 9-2-2. Moving a spectroscopy point. Left: original position and movement direction; right: final position after move. 186

Figure 9-2-3. Moving all spectroscopy points. Left: original position and movement direction; right: final position after move. 187

Figure 9-2-4. Point grid setup and grid box 188

Figure 9-3-1. Data View Axis menu 189

Figure 9-3-2. Single cursor example 189

Figure 9-3-3. Copy menu pop-up box 189

Figure 9-4-1. Spectroscopy data axis 190

Figure 9-5-1. F/d spectroscopy parameters 191

Figure 9-6-1. I/V Spectroscopy parameters 194

Figure 9-7-1. Piezo Res Spectroscopy parameters 196

Figure 9-9-1. A/d spectroscopy control window 204

Figure 9-10-1. I/d spectroscopy control window 206

Figure 9-11-1. ThA spectroscopy control window 208

Figure 10-1-1. Program Mode workspace 211

Figure 10-1-2. XY Stage View workspace 212

Figure 10-1-3. Column mode 212

Figure 10-1-4. Cell mode 213

Figure 10-1-5. Popup mode *213*

Figure 10-2-1. Control View workspace *214*

Figure 10-2-2. Method window workspace *215*

Figure 10-2-3. Data file information window.. *215*

Figure 10-2-4. PowerScript window *216*

Figure 11-1-1. Data browsing and file view control *217*

Figure 11-1-2. File system and view *218*

Figure 11-1-3. Using the filter criteria field *219*

Figure 11-1-4. Advanced Filter dialog *220*

Figure 11-1-5. Select Columns dialog and example *220*

Figure 11-2-1. Image View *222*

Figure 11-2-2. Changing the image palette... *223*

Figure 11-2-3. Palette panel... *224*

Figure 11-2-4. Contrast range adjustment *225*

Figure 11-2-5. Contrast level adjustment *226*

Figure 11-2-6. Line profile indicators and panel... *226*

Figure 11-3-2. Information table example *228*

Figure 11-3-3. The Flattener tab... *232*

Figure 12-1-1. The maintenance mode workspace *234*

Figure 12-3-1. Z Scanner calibration setup.. *235*

Figure 12-3-2. XY scanner calibration setup.. *238*

Figure 12-3-3. XY scanner calibration example *239*

Figure 12-3-4. Cantilever calibration setup *242*

Figure 12-3-5. Cantilever Offsets setup *244*

Figure 12-3-6. Log Amplifier setup... *244*

Figure 12-4-1 Sweep Result workspace *245*

Figure 12-4-2. Horizontal Axis button with Driving Channel selected *246*

Figure 13-0-1 Sweep plotting *249*

Figure 13-1-1 Sweep Result View *250*

Figure 13-1-2. Changing horizontal axis *251*

Figure 13-1-3. Cursors *252*

Figure 13-2-1. Sweep control tab *253*

Figure 13-2-2. Driving source and definition of From/To and Period *254*

Figure 13-2-3. Preset channels for sweep tests *256*

Figure 13-2-4. Creating a custom preset *256*

Figure 13-2-5. Channel Config *257*

Chapter 1. Introduction to SmartScan

This chapter introduces SmartScan, the TIFF data format used to store images, and SmartScan installation procedures.

1-1. Introduction to the NX System Operating Software

Park Systems NX-series AFM instruments include two software applications, SmartScan and XEI. SmartScan is used to operate and control the NX hardware system. XEI is the image processing and analyzing tool for use with previously acquired data. This document focuses on the SmartScan software. For information on processing images with XEI, please consult the XEI software manual. Figure 1-1-1 shows the icons for SmartScan and XEI.

Figure 1-1-1. SmartScan and XEI icons

1-2. The NX Data Acquisition Software

SmartScan, the NX operating software, communicates with the NX control electronics and thereby controls the NX AFM system. This program is used to collect sample data. Figure 1-2-1 shows the SmartScan interface.

This manual provides instructions on how to use the SmartScan software to control the NX system. For example, using SmartScan, you can select a wide variety of measurement modes, depending on the properties of the samples you want to observe. These modes include contact AFM, non-contact AFM (NC-AFM), Tapping mode microscopy (Tapping), lateral force microscopy (LFM), electrostatic force microscopy (EFM), and others. Also, you can adjust several parameters for taking a measurement of your sample. This manual describes, in detail, what each parameter means and how these parameters are applied to the images so that you can acquire more accurate images. In addition, it is recommended that you read this software manual together with the User’s Manual in order to best understand the NX system operation and the variety of operating modes.

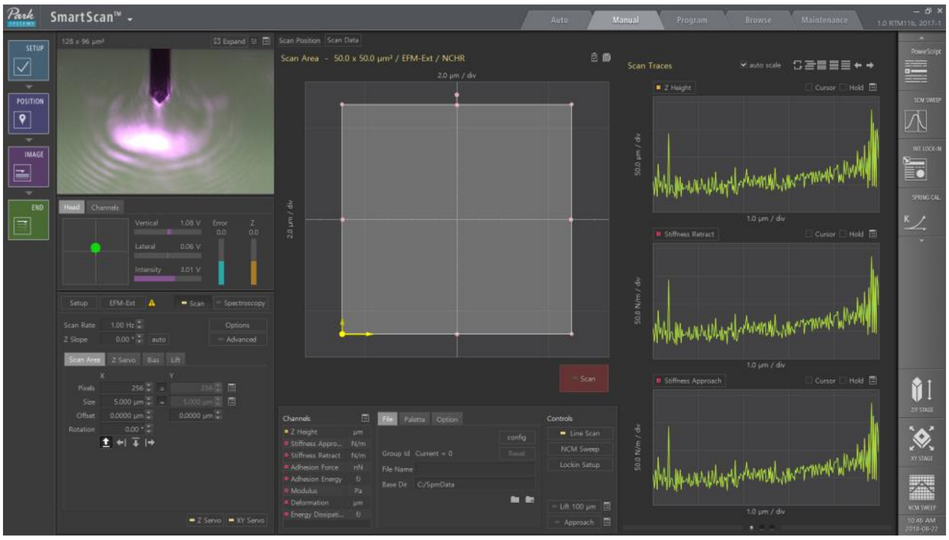


Figure 1-2-1. SmartScan interface

1-3. Save as TIFF

1-3-1. What is TIFF?

Tagged Image File Format, maintained by Adobe Systems, is a format for storing images together with arbitrary “tag” data. The TIFF format is supported by most image viewers.

1-3-2. Why TIFF format?

The data files produced by conventional AFM instruments are not stored in a common image file format. To see these acquired images in an image viewer and the traditional Windows Explorer display, it is necessary to convert the file format saved by individual AFM instruments into an image file format by using image processing software.

If the collected data is saved as a common image file format, it may be convenient to view the images without any special software conversion process. However, this is difficult since conventional image file formats include only image data (RGB) and cannot save the large amount of sample data measured by NX systems.

The TIFF format retains the better aspects of these two options, allowing AFM images to be opened by common image viewers, as well as losslessly storing all AFM data.

1-4. Installing Park SmartScan Operating Software

The SmartScan software for NX systems is compatible with all variants of the Windows 7 operating system.

1-4-1 SmartScan Installation

1. **Start SmartScan**

   Locate and double-click the SmartScan X.X.X.exe file on the SmartScan software CD.

2. **Start the SmartScan Setup Wizard**

   Click **Next** to continue installation setup as shown in Figure 1-4-1a. It is recommended that you close all other applications before continuing.

3. **Read and agree to the license agreement**

   Read the license agreement. You must accept this agreement before continuing with the installation by checking **I accept the agreement** and clicking **Next** to continue setup as shown in Figure 1-4-1b.

4. **Select a Destination Directory**

   By default, the setup wizard will create the Park Systems folder in the root directory (C:\) of the hard drive. This is the base directory of the NX software. You may select a different destination directory by clicking **Browse**. Click **Next** as shown in Figure 1-4-1c to continue.

5. **Create the database**

   If a previously installed database is found on the system, you will be asked to specify an installation option for the database file. Available options are **Clean**, **Backup**, and **Retain** (see Figure 1-4-2).

   - **Clean** will install a default database file. This file will contain the correct software calibration for your system and will require you to recalibrate your scanners from scratch.
   - **Backup** will install a default database file and backup the original file in the C:\Park Systems\bin folder.
   - **Retain** will keep the original file in the C:\Park Systems\bin

folder, and no other database file will be installed.

6. **Select a Start Menu Folder**

   To create application shortcuts in the selected Start Menu folder, check **Create shortcuts for all users**. To continue, click **Next** as shown in Figure 1-4-1d.

7. **Select additional installation options**

   Select additional tasks you would like Setup to perform while installing SmartScan. Currently, **Create a desktop icon** is selectable. If desired, check this box, and then click **Next** as shown in Figure 1-4-1e.

8. **Begin installation**

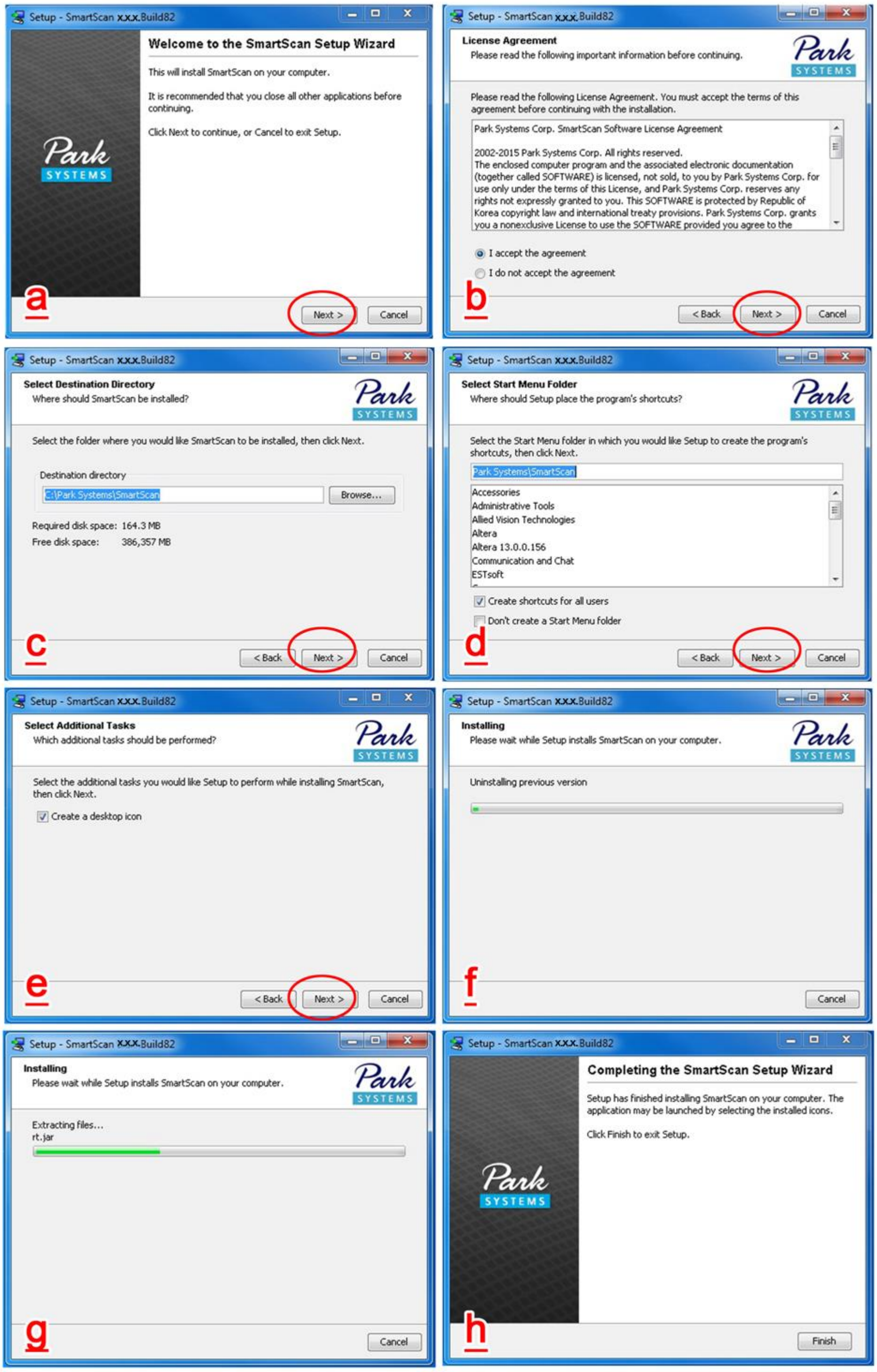
   The SmartScan software will begin installing. Please wait until installation is finished before continuing. Refer to Figure 1-4-1f and Figure 1-4-1g. To stop installation, click **Cancel**.

9. **Complete the SmartScan Setup Wizard**

   Once setup has completed, click **Finish** as shown in Figure 1-4-1h.

10. **Configure SmartScan**

    Once SmartScan is installed, a dialog box will appear to confirm the desired Database Installation Options. Refer to Figure 1-4-2. But if you do not have existing database files, you will need to configure the software for the system. Please contact your local Park Systems representative for the database files or instructions to proceed with the configuration process. See Section 1-4-3 for instructions on restoring database files.



a

Setup - SmartScan x.x.x.Build82

Welcome to the SmartScan Setup Wizard

This will install SmartScan on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

b

Setup - SmartScan x.x.x.Build82

License Agreement

Please read the following important information before continuing.

Please read the following License Agreement. You must accept the terms of this agreement before continuing with the installation.

Park Systems Corp. SmartScan Software License Agreement

2002-2015 Park Systems Corp. All rights reserved.
The enclosed computer program and the associated electronic documentation (together called SOFTWARE) is licensed, not sold, to you by Park Systems Corp. for use only under the terms of this License, and Park Systems Corp. reserves any rights not expressly granted to you. This SOFTWARE is protected by Republic of Korea copyright law and international treaty provisions. Park Systems Corp. grants you a nonexclusive License to use the SOFTWARE provided you agree to the

● I accept the agreement
○ I do not accept the agreement

c

Setup - SmartScan x.x.x.Build82

Select Destination Directory

Where should SmartScan be installed?

Select the folder where you would like SmartScan to be installed, then click Next.

Destination directory: C:\Park Systems\SmartScan

Required disk space: 164.3 MB
Free disk space: 386,357 MB

d

Setup - SmartScan x.x.x.Build82

Select Start Menu Folder

Where should Setup place the program's shortcuts?

Select the Start Menu folder in which you would like Setup to create the program's shortcuts, then click Next.

Park Systems\SmartScan

Accessories
Administrative Tools
Allied Vision Technologies
Altera
Altera 13.0.0.156
Communication and Chat
ESTsoft

☑ Create shortcuts for all users
☐ Don't create a Start Menu folder

e

Setup - SmartScan x.x.x.Build82

Select Additional Tasks

Which additional tasks should be performed?

Select the additional tasks you would like Setup to perform while installing SmartScan, then click Next.

☑ Create a desktop icon

f

Setup - SmartScan x.x.x.Build82

Installing

Please wait while Setup installs SmartScan on your computer.

Uninstalling previous version

g

Setup - SmartScan x.x.x.Build82

Installing

Please wait while Setup installs SmartScan on your computer.

Extracting files...
rt.jar

h

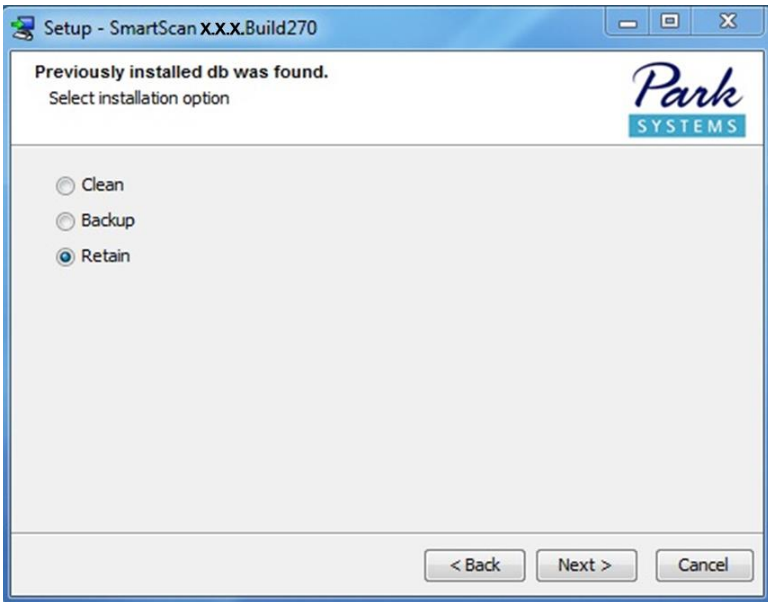
Setup - SmartScan x.x.x.Build82

Completing the SmartScan Setup Wizard

Setup has finished installing SmartScan on your computer. The application may be launched by selecting the installed icons.

Click Finish to exit Setup.

Figure 1-4-1a to Figure 1-4-1h. SmartScan Installation Setup



Setup - SmartScan X.X.X.Build270

Previously installed db was found.

Select installation option

○ Clean

○ Backup

● Retain

Figure 1-4-2. Database (db) installation options

When installation completes, SmartScan will create the folder C:\Park Systems\SmartScan. If you selected the option to create a desktop shortcut, SmartScan will create the icon, as well as a Start Menu shortcut as shown in Figure 1-4-3.

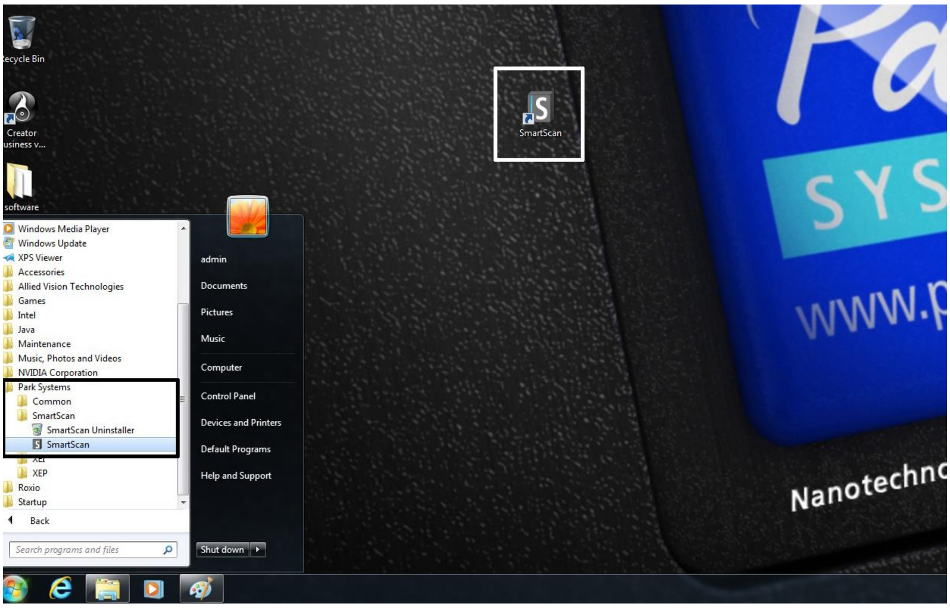


Figure 1-4-3. Desktop after SmartScan installation

1-4-2. The SmartScan Splash Screen

Clicking the SmartScan icon (S) will start the SmartScan application. The SmartScan splash screen will appear, displaying the software build number and date.

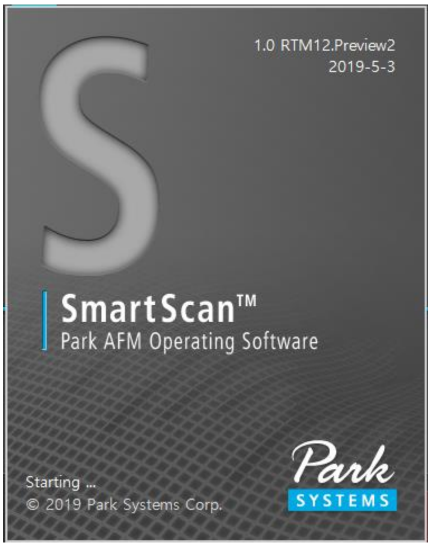


Figure 1-4-4. SmartScan splash screen

1-4-3 Upgrading SmartScan Software

Each system has a unique database file used to identify scanning modes and provide parameters needed for scanner calibration. This information is stored in the spm.db file. This database file must be backed up and restored prior to a software upgrade. It is good practice to keep a clean copy of these files in a safe location so that you can revert to the last known stable configuration in the event of a problem. These files will be needed if the system is installed on a new computer or if an issue occurs during scanner calibration. Follow the procedure below to upgrade SmartScan.

1. Backup the current SmartScan installation

   For details, refer to Section 1-4-4 below.

2. Run the SmartScan installer

   For details, refer to Section 1-4-1 above.

3. Restore the database

   For details, refer to Section 1-4-4 below.

1-4-4. Backing up and Restoring the Database

1. Backing up the current SmartScan installation

   Copy the SmartScan folder, located at C:\Park Systems**.** Rename the existing SmartScan folder as **SmatScan-Copy**. Then paste the original SmartScan folder into the directory.

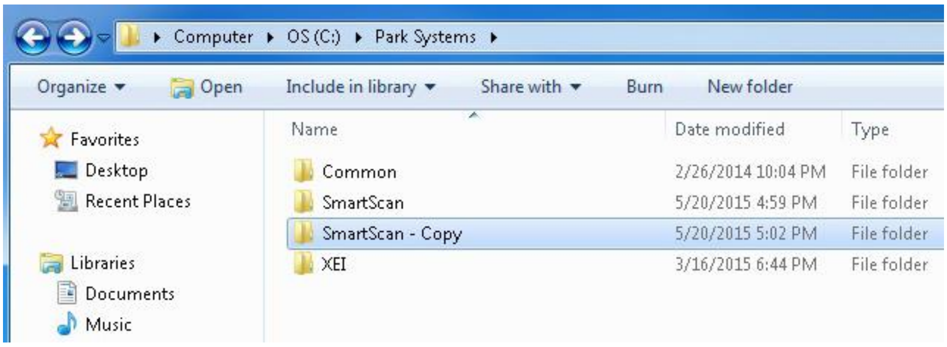

Computer ▸ OS (C:) ▸ Park Systems ▸
Organize ▾
Open
Include in library ▾
Share with ▾
Burn
New folder
Favorites
Desktop
Recent Places
Libraries
Documents
Music
Name
Date modified
Type
Common 2/26/2014 10:04 PM File folder
SmartScan 5/20/2015 4:59 PM File folder
SmartScan - Copy 5/20/2015 5:02 PM File folder
XEI 3/16/2015 6:44 PM File folder

Figure 1-4-5. Backing up the database

2. Restoring the database

   After installing the new SmartScan version, copy C:\Park Systems\SmartScan-Copy\bin\spmV2.db and then paste the database file to C:\Park Systems\SmartScan\bin.

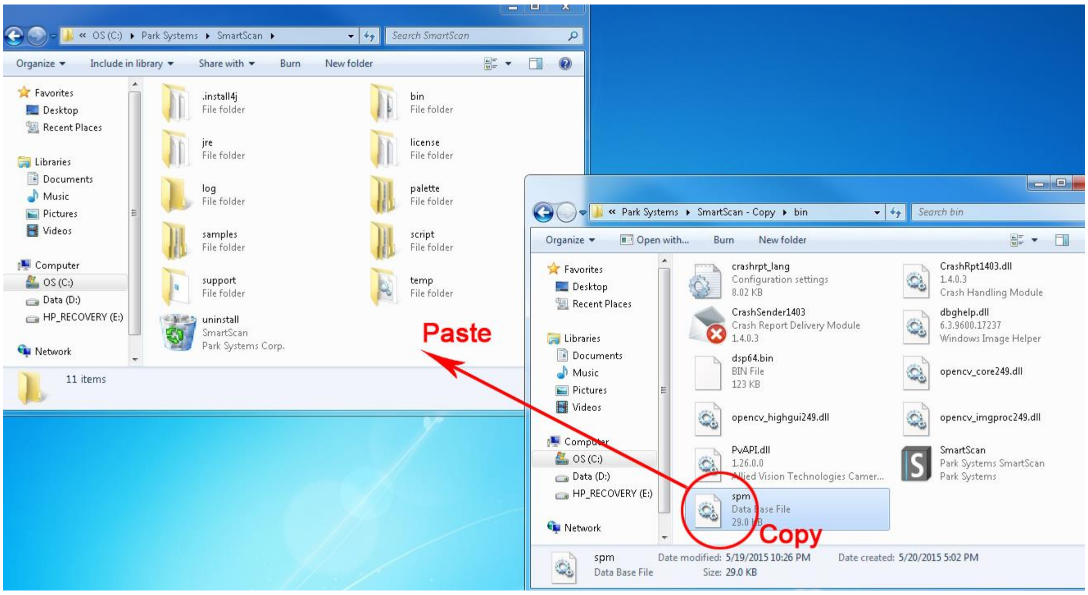

« OS (C:) ▸ Park Systems ▸ SmartScan ▸
Search SmartScan
.install4j File folder
bin File folder
jre File folder
license File folder
log File folder
palette File folder
samples File folder
script File folder
support File folder
temp File folder
uninstall SmartScan Park Systems Corp.
11 items
Paste
« Park Systems ▸ SmartScan - Copy ▸ bin
Search bin
crashrpt_lang Configuration settings 8.02 KB
CrashRpt1403.dll 1.4.0.3 Crash Handling Module
CrashSender1403 Crash Report Delivery Module 1.4.0.3
dbghelp.dll 6.3.9600.17237 Windows Image Helper
dsp64.bin BIN File 123 KB
opencv_core249.dll
opencv_highgui249.dll
opencv_imgproc249.dll
PvAPI.dll 1.26.0.0 Allied Vision Technologies Camer...
SmartScan Park Systems SmartScan Park Systems
spm Data Base File 29.0 KB
Copy
spm Data Base File Date modified: 5/19/2015 10:26 PM Size: 29.0 KB Date created: 5/20/2015 5:02 PM

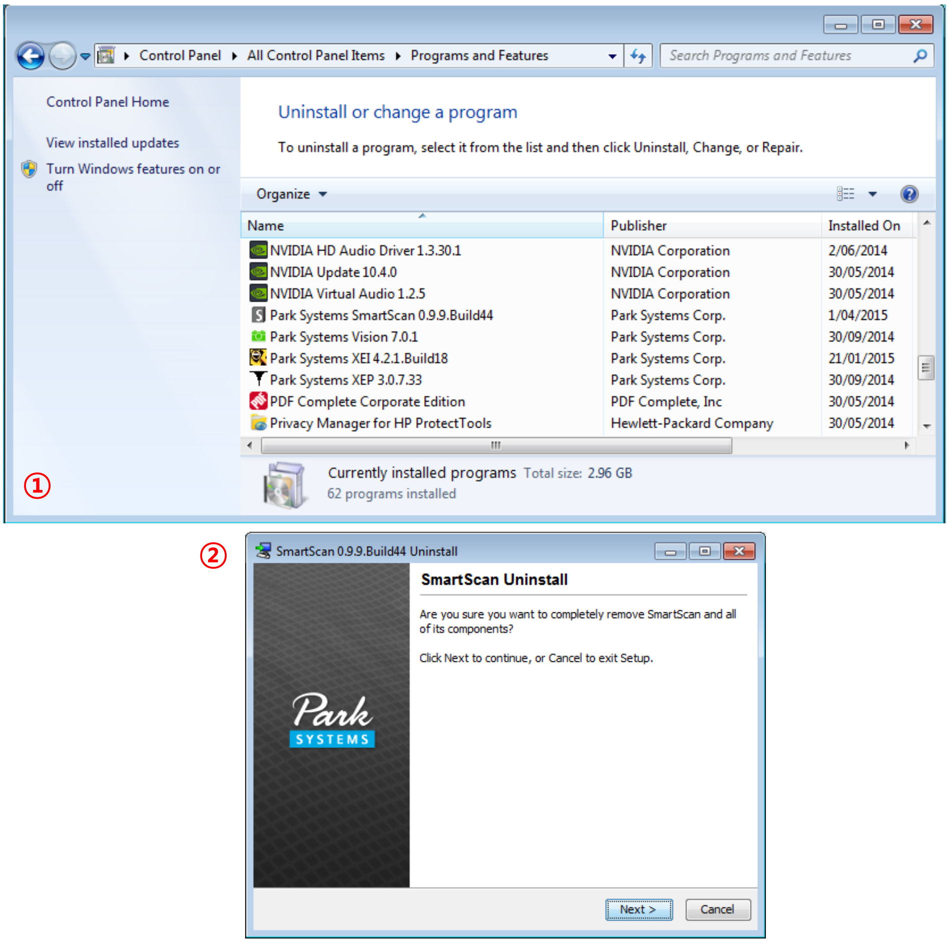
Figure 1-4-6. Restoring the database

1-4-5. Uninstalling a previous SmartScan version

If you have a previous version of Park Systems SmartScan installed on your computer, you should first backup the current SmartScan database files (see Section 1-4-4) and then remove the previous version of SmartScan using the Windows Control Panel or the SmartScan installer.

Removing SmartScan using the Windows Control Panel

1. Select **Park Systems SmartScan** in the **Uninstall or change a program** option found in the Windows Control Panel.
2. The SmartScan Uninstall dialog appears. Click **Next** to proceed with uninstallation.
3. The **SmartScan was successfully removed from the computer** message is generated when SmartScan is successfully removed. Click **Finish** to close the SmartScan Uninstall dialog.



①
②
Control Panel ▸ All Control Panel Items ▸ Programs and Features
Search Programs and Features
Control Panel Home
View installed updates
Turn Windows features on or off
Organize
Next >
Cancel

Uninstall or change a program

To uninstall a program, select it from the list and then click Uninstall, Change, or Repair.

Name	Publisher	Installed On
NVIDIA HD Audio Driver 1.3.30.1	NVIDIA Corporation	2/06/2014
NVIDIA Update 10.4.0	NVIDIA Corporation	30/05/2014
NVIDIA Virtual Audio 1.2.5	NVIDIA Corporation	30/05/2014
Park Systems SmartScan 0.9.9.Build44	Park Systems Corp.	1/04/2015
Park Systems Vision 7.0.1	Park Systems Corp.	30/09/2014
Park Systems XEI 4.2.1.Build18	Park Systems Corp.	21/01/2015
Park Systems XEP 3.0.7.33	Park Systems Corp.	30/09/2014
PDF Complete Corporate Edition	PDF Complete, Inc	30/05/2014
Privacy Manager for HP ProtectTools	Hewlett-Packard Company	30/05/2014

Currently installed programs Total size: 2.96 GB
62 programs installed

SmartScan 0.9.9.Build44 Uninstall

SmartScan Uninstall

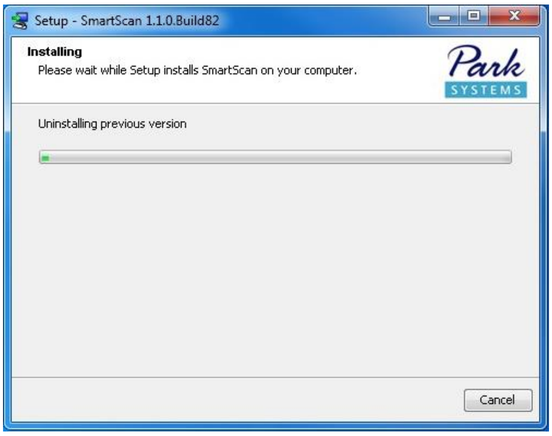
Are you sure you want to completely remove SmartScan and all of its components?

Click Next to continue, or Cancel to exit Setup.

Figure 1-4-7. Uninstalling SmartScan with the Windows Control Panel

Removing SmartScan using the SmartScan installer

To uninstall SmartScan using the installer, simply run the installer.



Setup - SmartScan 1.1.0.Build82

Installing

Please wait while Setup installs SmartScan on your computer.

Uninstalling previous version

Figure 1-4-8. Uninstalling SmartScan using the SmartScan installer

1-5. Input Widgets

Option button

An option dialog appears when this icon is clicked.

Spinner buttons

Click ▲ and ▼ to increment or decrement a value.

Radio button

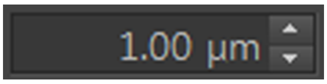
Select one among mutually exclusive options.

Check box

Toggle an option.

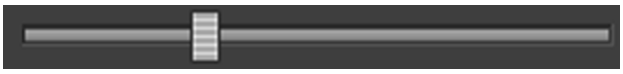
Combo box

Select from among several preset options.



Text field

Enter a value with the keyboard.


Slider

Click and drag ▲ to adjust the value.

1-6. Hotkey List

Hotkey (General)	**Description**
CTRL + 1	Auto mode
CTRL + 2	Manual mode
CTRL + 4	Browse
CTRL + 5	Maintenance
CTRL + C	Copy plots
CTRL + Space	Vision expand toggle

Hot Key (Plots)	**Description**
ESC, CTRL + Y	Auto mode
I, O	Zoom in (**I**) or out (**O**) around the mouse cursor position
Space, Enter	Autoscale plots to contents
Key Arrow	Panning
+, -	Zoom in, zoom out

1-7. TCP/IP Configuration for AFM Controller

1. a) Control Panel >> Network and Sharing Center

   or b) you can click the icon from Right-bottom side of monitor.

   For details, refer to Section 1-7-1 below.

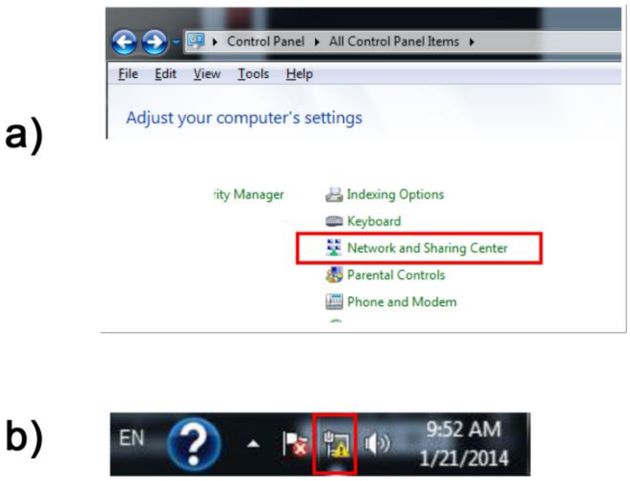


Figure 1-7-1. Network and Sharing Center

2. c) Network and Sharing Center >> Change adapter setting

   d) Mouse right click to the Local Area Connection >> Properties

   For details, refer to Section 1-7-2 above.

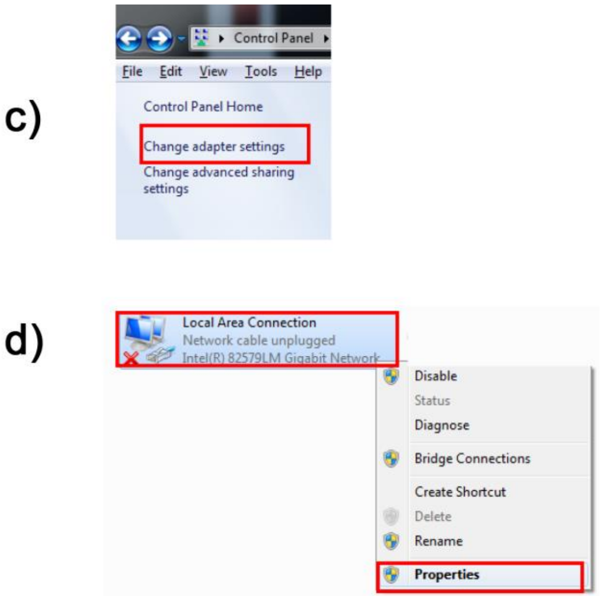


Figure 1-7-2. Properties of Local Area Connection

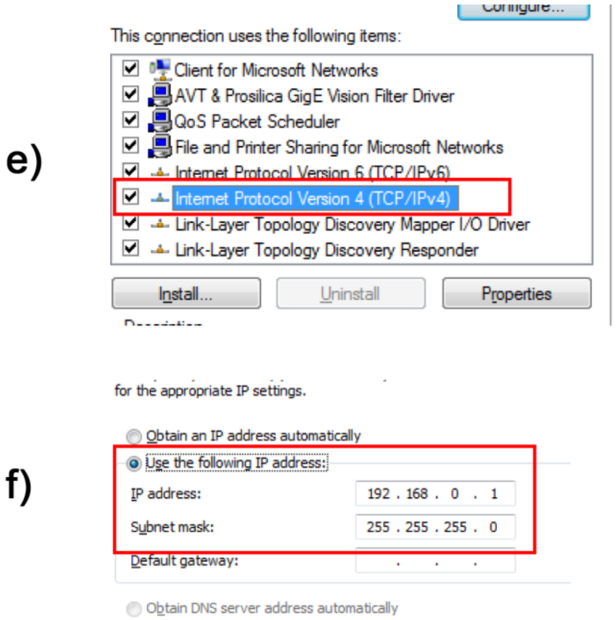
3. e) Properties >> Double click to Internet Protocol Version 4 (TCP/IPv4)

   f) Use the following IP address

   IP Address: 192.168.0.1

   Subnet mask: 255.255.255.0

   For details, refer to Section 1-7-3 below.



This connection uses the following items:

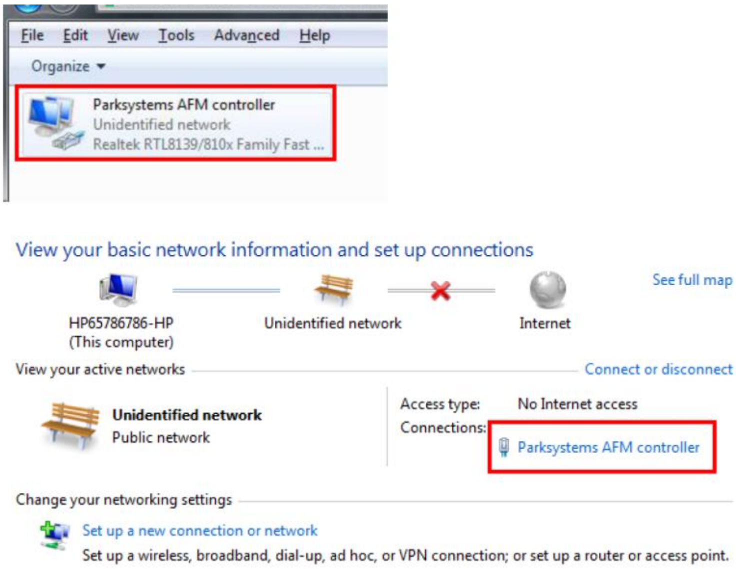
☑ Client for Microsoft Networks
☑ AVT & Prosilica GigE Vision Filter Driver
☑ QoS Packet Scheduler
☑ File and Printer Sharing for Microsoft Networks
☑ Internet Protocol Version 6 (TCP/IPv6)
☑ Internet Protocol Version 4 (TCP/IPv4)
☑ Link-Layer Topology Discovery Mapper I/O Driver
☑ Link-Layer Topology Discovery Responder

for the appropriate IP settings.

○ Obtain an IP address automatically
● Use the following IP address:
IP address: 192 . 168 . 0 . 1
Subnet mask: 255 . 255 . 255 . 0
Default gateway: . . .
○ Obtain DNS server address automatically

Figure 1-7-3. Use the following IP address

4. Rename “Local Area Connection” as “ParkSystems AFM Controller”.



Parksystems AFM controller
Unidentified network
Realtek RTL8139/810x Family Fast ...

View your basic network information and set up connections

View your active networks

Unidentified network
Public network

Access type: No Internet access
Connections: Parksystems AFM controller

Change your networking settings

Set up a new connection or network
Set up a wireless, broadband, dial-up, ad hoc, or VPN connection; or set up a router or access point.

Figure 1-7-4. Rename

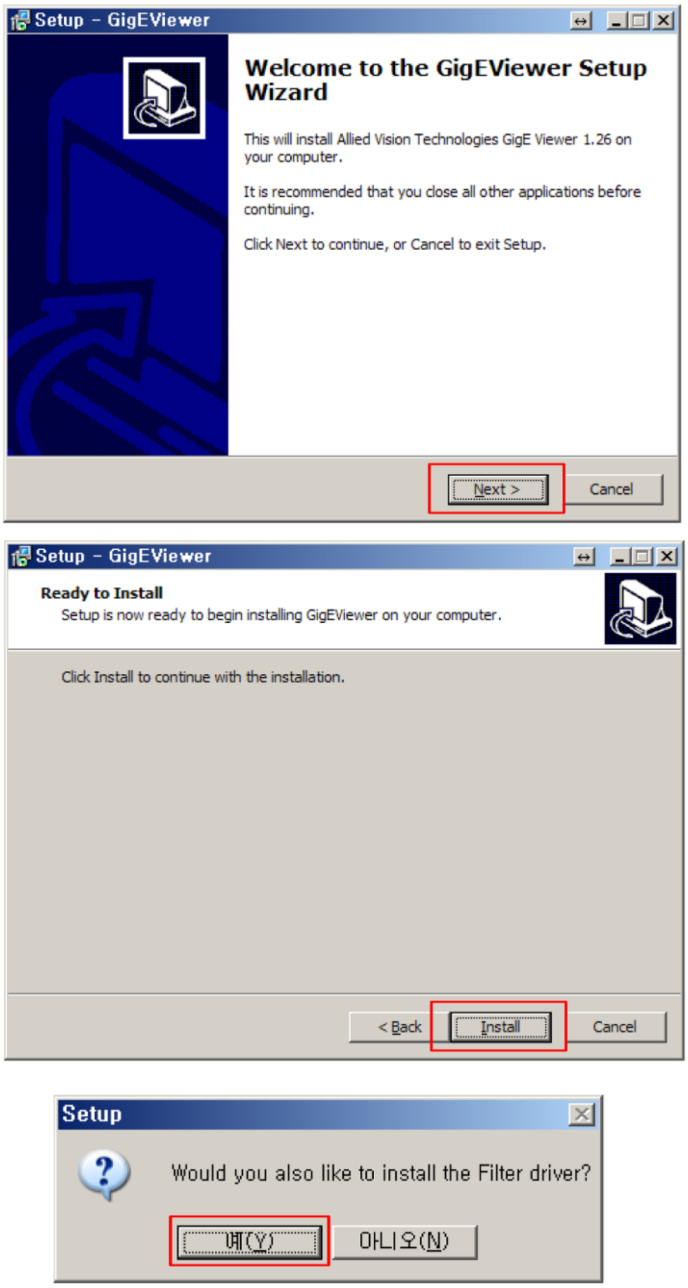
1-8. GigE Viewer Installation and Ethernet Card Configuration

1-8-1. Install GigE Viwer and Filter driver

1. GigE Sample Viewer for Windows v1.26 >> Next >> Install > Yes

   Download and install GigE Viewer and the install Filter driver also.

   For details, refer to Section 1-8-1 below.



Welcome to the GigEViewer Setup Wizard

This will install Allied Vision Technologies GigE Viewer 1.26 on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.

Ready to Install

Setup is now ready to begin installing GigEViewer on your computer.

Click Install to continue with the installation.

Would you also like to install the Filter driver?

Figure 1-8-1. Use the following IP address

1-8-2. Ethernet Card Configuration

1. Set up to Ethernet adapter IP.

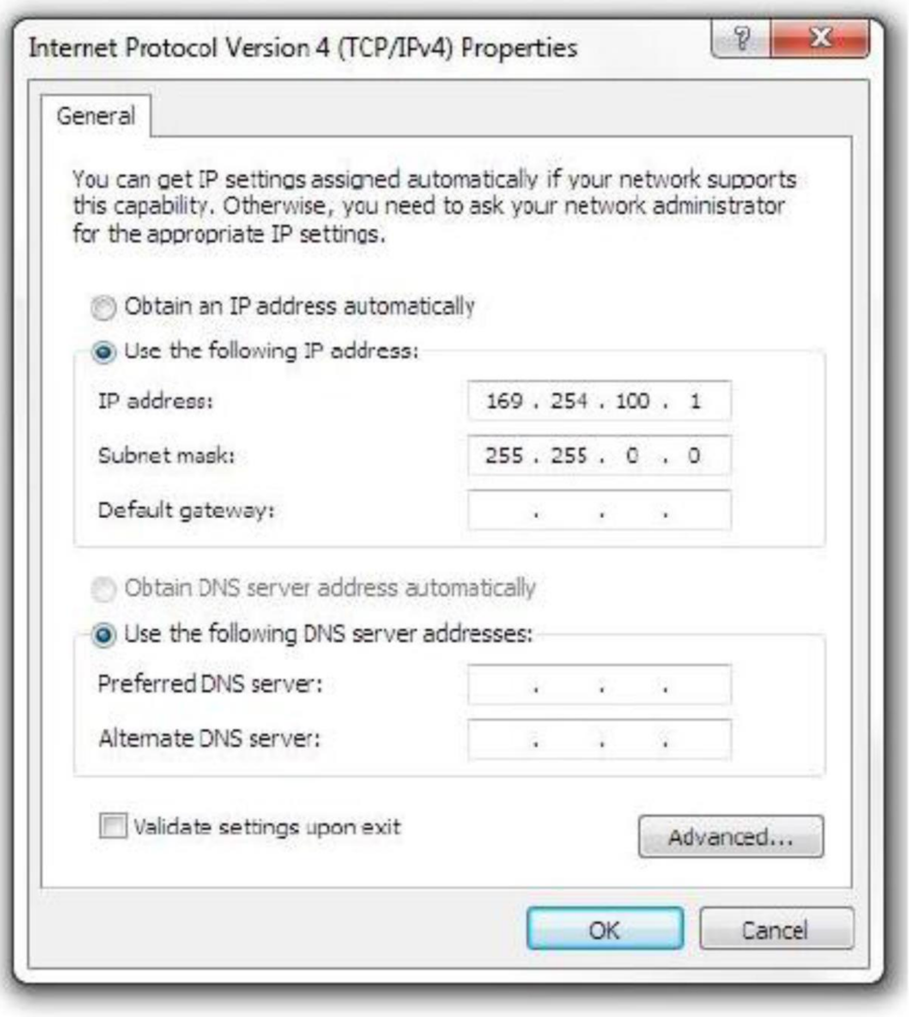
   Window start >> Control Panel >> Network and Internet >> View network status and tasks >> Change adapter settings >> Right click Network Connection >> Properties >> Select Internet Protocol Version 4 Click Properties >> Select Use the following IP address

   IP Address: 169.254.100.1

   Subnet mask: 255.255.0.0

   Default gateway: blank

   For details, refer to Section 1-8-2 below.



Internet Protocol Version 4 (TCP/IPv4) Properties

You can get IP settings assigned automatically if your network supports this capability. Otherwise, you need to ask your network administrator for the appropriate IP settings.

○ Obtain an IP address automatically
● Use the following IP address:
IP address: 169 . 254 . 100 . 1
Subnet mask: 255 . 255 . 0 . 0
Default gateway: . . .

○ Obtain DNS server address automatically
● Use the following DNS server addresses:
Preferred DNS server: . . .
Alternate DNS server: . . .

☐ Validate settings upon exit

Figure 1-8-2. Fixed IP address, Auto-IP range. Windows.

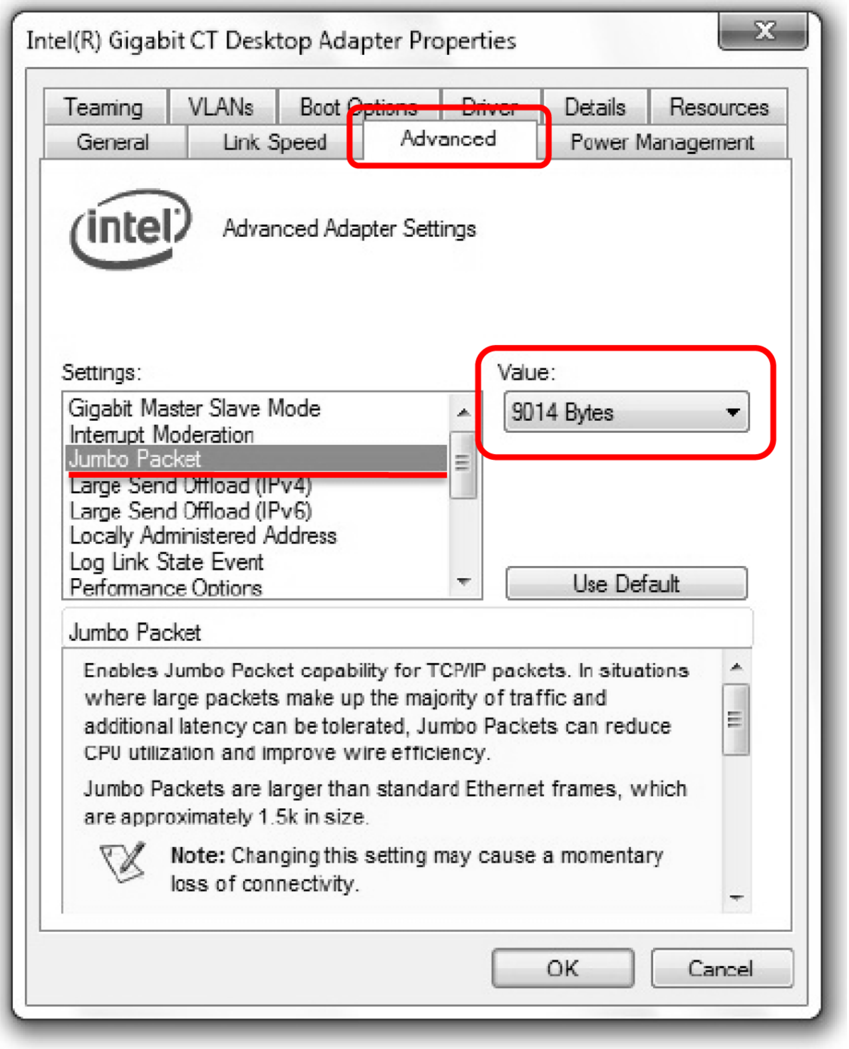
2. Camera packet size

Adjust camera packet size (Windows 7, Intel Gigabit CT)

Window start >> Control panel >> Hardware and sound >> Device Manager >> Network Adapter >> Right click adapter device name >> Properties >> Advanced tab >> Settings

Settings: Jumbo Packet

Value: 9014 Bytes


Intel(R) Gigabit CT Desktop Adapter Properties
Teaming
VLANs
Boot Options
Driver
Details
Resources
General
Link Speed
Advanced
Power Management
intel
Advanced Adapter Settings
Gigabit Master Slave Mode
Interrupt Moderation
Large Send Offload (IPv4)
Large Send Offload (IPv6)
Locally Administered Address
Log Link State Event
Performance Options
Use Default
OK
Cancel

Settings: Jumbo Packet

Value: 9014 Bytes

Jumbo Packet

Enables Jumbo Packet capability for TCP/IP packets. In situations where large packets make up the majority of traffic and additional latency can be tolerated, Jumbo Packets can reduce CPU utilization and improve wire efficiency.

Jumbo Packets are larger than standard Ethernet frames, which are approximately 1.5k in size.

Note: Changing this setting may cause a momentary loss of connectivity.

Figure 1-8-3. Intel adapter properties. (Windows 7, Intel Gigabit CT.)

3. Buffers and moderation rate

   Adjust buffers and moderation rate (Windows 7, Intel Gigabit CT)

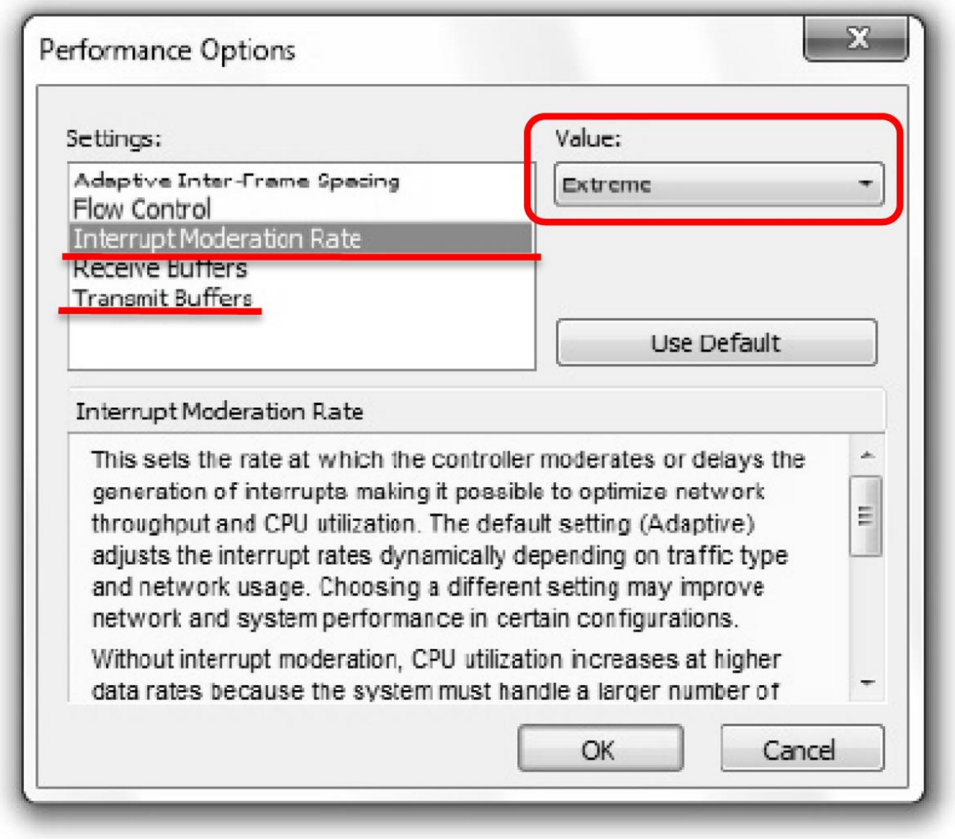
   Window start >> Control panel >> Hardware and sound >> Device Manager >> Network Adapter >> Right click adapter device name >> Properties >> Advanced tab >> Performance Options

   Settings: Interrupt Moderation rate

   Value: Extreme

   Settings: Transmit Buffers

   Value: 256 bytes



Performance Options

Settings:

Adaptive Inter-Frame Spacing
Flow Control
Interrupt Moderation Rate
Receive Buffers
Transmit Buffers

Value: Extreme

Interrupt Moderation Rate

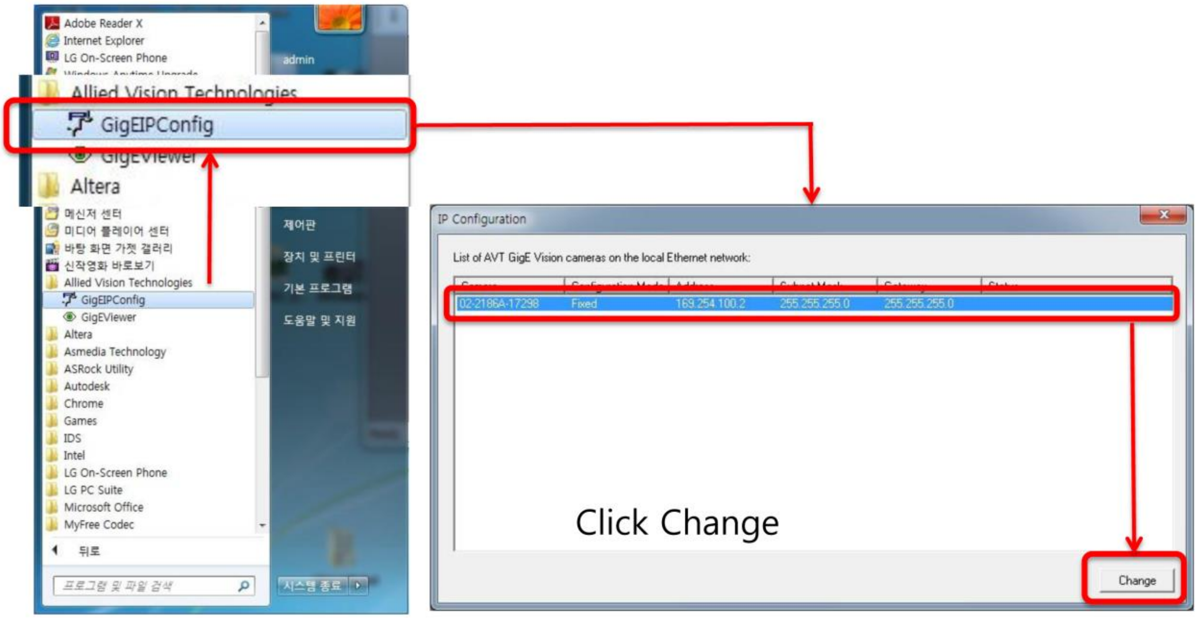
This sets the rate at which the controller moderates or delays the generation of interrupts making it possible to optimize network throughput and CPU utilization. The default setting (Adaptive) adjusts the interrupt rates dynamically depending on traffic type and network usage. Choosing a different setting may improve network and system performance in certain configurations.

Without interrupt moderation, CPU utilization increases at higher data rates because the system must handle a larger number of

Figure 1-8-4. Intel adapter performance options. (Windows 7, Intel Gigabit CT.)

4. Camera IP

a) Start >> Allied Vision Technologies >> Execute “GigE IP Config”

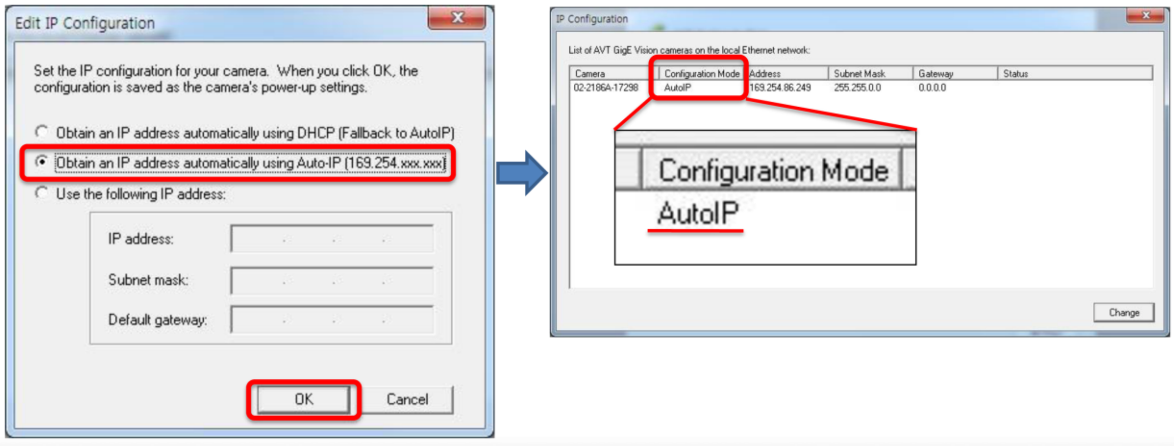


List of AVT GigE Vision cameras on the local Ethernet network:

Camera	Configuration Mode	Address	Subnet Mask	Gateway	Status
02-2186A-17298	Fixed	169.254.100.2	255.255.255.0	255.255.255.0	

Figure 1-8-4. Camera IP Configuration

b) Select ‘Obtain an IP address automatically’ and then click “OK”. Confirm IP Configuration is modified to “AutoIP’



Set the IP configuration for your camera. When you click OK, the configuration is saved as the camera's power-up settings.

○ Obtain an IP address automatically using DHCP (Fallback to AutoIP)

● Obtain an IP address automatically using Auto-IP (169.254.xxx.xxx)

○ Use the following IP address:

List of AVT GigE Vision cameras on the local Ethernet network:

Camera	Configuration Mode	Address	Subnet Mask	Gateway	Status
02-2186A-17298	AutoIP	169.254.86.249	255.255.0.0	0.0.0.0	

Figure 1-8-5. Camera IP Configuration

Chapter 2. SmartScan Overview

This chapter provides an overview of all available features found in SmartScan and is a good starting point for becoming more familiar with the software.

2-1. The SmartScan Main Screen

Start SmartScan by double-clicking the SmartScan icon () on your computer desktop. As shown in Figure 2-1-1, the main components of the SmartScan software consist of the title bar, mode tabs, the auto mode sidebar, the right sidebar, and the workspace. There is a separate workspace for each item in the menu bar.

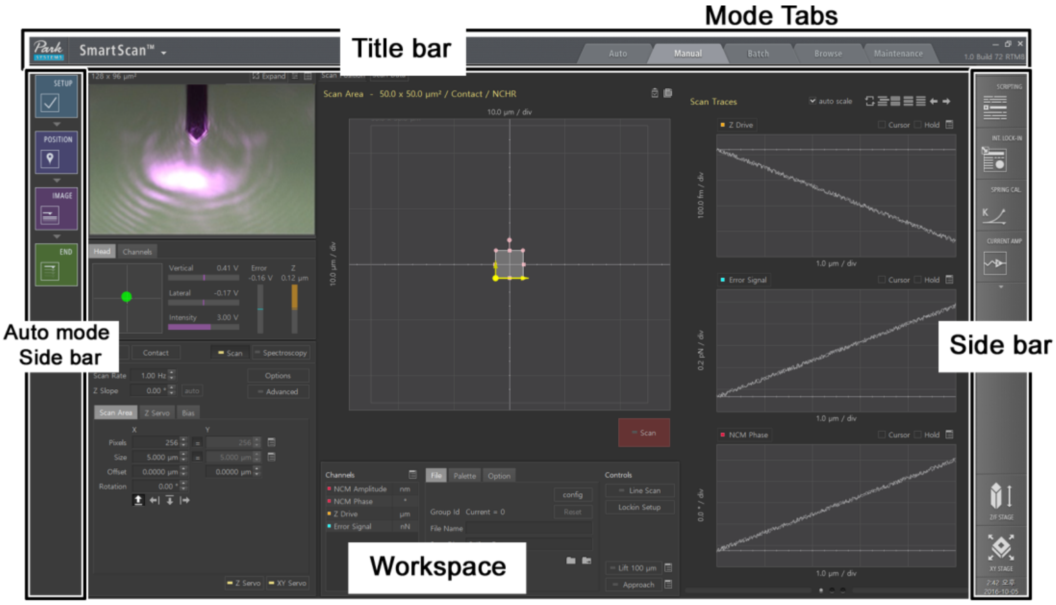


Figure 2-1-1. The SmartScan main screen

2-2. Interface Functions

2-2-1. Title bar

The title bar displays application and job status. It features controls for basic operations, such as connecting to the controller, copying/capturing plots, changing the workspace, and setting preferences. A more detailed explanation is provided in Chapter 3, The Title bar. Figure 2-2-1 shows the title bar and its items.

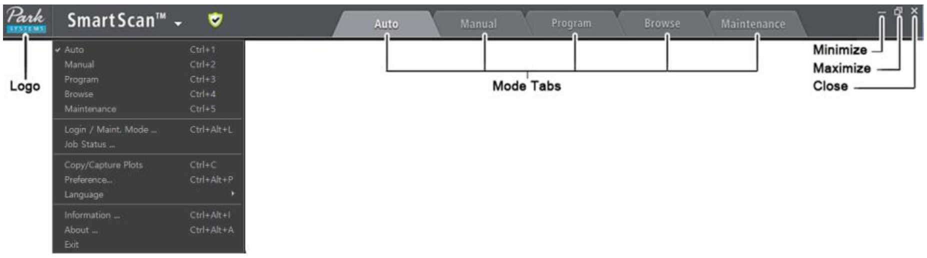


Figure 2-2-1. The SmartScan titlebar

2-2-1. Workspace and Mode Tabs

The centermost area of the screen is the workspace. The workplace display can be changed using the mode tabs. Mode tabs provide one-click access to the workspace panel. Figure 2-2-2 shows the different workspace configurations for the various mode tabs. More information about the mode tabs can be found in Chapter 3.

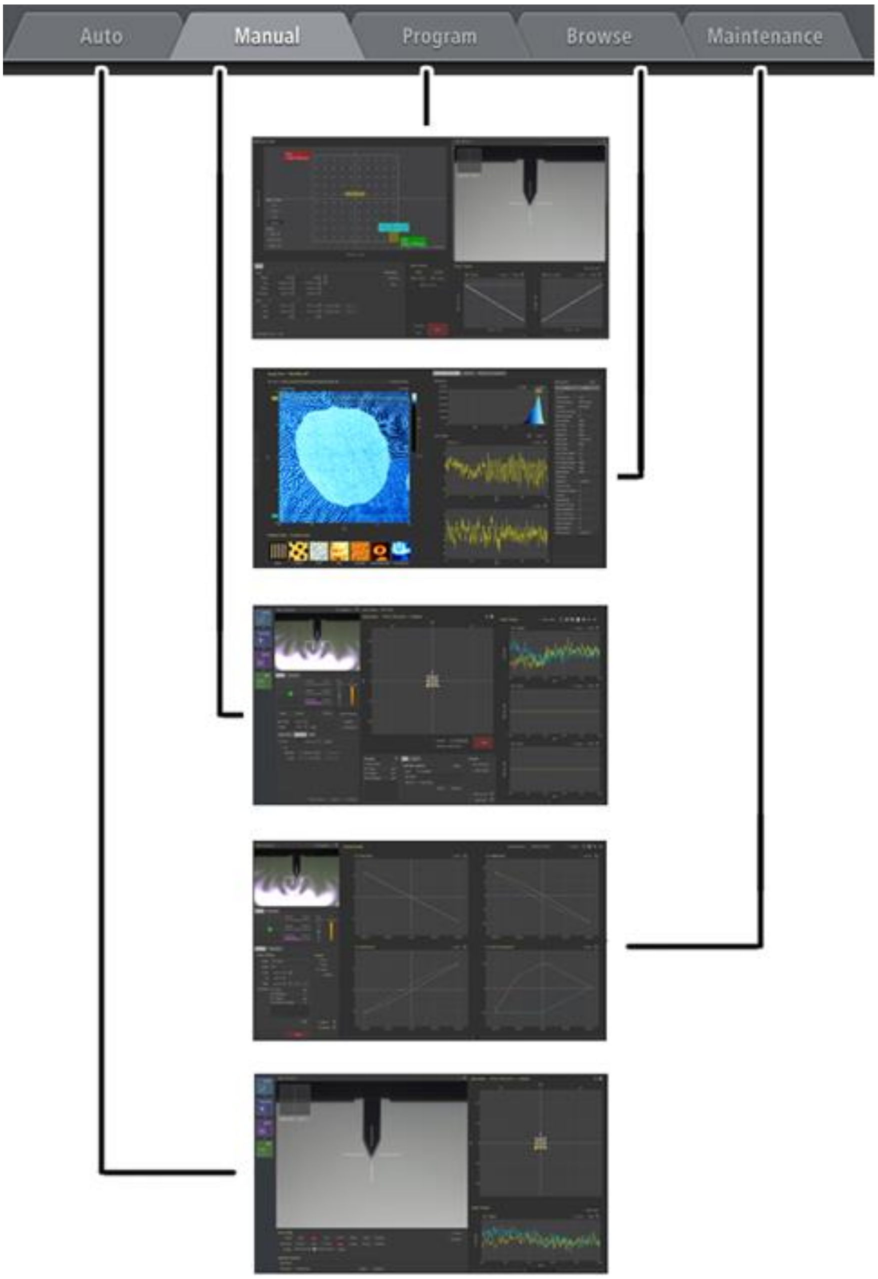


Figure 2-2-2. Mode tabs

2-2-2. Auto Mode Sidebar

The auto mode sidebar offers buttons for step-by-step operation, from setup to image end in auto image scanning mode. A more detailed description of the buttons in this sidebar can be found in Chapter 4. Figure 2-2-3 shows the auto mode sidebar buttons.

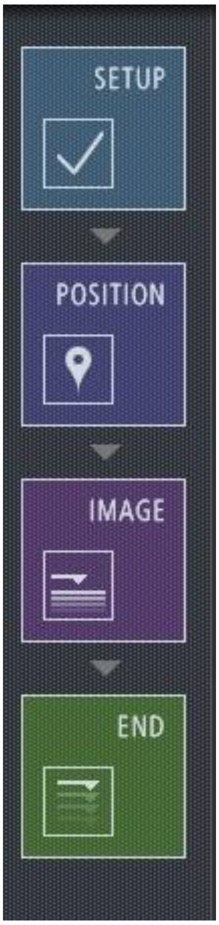


Figure 2-2-3. The auto mode sidebar

2-2-3. Sidebar (Toolbar)

The right sidebar offers icons for direct access to menu items not directly related to scan control but still frequently used depending on the user’s application or sample positioning. A more detailed description of the right sidebar can be found in Chapter 5. The Sidebar. Figure 2-2-4 shows the right sidebar and related windows.

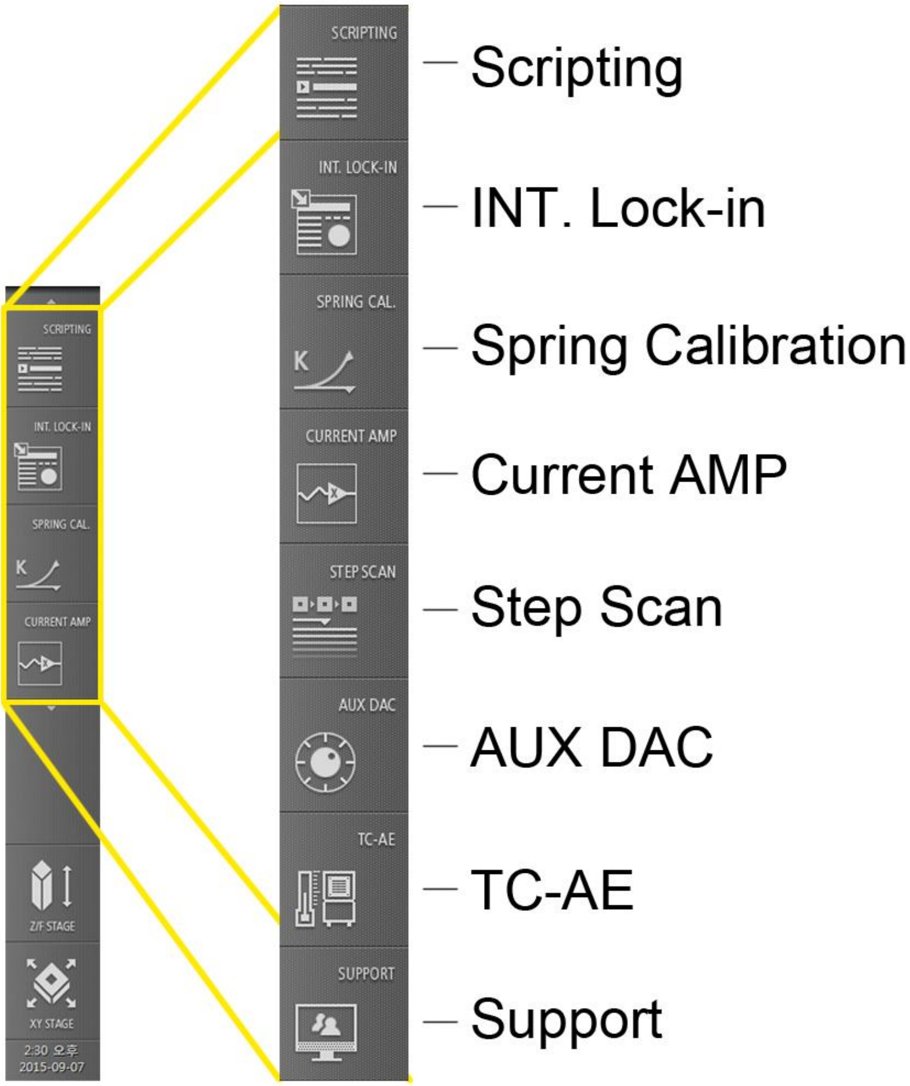


Figure 2-2-4. The right sidebar

Chapter 3. The Title bar

The title bar offers basic software controls and is shown in Figure 3-0-1.

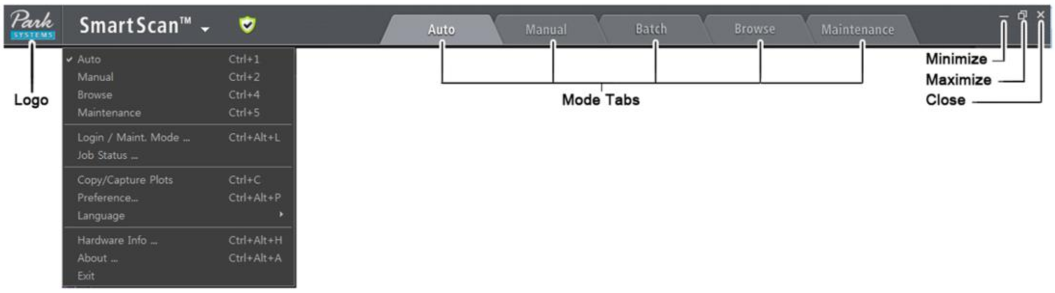


Figure 3-0-1. The titlebar

3-1. Park Systems Logo

The first item of the title bar is the Park Systems logo. Clicking this logo will take you to the Park Systems website. This feature does not function correctly if your PC is not connected to the Internet.

Click

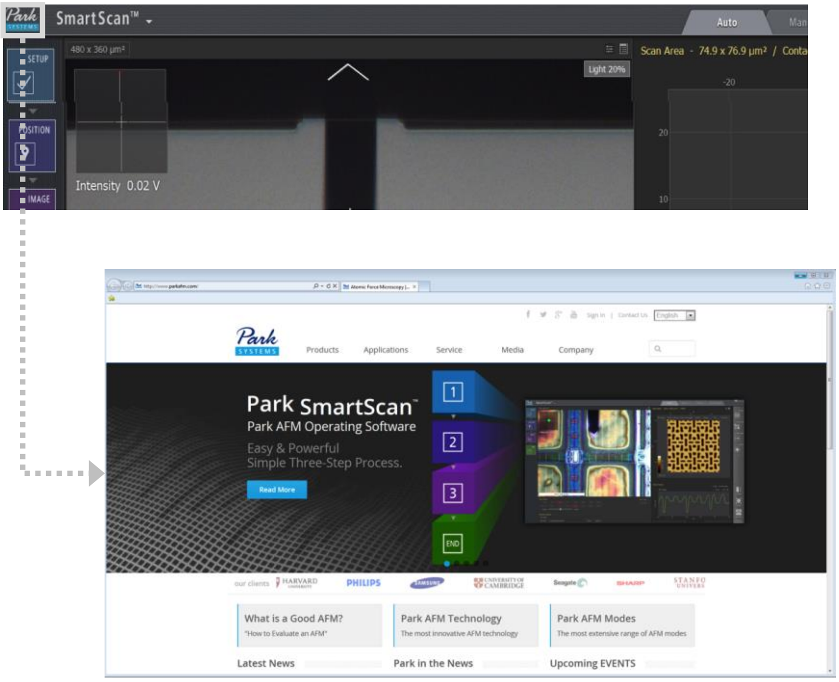


Figure 3-1-1. The Park Systems website

3-2. SmartScan ▼

The SmartScan drop-down menu displays basic software control options when clicked.

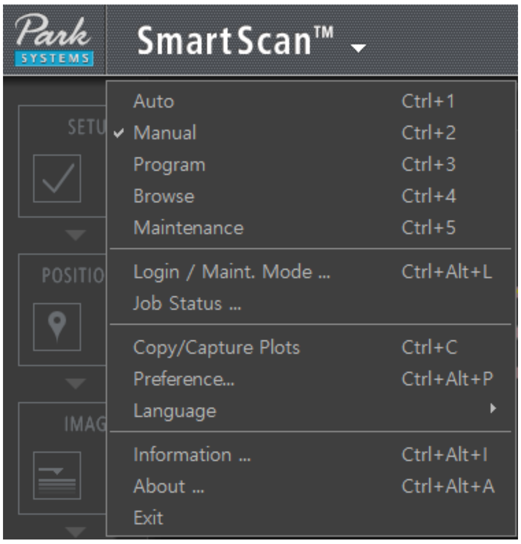


Figure 3-2-1. The SmartScan drop-down menu

3-2-1. Auto

Selecting **Auto** (or pressing **CTRL+1**) loads the auto mode workspace. The auto mode workspace can also be displayed by choosing the **Auto** tab in the title bar. Auto mode provides a four-step process for image acquisition. See Chapter 4 for more information.

3-2-2. Manual Mode

Selecting **Manual** (or pressing **CTRL+2**) loads the manual mode workspace. The manual mode workspace can also be displayed by choosing the **Manual** tab in the title bar. Manual mode provides an interface for common tasks, including:

- Preparation—beam alignment, frequency sweeps
- Monitoring—oscilloscope trace
- Measurement—scan, advanced, and option parameters

More information on manual mode can be found in Chapter 7.

3-2-3. Browse Mode

Clicking **Browse** (or pressing **CTRL+3**) loads the data browsing workspace. The data browsing workspace can also be displayed by choosing the **Browse** tab in the title bar. The data browsing workspace displays previously taken images and provides basic data analysis capabilities. See Chapter 8 for more information on browse mode.

3-2-4. Maintenance Mode

Maintenance mode displays a workspace for system maintenance, sweep tests (called trace mode tests in XEP), and scanner calibration. To enter maintenance mode, click **Maintenance** in the drop-down application menu or select the **Maintenance** tab in the title bar. See Chapter 11 for more information on maintenance mode.

3-2-5. Login / Maint. Mode

Selecting **Login/Maint. Mode** opens a dialog window (Figure 3-2-2) to enter maintenance mode. Maintenance mode unlocks various features in the software, such as calibration parameters.

The default admin password is **probe**.

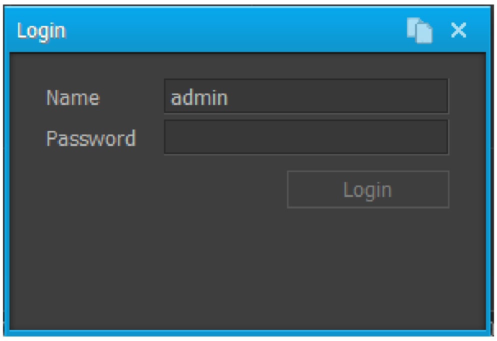


Figure 3-2-2. Maintenance mode login

When logged in as administrator in maintenance mode, a small checkmark will appear next to the SmartScan drop-down menu.

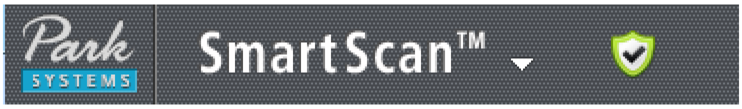
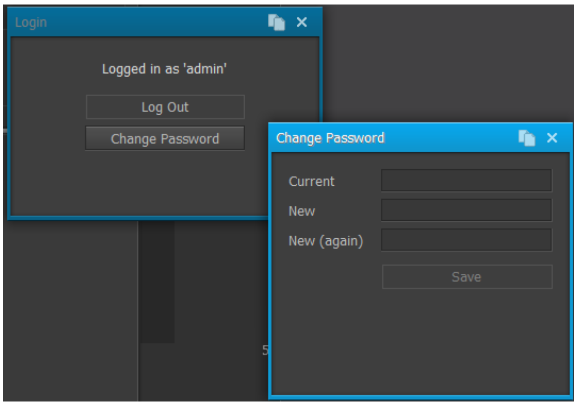


Figure 3-2-3. Administrator login indicator

Log Out/Password Change

When logged in as administrator, the Login window will display login status, as well as options for logging out and changing the admin password. Click **Log Out** to log out as administrator. Click **Change Password** to open the Change Password dialog. To change the password, enter the current password, the new password, and its verification. Figure 3-2-4 shows both the Login and Change Password dialogs.

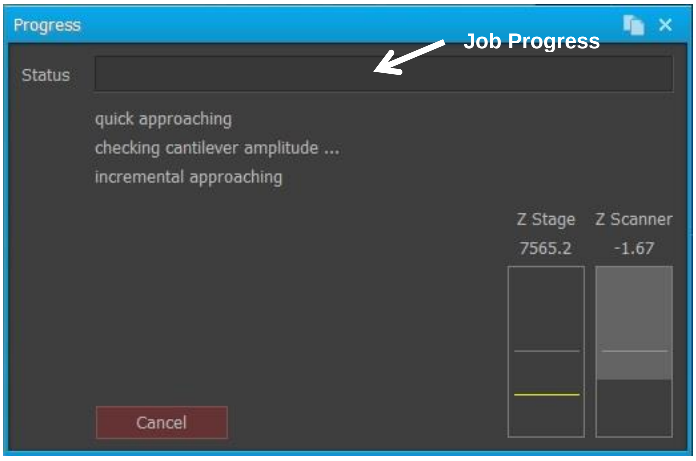


Logged in as 'admin'

Figure 3-2-4. Login and Change Password dialogs

3-2-6. Job Status

The Job Status dialog displays the status of various software operations. Progress displays are available for system startup, system shutdown, approach, and scripting processes.



Job Progress

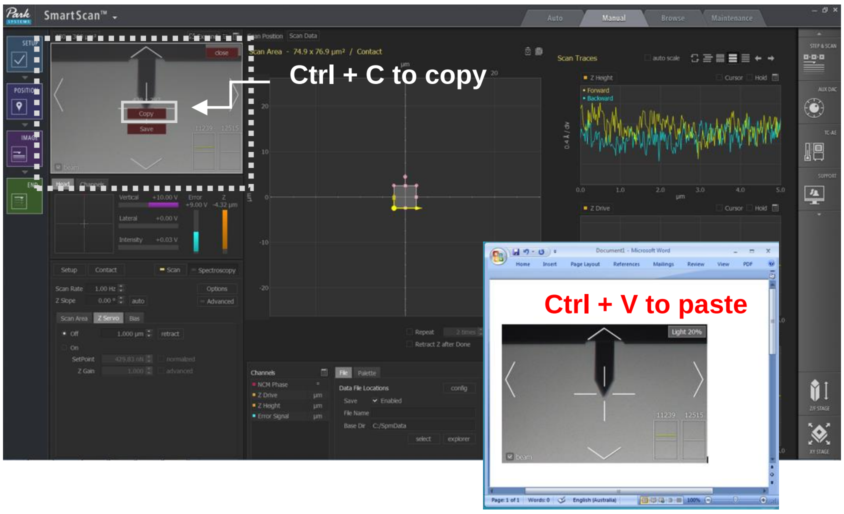
quick approaching
checking cantilever amplitude ...
incremental approaching

Z Stage 7565.2
Z Scanner -1.67

Figure 3-2-5. Progress indicator display

3-2-7. Copy/Capture Plots

Data and images from the vision, scan area, and trace list objects can be copied and exported. When **Copy/Capture** is selected, the item under the cursor is highlighted in light grey. Select the highlighted item by left-clicking on it. Then click **Copy** to store the image on your clipboard or **Save** it as an image file. If copied to your clipboard, you can paste the copied data to other software such as Microsoft Word.



Ctrl + C to copy

Ctrl + V to paste

Figure 3-2-6. Copy and capture screen

3-2-8. Preference

Preferences allow you to set features and values that are less commonly used.

Start Up

Set initial scan size to zero

Perform a zero scan when the program is rebooted or initialized.

Skip initial NCM frequency sweep

Do not perform an NCM frequency sweep after initial startup or a program reboot.

Do not show stage reset dialog

The “stage reset” window, which asks whether the user wants to reset the stage, can be disabled when the AFM controller is restarted. However, if Park XEP and Park SmartScan are used at the same time, the stage must be reset manually.

(Adimin) Safety

Turn off safety interlock if admin (PSPD or AUX)

When the beam is turned on with the AFM Head connected, when there is a difference of more than 3.0 V compared to the initial Deflection value, and when there is a difference of more than Min. Intensity compared to the initial Intensity value, the interlock only operates in these cases. If the initial Intensity value is less than Min. Intensity, the interlock will not work. Min. Intensity is located within 'Cantilever DB'.

When in head mode using Aux2 Signal (AUX1, Hysitron), If Aux2 In Signal exceeds the -9 V to +9 V range, Interlock will operate.

Turn off head crash prevention if admin (Z Detector)

The Z stage’s safety interlock is designed to prevent the probehand from being crushed due to a collision between the tip and sample.

(A user can log in to enable or disable this feature.)

Turn off application level interlock if admin

As a function that enables you to respond to potential and risks of accidents on your PC, you can disable the feature in the Preferences window, such as the existing Interlock features. Only possible if you are logged in as admin.

Others

Ignore beam intensity when evalulating PSPD status

If the beam intensity value on the PSPD is above 1 V due to hardware or experimental constraints, then the system will automatically generate an error message alarming the user that the laser is not properly aligned on the cantilever or the Z stage interlock is automatically enabled. Hoverer, it is possible to toggle this restrictive feature on and off.

3-2-9. Language

Clicking **Language** displays a change to 4 languages (English, Korean, Japanese, Chinese) in software.

3-2-10. Logging window

The log window allows you to read through software messages indicating issues that occur during program operations. There is also the ability to log Servo-related Channel and Z Detector Channel values periodically when Z Stage moves. Logging Window Menu is only marked when Login as Admin.

3-2-11. Information

Clicking **Language** displays a change to 4 languages (English, Korean, Japanese, Chinese) in software.

3-2-12. About

Clicking **About** displays a dialog with hardware and software information.

SmartScan Info

Software information includes build date, number, and version.

Hardware Info

Clicking **Hardware Info** displays hardware information such as board revision, firmware revision, firmware I/D and DSP code version.

License Info

SmartScan software uses some LGPL-licensed third-party libraries. Clicking **License Info** displays this license information.

Rev. History Info

Clicking **Rev. History Info** displays the Software and Hardware revision details in RTM (Release to Market) version as well as the date of configuration.

3-2-13. Exit

Clicking **Exit** closes SmartScan. After you click **Exit**, you will see a confirmation message box asking if you want to close SmartScan. Clicking **Yes** will end the program.

Chapter 4. The Auto Mode Sidebar

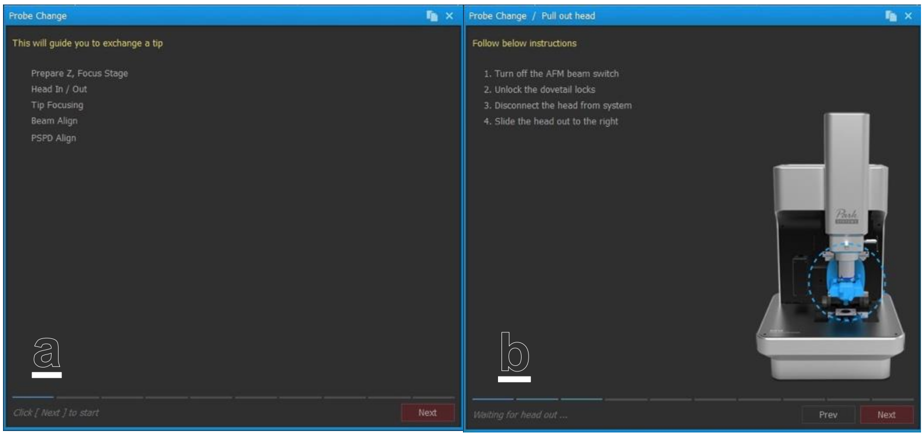
The auto mode sidebar contains automated scanning features. Each button guides the user through the AFM imaging process from start to finish. If all buttons are displayed in color, the system is ready for imaging and in an idle state. If only one button is displayed in color, the process indicated by that button is currently running.

4-1. Setup

Setup provides access to a setup wizard that guides the user through probe and sample setup. While the setup process is active, the button will appear blue in color and pulse. Once a process/button is active, the process can be canceled/exited by clicking the pulsing button.

4-1-1. Probe Setup

The probe setup wizard begins by lifting the Z and focus stage as the Probe Setup botton was selected, and simultaneously a diaolog box will appear as shown in Figure 4-1-1a. Then, click NEXT. Once lifted to a sample position above the surface, the user is prompted to remove the head and exchange the cantilever as shown in Figure 4-1-1b. After the head is replaced, the cantilever is placed back into focus.



This will guide you to exchange a tip

Prepare Z, Focus Stage
Head In / Out
Tip Focusing
Beam Align
PSPD Align

Click [Next] to start

Follow below instructions

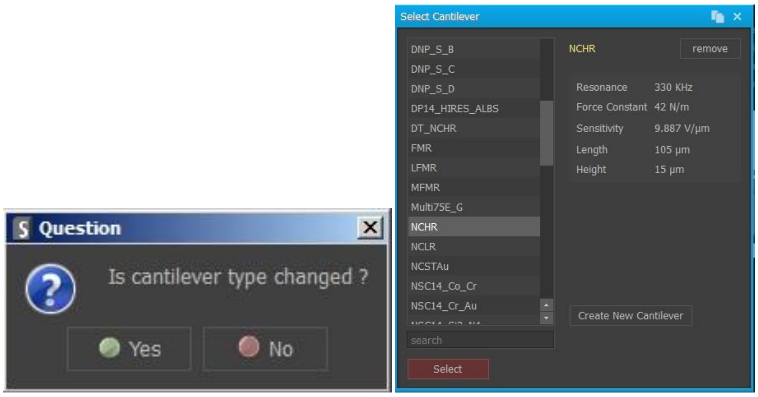
1. Turn off the AFM beam switch
2. Unlock the dovetail locks
3. Disconnect the head from system
4. Slide the head out to the right

Waiting for head out ...

Figure 4-1-1. The probe setup wizard

The wizard will prompt the user whether the cantilever type has been changed or not (see Figure 4-1-2a). Clicking **Yes** will open a cantilever selection window listing the most common cantilevers offered by Park Systems (see Figure 4-2-2b). Then, click **SELECT**. If your cantilever is not listed, a new cantilever listing can be created by clicking the **Create New Cantilever button**.

The **Create New Cantilever button** will create a new cantilever file with the parameters of the cantilever file currently highlighted. Choose a cantilever that closely matches your current cantilever in resonance, force constant, sensitivity, length, and height. These parameters can be further adjusted in maintenance mode.



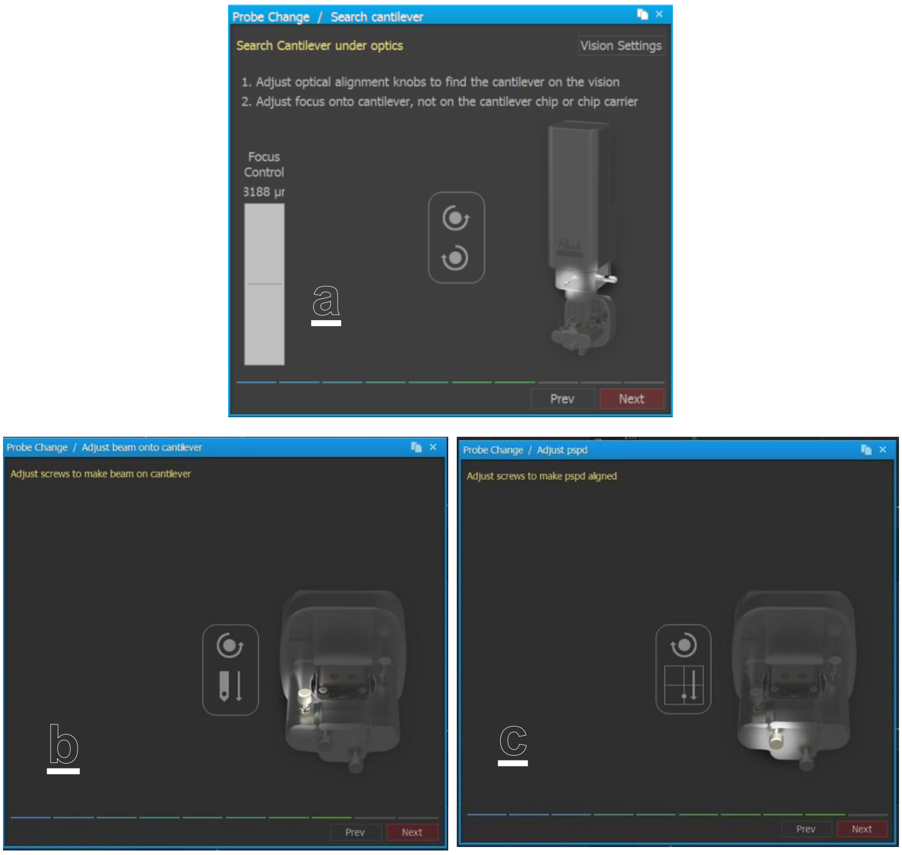
Is cantilever type changed ?

NCHR

Resonance 330 KHz
Force Constant 42 N/m
Sensitivity 9.887 V/µm
Length 105 µm
Height 15 µm

Figure 4-1-2a and 4-1-2b. Selecting a cantilever

Prompts are provided for searching cantilever (see Figure 4-1-3a), beam alignment (see Figure 4-1-3b) onto the cantilever and then onto the PSPD (see Figure 4-1-3c).



Search Cantilever under optics

1. Adjust optical alignment knobs to find the cantilever on the vision
2. Adjust focus onto cantilever, not on the cantilever chip or chip carrier

Adjust screws to make beam on cantilever

Adjust screws to make pspd aligned

Probe Change / Search cantilever
Vision Settings
Focus Control
3188 µr
a
Prev
Next
Probe Change / Adjust beam onto cantilever
b
Prev
Next
Probe Change / Adjust pspd
c
Prev
Next

Figure 4-1-3. Searching Cantilever, Beam alignment and PSPD adjustment

Once the laser has been aligned, you will be given three choices:

Change Sample: Begins the sample setup process

Position: Begins the positioning process

Finish: Displays the auto mode workspace

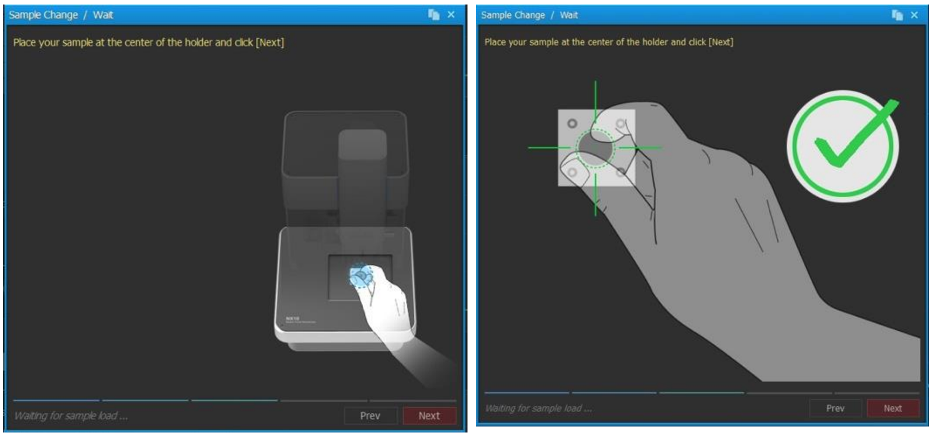
4-1.2. Sample Setup

The sample setup wizard begins by lifting the Z stage up away from the sample stage. It then brings the sample holder toward the front of the AFM so the user can easily access the sample area.

NOTE: The X-Y sample stage moves toward the edge. If the sample is larger than the sample holder, please remove the sample or take care that the sample does not hit any parts of the AFM during the sample setup process.

Once the sample on the magnetic sample holder, the sample stage is brought back so that the center of the stage is under the probe.

NOTE: Ensure the sample is located in the center of the stage directly below the cantilever holder. Otherwise the initial tip approach may occur at the wrong location and the cantilever/sample may be broken.



Place your sample at the center of the holder and click [Next]

Waiting for sample load ...

Place your sample at the center of the holder and click [Next]

Waiting for sample load ...

Figure 4-1-4. Changing a sample

Once the sample has been replaced, two options are displayed:

Position: Begins the positioning process

Finish: Displays the auto mode workspace

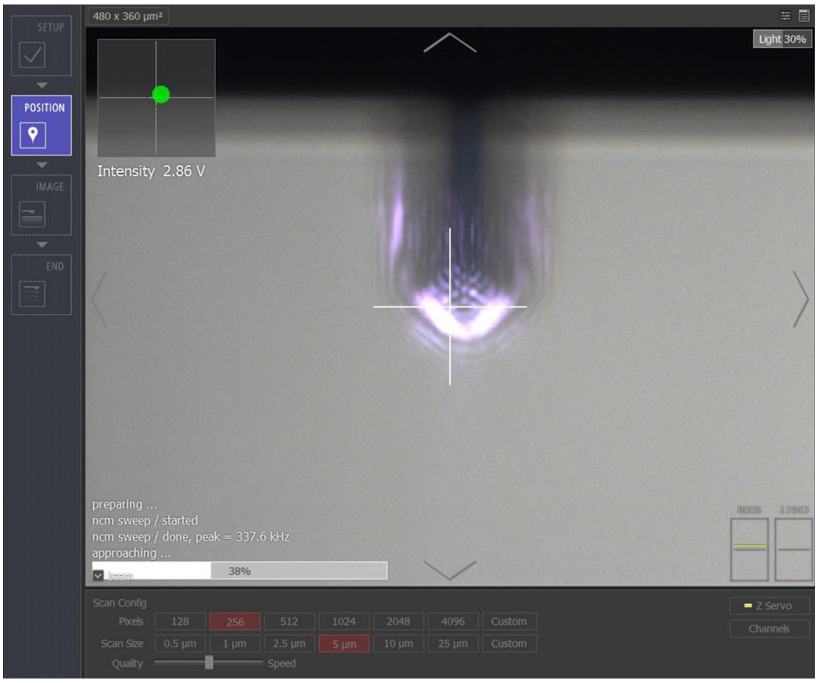
4-2. Position

Clicking the **Position** button begins the following process:

1. Performs non-contact mode frequency sweep
2. Approaches the surface
3. Goes into feedback
4. Immediately lifts away from the surface
5. Sets focus on the sample

During the positioning process, the **Position** button will pulse, and all other buttons will be inactive. To cancel the positioning process at any time, click **Position**.

The positioning process begins with a frequency sweep. The system performs a frequency sweep to determine the resonance frequency of the cantilever. The set point is automatically chosen. The system will then bring the cantilever into feedback at 85% of the free cantilever position. Next, the system will lift the tip 100μm from the feedback position. Finally, the system will bring the sample into focus. Once the above process has completed, the system will be ready to move the sample location to an area of interest. Figure 4-2-1 shows the optical view output of the positioning process.



```
preparing ...
ncm sweep / started
ncm sweep / done, peak = 337.6 kHz
approaching ...
```

Figure 4-2-1. Optical view of position

4-3. Image

Clicking the **Image** button will bring the cantilever into feedback with the surface and begin acquiring an image using the parameters set in the **Scan Parameters** dialog in the auto mode workspace. While imaging, the **Image** button will pulse, and the other auto mode sidebar buttons will be grayed out. To cancel imaging at any time during image acquisition, click **Image** or use the controls found on the Manual tab.

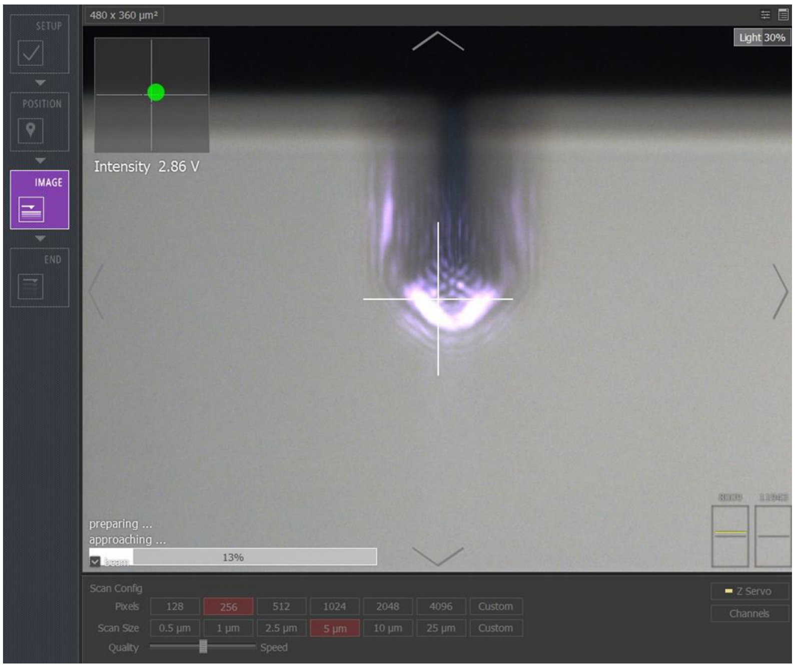
Imaging parameters that can be set in the auto tab workspace are **Pixel**, **Scan Size**, **Quality**, and **Filename**. Parameters should be adjusted prior to clicking the **Image** button. To adjust parameters, click the desired preset button or customize the parameter individually using the **Custom** button. See Chapter 6, Auto Mode, for more information about setting these parameters.

Image quality can be adjusted during the image acquisition process. Simply adjust the slider toward **Quality** for a better quality image or toward **Speed** to sacrifice quality in favor of faster image acquisition.

During the imaging process, a status bar is displayed in the lower left-hand corner of the optical view. The status bar provides information about the number of lines acquired, current scan speed, and estimated time remaining.

NOTE: Before clicking the **Image** button, ensure that the frequency sweep and other setup options have been properly configured.

NOTE: Begin imaging with the **Quality/Speed** slider set in the center.



preparing ...
approaching ...

Intensity 2.86 V

Pixels: 256

Scan Size: 5 µm

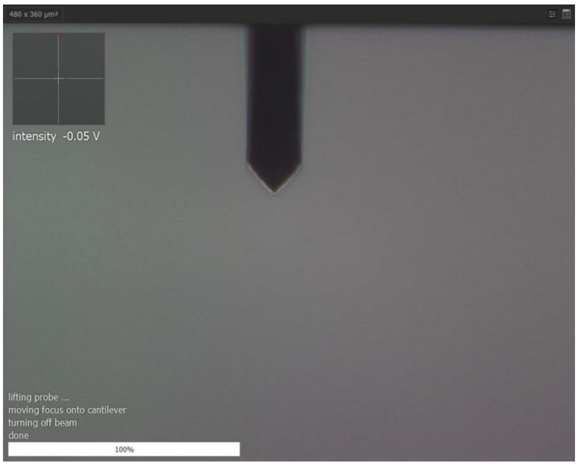
Figure 4-3-1. Optical view during imaging

4-4. End

When your imaging session has completed, click **End** to quit the session and leave the system ready for the next user. Clicking the **End** button will perform the following operations:

1. Lift the probe away from the surface
2. Move the focus onto the cantilever
3. Turn off the beam

Figure 4-4-1 shows the optical view with an output for the resulting process steps.



```
lifting probe ...
moving focus onto cantilever
turning off beam
done
```

Figure 4-4-1. Optical view during imaging session end

Chapter 5. The Sidebar

The sidebar consists of menu items not directly related with scan control but frequently used for certain applications. Commonly used features, such as the motorized stage controls, can be found in the lower section of the sidebar. For any mode using an AC oscillation, such as MFM, EFM, tapping, or non-contact mode, the NCM Sweep feature is displayed. Useful items are shown at the top of the sidebar. Four of the items can be displayed at once; use the ▲▼ buttons or mouse wheel to change the visible items (see Figure 5.5.1b).

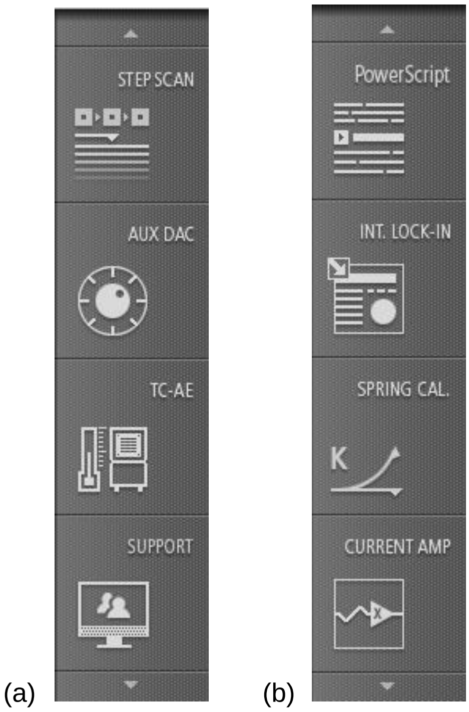


Figure 5-0-1. Frequently used items

5-1. Z/Focus Stage

The Z/Focus Stage dialog provides Z and focus stage controls.

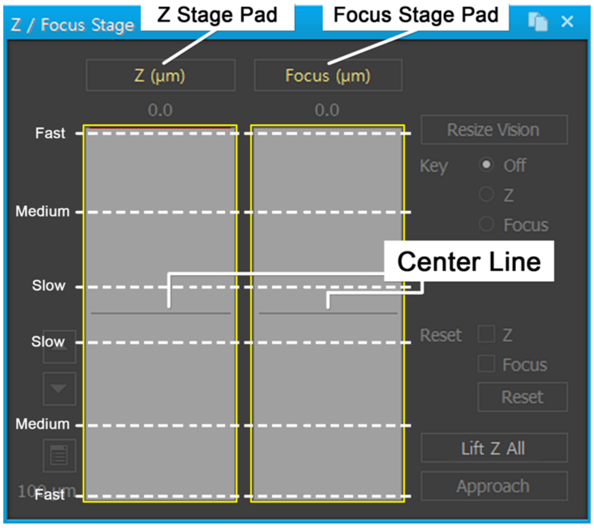


Figure 5-1-1. Motor control window

5-1-1. Z stage pad

The Z stage pad can be used to move the tip up and down in the Z direction relative to the sample. The Z stage pad controls both the direction and the speed of the Z stage. Shown in Figure 5-1-1, the upper half of the Z stage pad moves the Z stage up, while the lower half of the Z stage pad moves the z stage down. You can control the speed by changing the distance of the cursor from the center of the Z stage pad. Clicking farther from the center of the Z stage pad moves the Z stage faster. Clicking close to the center allows for finer control. The optical stage travels together with the Z stage, allowing the optical view to stay focused on the probe.

WARNING!

If the Z stage is lowered too quickly, the cantilever may “crash” into the sample surface. Such a forceful interaction may break the probe tip, damage or destroy the sample, and/or seriously damage the XY or Z scanners.

5-1-2. Focus Stage Pad

The focus stage pad allows separate control of the focus stage. The control is similar to the Z stage pad. Note that this control moves only the focus stage; the Z stage does not follow the focus stage’s movements. The direction and speed of movement is controlled similarly to the Z stage pad.

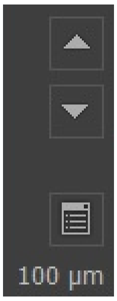
5-1-3. Z Stage(μm) Digital Panel

The Z Stage (μm) digital panel displays the location of the Z stage in the vertical direction. The maximum values for the Z stage can be adjusted in the database file for each system. By default, the Z stage coordinate is set to 30000.0μm at the maximum “upper limit,” at which the Z stage is fully raised. Therefore, the Z stage’s position at 0.0μm is where the Z stage is 30000.0μm away from the maximum upper limit.

5-1-4. Focus Stage(μm) Digital Panel

The Focus Stage (μm) digital panel displays the location of the focus stage in the vertical direction. The maximum value of the focus stage can be adjusted in the database file for each system. By default, the focus stage coordinate is set to 25000.0μm at the maximum “upper limit,” at which the focus stage is fully lifted. Therefore, the focus stage’s position at 0.0μm indicates the focus stage’s position when it is 25000.0μm away from its maximum upper limit.

5-1-5. Stepwise Control



This function allows users to move the Z stage one step by selecting a desired step size. To use the function, select the desired step size by choosing a value from the preset numbers in the pop-up dialog. To display the dialog, click the ▤ icon, and then click the desired direction ▲/▼(down/up) button. To stop the motion of the Z stage, click **Cancel** (✖ Cancel), shown after clicking the arrow button.

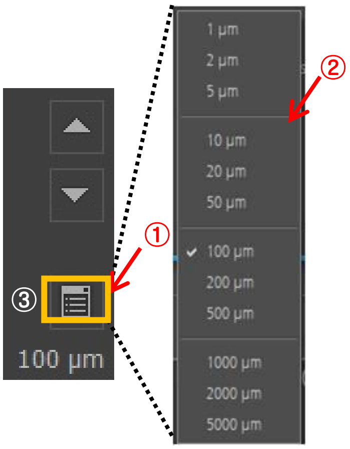


Figure 5-1-2. Stepwise stage control

CAUTION!

When the encoder is not installed in the Z/focus stage, the displayed values on the Z and Focus Stage (μm) digital panel do not match the exact coordinates of the stages. Therefore, please make sure to verify distance between tip and sample using optical microscopy.

Control	Function
▲	Move up the stage by the selected step size.
▼	Move down the stage by the selected step size.
▤	Determine step size (the height to lift up or down). After selection, the step-size display will be changed accordingly. Currently, 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, or 5000μm is selectable.

5-1-6. Key (Off/Z/Focus)

You can control the Z and focus stages with your keyboard:

- Choose either **OFF**, **Z**, or **Focus**. To turn this feature off, the radio button should be set to **OFF**. To control the Z stage with the keyboard, set the radio button to **Z**. To control the focus stage with the keyboard, set the radio button to **Focus**.
- Hold down the **stage select** key and the **up** or **down arrow** key to move the respective stage's position. The **Z** key selects the Z stage, and the **F** key selects the focus stage. Current Amplifier
- Hold the **shift** key for finer control of the Z and focus stages.

WARNING!

If the Z stage is lowered too quickly, the cantilever may "crash" into the sample surface. Such a forceful interaction may break the probe tip, damage or destroy the sample, and/or seriously damage the X-Y/Z scanner.

5-1-7. Reset Stages (Z/Focus)

The **Reset** button allows you to reset the focus stage and/or the Z stage of your instrument. If the position is not displayed in the digital panels, or the Z and focus stages do not respond to controls, use this command to restore them to the default state. Check the desired motorized stage to be reset, and then click

Reset.

Resetting a stage has several effects: the Z or focus stages return to their maximum height, the hardware sensors define the final position as the origin, and the position of the stage is defined as the origin in the software.

To stop the reset motion, click the ✖ Cancel button, shown after clicking the arrow button.

5-1-8. Retract Z All

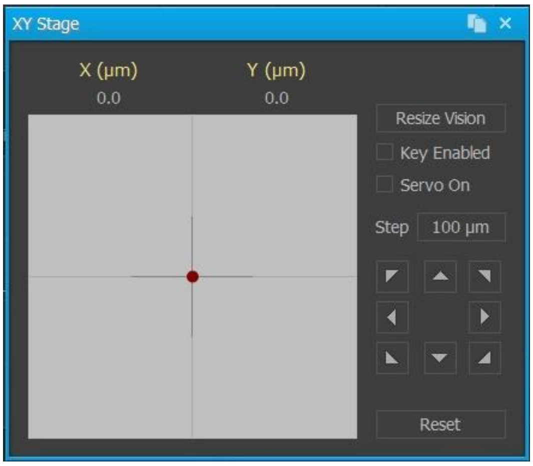
In addition to clicking the upper half of the Z stage, the **Retract Z All** button is another way to lift the Z stage. After clicking this button, the Z stage moves upward at the fastest speed, and this button label is changed to ✖ Cancel, shown after clicking the arrow button. The Z stage will be raised to the maximum height.

5-1-9. Approach

Approaches the tip to the sample automatically with controlled velocity until the value of the reference signal reaches the **Set Point** value of the Parameters Control View.

5-2. XY Stage

The XY Stage window allows control of the motorized XY stage so that the tip can be easily positioned around the sample surface. Figure 5-2-1 shows the XY Stage window.



XY Stage

X (μm) 0.0

Y (μm) 0.0

☐ Key Enabled

☐ Servo On

Step 100 μm

Figure 5-2-1. XY Stage window

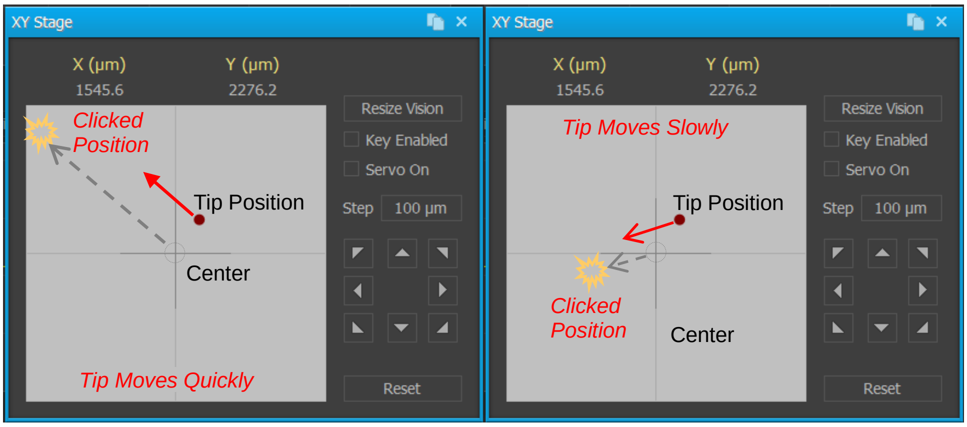
The XY stage can be moved in both the X and Y directions. It moves the sample relative to the probe. The XY stage pad controls both the direction and the speed of the XY stage.

NOTE!

Before you use the XY stage pad, be sure to lift the tip off the sample using the Z stage pad. Otherwise, both the tip and your sample may incur serious damage.

The red point in the XY stage pad indicates the tip's position. To move the tip to another position on the sample surface, click and hold the mouse on the XY stage pad. The tip will move toward the cursor position. Clicking farther away from the tip will result in faster movement.

The XY stage moves in the opposite direction of the clicked position, as its position is defined relative to the tip, not the user. The XY stage's motion directions are shown in Figure 5-2-2.



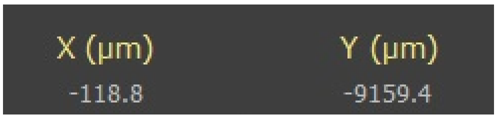
**Tip is fixed; the XY Stage moves in the opposite direction*

Figure 5-2-2. Direction of the XY stage's motion

5-2-1. Key Enabled

Clicking the **Key Enabled** check box allows control of the XY stage using the keyboard. By using the arrow keys, the XY stage can be moved up/down and left/right. Finer control (slower stage speed) can be achieved by holding down the **shift** key and the appropriate arrow key—↑, ↓, →, ←.

5-2-2. X/Y Position (µm)



X (µm) -118.8

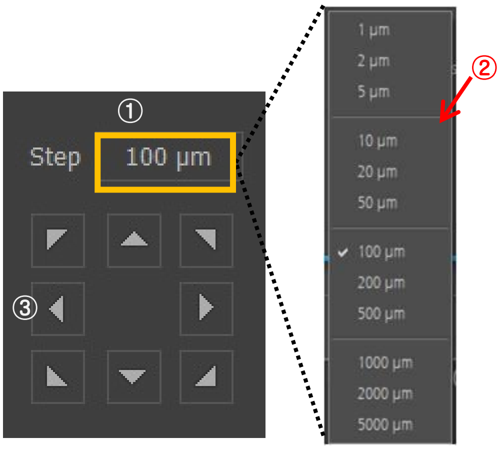
Y (µm) -9159.4

Figure 5-2-3. XY position display fields

These fields display the current X and Y position of the XY stage in micrometers.

5-2-3. Stepwise Control

This function moves the XY stage in steps according to a selected step size. To use the function, select the desired step size by choosing a value from the preset numbers in the pop-up dialog shown by clicking the displayed step size button and pressing the desired direction arrow button. When movement of the XY stage needs to be stopped, click **Cancel** (✖), shown after clicking the arrow button.



Step 100 µm

Figure 5-2-4. Stepwise stage control

<u>CAUTION!</u>

<u>CAUTION!</u>

When he encoder is not installed in the XY stage, the displayed value on XY Stage (µm) digital panel does not match exact coordinate of the XY stage.

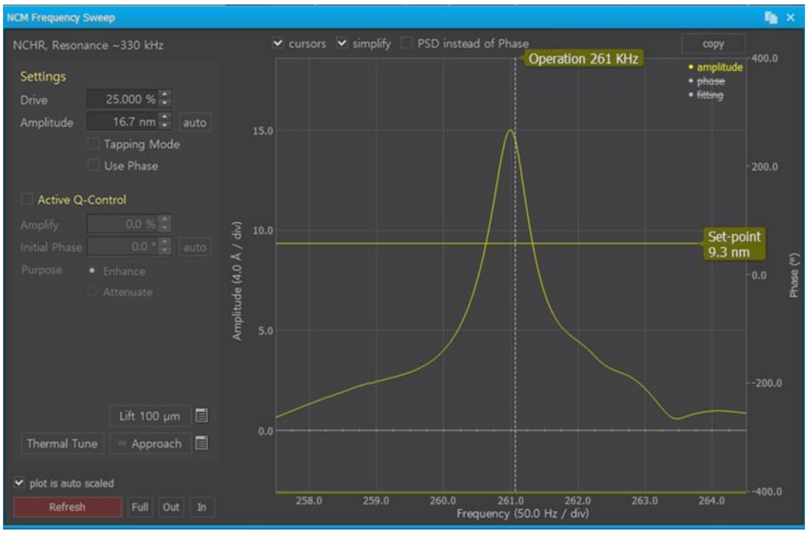
Control	Function
▲▼	Move up/down the stage (viewed from the probe) to the selected step size
◂▸	Move left/right the stage (viewed from the probe) to the selected step size
◥◤◣◢	Move 45º/135º/225º/315º direction (viewed from the probe) to the selected step size
Step Size Button	Provides preset step-size values. After selection, the step size display will be changed accordingly. Currently, **10**, **20**, **50**, **100**, **200**, **500**, **1000**, **2000** or **5000**μm is selectable.

5-2-4. Reset

Clicking **Reset** returns the XY stage to the center position after moving to the limit positions and redefines the X and Y position of the XY stage. After the reset has completed, the X and Y position fields will be set to 0. Clicking **Cancel** (✖ Cancel), shown after clicking **Reset**, will halt the stage's movement.

5-3. Frequency Sweep

The Frequency Sweep menu appears only in non-contact-based modes such as NC-AFM, tapping, EFM, MFM, and FMM modes. The NCM Frequency Sweep dialog, as shown in the figure on the next page, can be displayed by clicking the **Frequency Sweep** menu.



NCHR, Resonance ~330 kHz

Drive 25.000 %

Amplitude 16.7 nm

Amplify 0.0 %

Initial Phase 0.0 °

Purpose ● Enhance ○ Attenuate

Lift 100 µm

☑ plot is auto scaled

Operation 261 KHz

Set-point 9.3 nm

Figure 5-3-1. NCM Frequency Sweep dialog

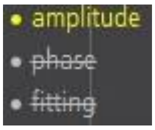
5-3-1. Frequency Sweep Plot

The NCM Frequency Sweep dialog displays the system response curve by plotting the cantilever’s vibration amplitude, phase vs. frequency, which is generated when the system drives the cantilever through a frequency sweep. You can determine the resonant frequency of the cantilever using this plot.

The number at the left of the frequency sweep plot is the size of the vertical scale unit, which is amplitude. The number on the bottom is the size of the horizontal scale unit, which is frequency.

When the phase signal is selected in the legend at the top right, the phase displays on the plot. The number at the right is the size of vertical scale unit on the phase.

Legend (Amplitude, Phase, Fitting)



The legend is located at the upper right corner of the Frequency Sweep plot. Items in the legend can be toggled on and off by clicking on them. Items representing hidden data are displayed with strikethrough lines. By default, only the amplitude is shown.

- **Amplitude**—Displays the amplitude of the response curve (yellow).
- **Phase**—Displays the phase of the response curve (white).
- **Fitting Curve**—Displays the calculated Lorentzian curve (green) for this cantilever. The curve is used to calculate the resonance frequency and Q factor of the cantilever.

Cursors check box

Clicking the **cursors** check box displays one vertical white dotted-line cursor and one horizontal yellow solid-line cursor as shown in the figure (grid lines are always displayed; markers will be displayed when **cursors** is checked).

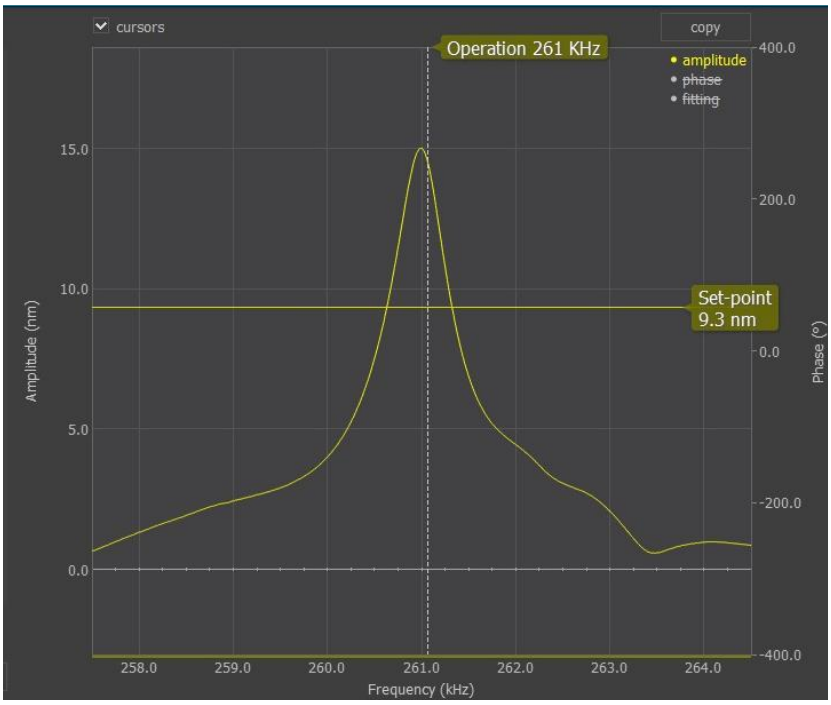


Figure 5-3-2. Cursors

- **Vertical line (operation frequency cursor)**

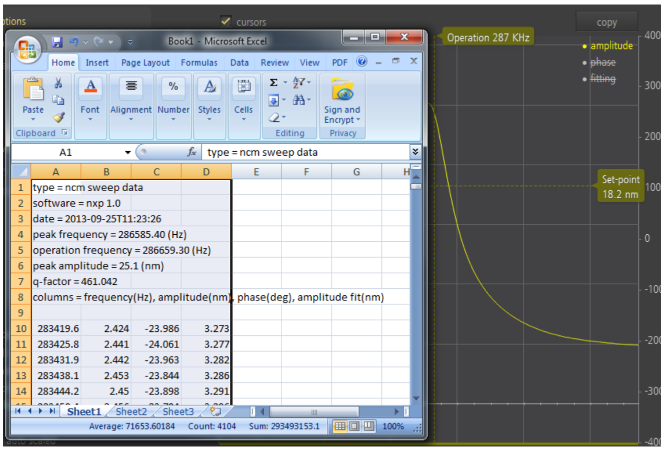
  The drive frequency is the selected frequency of the AC voltage signal from the sine wave generator that drives the cantilever to vibrate. The drive frequency is selected based on the value of the cantilever’s free space resonant frequency. The white vertical dotted line (displayed as “Operation cursor”) on the resonant curve marks the drive frequency for the cantilever. The selected frequency can be changed by dragging the operation cursor to the desired frequency. When the cursor is relocated, the setpoint is also determined.

- **Horizontal line (set point cursor)**

  The set point is the reference value of the cantilever vibration that is held constant during a scan by the feedback loop. The default value of the setpoint is represented by a horizontal yellowish-green dotted line (displayed as “SetPoint cursor”) that cuts across the response curve at about 2/3 of the maximum peak height. You can adjust the setpoint value by dragging the horizontal line up or down on the response curve. The new setpoint value is automatically updated. The setpoint value can also be changed in the parameters setting panel while imaging.

Copy

This copies the signal display on the screen to a clipboard as text. You can paste (**Ctrl+V**) the copied data to other programs, e.g., text editors or spreadsheets.



type = ncm sweep data
software = nxp 1.0
date = 2013-09-25T11:23:26
peak frequency = 286585.40 (Hz)
operation frequency = 286659.30 (Hz)
peak amplitude = 25.1 (nm)
q-factor = 461.042
columns = frequency(Hz), amplitude(nm), phase(deg), amplitude fit(nm)

	A	B	C	D
10	283419.6	2.424	-23.986	3.273
11	283425.8	2.441	-24.061	3.277
12	283431.9	2.442	-23.963	3.282
13	283438.1	2.453	-23.844	3.286
14	283444.2	2.45	-23.898	3.291

Figure 5-3-3. Copying the frequency sweep plot

5-3-2. Settings

Settings parameters include parameters to set the amplitude of the operational driving frequency for non-contact mode. The amplitude of oscillation is a function of the drive voltage to the piezo bimorph, which mechanically oscillates the cantilever. Increasing the drive effectively increases the amplitude.

Drive

The drive amplitude is the amplitude of the AC voltage signal from the signal wave generator that drives the cantilever to vibrate. This number is a fixed percentage (from 0.001 to 100) of the maximum allowed voltage to the piezoelectric transducer which oscillates the cantilever. To change the drive amplitude, enter a new percentage value in the **Drive** field or use the spinner.

To increase the drive manually, change the drive percentage and click the **Refresh** button.

Amplitude

The amplitude value is used to specify the amplitude at the operation frequency. This value will be used as a target value that the software uses to set the drive percentage. Once the frequency sweep process is complete, the amplitude display will show the final amplitude of the resonance frequency.

Changing the value in the display box does increases or decreases the amplitude ONLY after the **Auto** button or **Refresh** button is clicked.

Auto Button

The **Auto** button performs a frequency sweep which begins starting from the full frequency range of the system. The software will look for the largest peak within the frequency range specified by the cantilever chosen during setup. Then the software will zoom into this peak through a series of shorter range frequency sweeps. If the **Tapping mode** box is checked, the software will choose a final operating frequency to the left of the actual peak. If the **Tapping mode** box is left unchecked, the software will choose a final operating frequency to the right. The exact position is chosen using the point of highest slope. The amplitude of the peak is determined by the value in the **Amplitude** display box.

Options

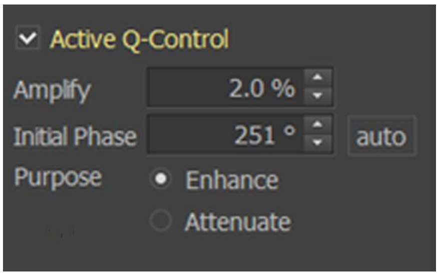
Drive amplitude settings include two options to adjust drive amplitude. The **Tapping mode** option is used when performing intermittent-contact mode measurements, also called dynamic contact or tapping mode.

Tapping mode

Selecting **Tapping mode** allows you to enter intermittent contact AFM (tapping mode AFM) automatically during the NCM sweep process. If the **Tapping mode** box is checked, the software will choose a final operating frequency to the left of the actual peak. If the **Tapping mode** box is left unchecked, the software will chose a final operating frequency to the right.

5-3-3. Active Q-Control

Select the **Active Q Control** check box to enable Q control mode and activate the relevant parameters. For more information on Q control mode, refer to the User's Manual.



☑ Active Q-Control

Amplify: 2.0 %

Initial Phase: 251 °

Purpose: ● Enhance ○ Attenuate

Figure 5-3-4. Active Q control settings

Amplify

This absolute Q amplify value applies to the Q control gain amplifier. The negative input changes the Q value in the direction of decreasing Q. The positive input changes the Q value in the direction of increasing Q. When you input **0** in Amplify field, Q control mode deactivated. Figure 5-3-4 shows that Q value changes when Q amplification is set to -5% (left) and 5% (right) after the initial phase calibration is done. The available range is -100~+100% in this field.

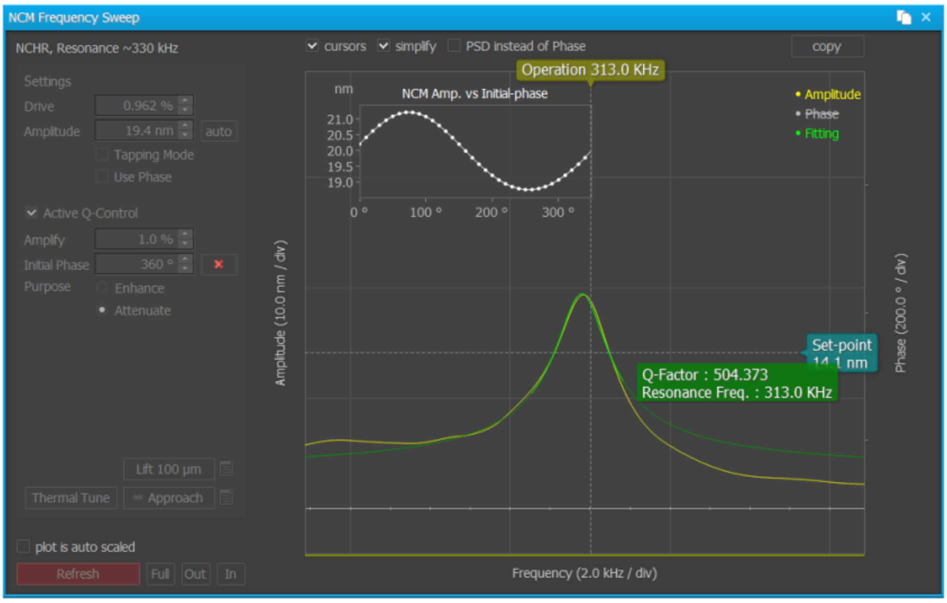
Q Amplify(%)	Gain	Phase
0	0 (deactivate Q Control)	-
0~100	IQ amplify input value	Initial phase-90
-100~0	IQ amplify input value	Initial phase+90

Initial Phase

In principle, resonant frequency is unchanged when phase is shifted to -90° in the NX system. In fact, however, the resonant frequency is shifted due to the electronics, drive frequency, cantilever, and so on. Therefore, when phase is set to -90°+ α, the resonance frequency is not changed during Q control. “α” is called “the initial phase.” In other words, the input value of the phase shifter is (+or-90°)+initial phase.

Auto Phase

Clicking **Auto Phase** automatically changes the phase little by little to find the initial phase without resonance frequency shift. This process is called “initial phase calibration.” The progress of calibration is shown in the upper left-hand corner of the frequency sweep plot.



NCHR, Resonance ~330 kHz

Drive 0.962 %

Amplitude 19.4 nm

☐ Tapping Mode

☐ Use Phase

☑ Active Q-Control

Amplify 1.0 %

Initial Phase 360 °

Purpose ○ Enhance ● Attenuate

☐ plot is auto scaled

☑ cursors ☑ simplify ☐ PSD instead of Phase

Operation 313.0 KHz

Set-point 14.1 nm

Q-Factor : 504.373
Resonance Freq. : 313.0 KHz

Figure 5-3-5. Frequency Sweep dialog during Q control Auto Phase

- **General Procedure**
- 1. Perform an NCM frequency sweep.
- 2. Adjust the Phase setting on the Q controller.
- 3. Calculate the average value of the NCM amplitude channel (Over 10,000 measurements are made on average in a span of 200 ms).
- 4. While repeating steps 2 and 3 for the entire range of Auto Phase; records NCM amplitude and phase values.
- 5. Upon completion of step 4, find the desired Phase from NCM amplitude vs Phase curve.
- 6. Set the Phase setting on the Q controller and perform an NCM frequency sweep

Purpose

The Enhance function is used to increase the Q value under normal circumstances. The Attenuate function reduces the Q value when the Park NX-Hivac is used in vacuum. It prevents the NCM amplitude from being too large at or around the resonance frequency.

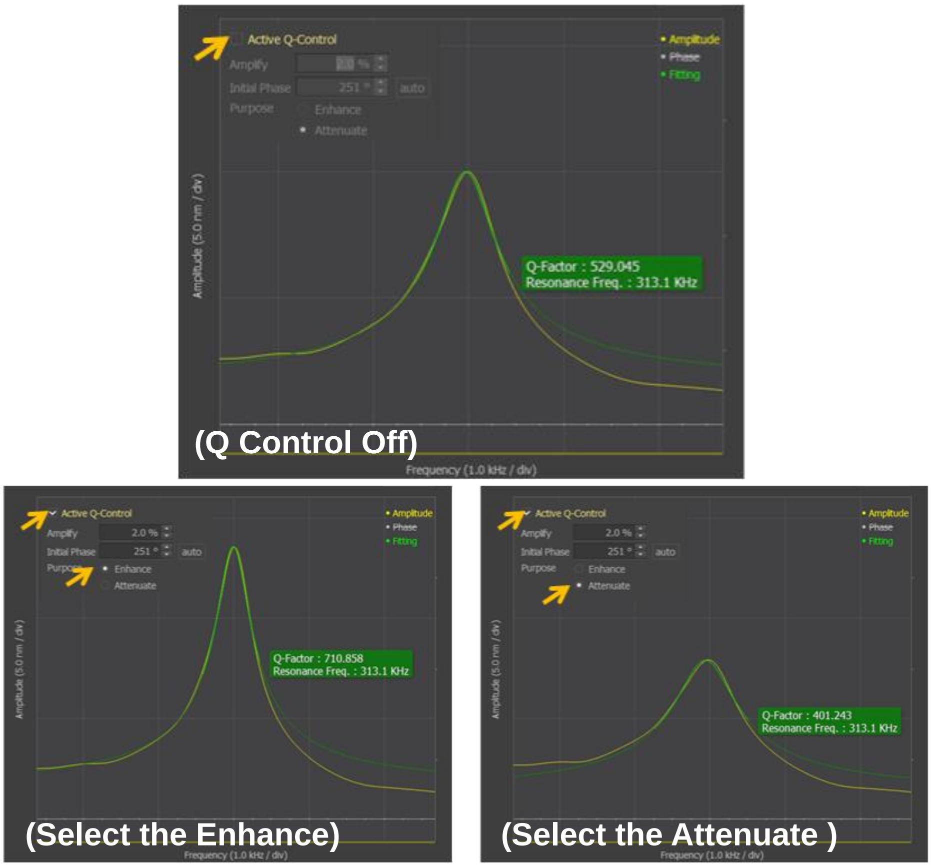


Figure 5-3-6. Changing NCM amplitude through the use of Q control

5-3-4. Approach

This function approaches the tip to the sample automatically with controlled velocity until the value of the amplitude signal at operation frequency reaches the set point value.

5-3-5. Lift Z

This function allows users to move the Z stage in steps by selecting a desired step size. To use the function, select the desired step size by choosing a value among the preset numbers (10, 20, 50, 100, 200, 500, 1000, 2000, and 5000) in the pop-up dialog shown by clicking the ☰ icon and then clicking **Lift Z**. When the motion of the Z stage needs to be stopped, click **Cancel** (✖ Cancel), shown after clicking **Lift Z**.

5-3-6. Other Functions

Refresh

When you click **Refresh**, the NCM will re-sweep the frequency using the frequency range displayed in the current frequency sweep plot. The Operation and SetPoint cursors will be reset using the default conditions where the operation frequency is chosen for the position of largest slope and the set point is 85% of the peak amplitude. After a cantilever exchange, it is advisable to use the **Auto** button in the Settings section rather than using the **Refresh** button, since the resonance peak may or may not be within the current displayed range.

Full

Zoom out the horizontal frequency in full range. The full frequency range is 5MHz.

In

Zoom in from the horizontal frequency range. The software will zoom into the smaller range centered around the operation frequency cursor.

Out

Zoom out from the horizontal frequency range.

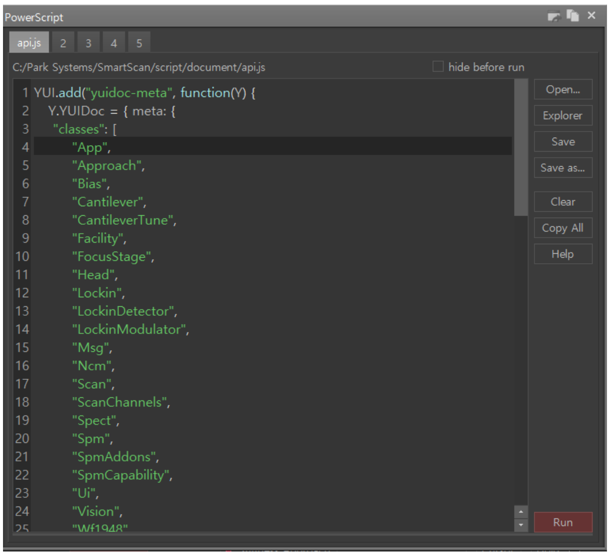
Note!

To zoom in/out from the vertical frequency range, right-click on the frequency display and use the mouse wheel to increase or decrease the range.

5-4. PowerScript

PowerScript allows running processes and setting parameters while acquiring data. Figure 5-4-1 shows the PowerScript window with a script open. The script can be edited to change process parameters. Example scripts can be found at C:\Park Systems\SMARTSCAN\script\examples.

Up to five scripts can be open at one time. The scripts can be displayed by toggling the script pages at the top of the Script Window. Once a script is open in the window, the numerical indicator will change to the script name.



C:/Park Systems/SmartScan/script/document/api.js

```
YUI.add("yuidoc-meta", function(Y) {
   Y.YUIDoc = { meta: {
    "classes": [
        "App",
        "Approach",
        "Bias",
        "Cantilever",
        "CantileverTune",
        "Facility",
        "FocusStage",
        "Head",
        "Lockin",
        "LockinDetector",
        "LockinModulator",
        "Msg",
        "Ncm",
        "Scan",
        "ScanChannels",
        "Spect",
        "Spm",
        "SpmAddons",
        "SpmCapability",
        "Ui",
        "Vision",
        "Wf1948"
```

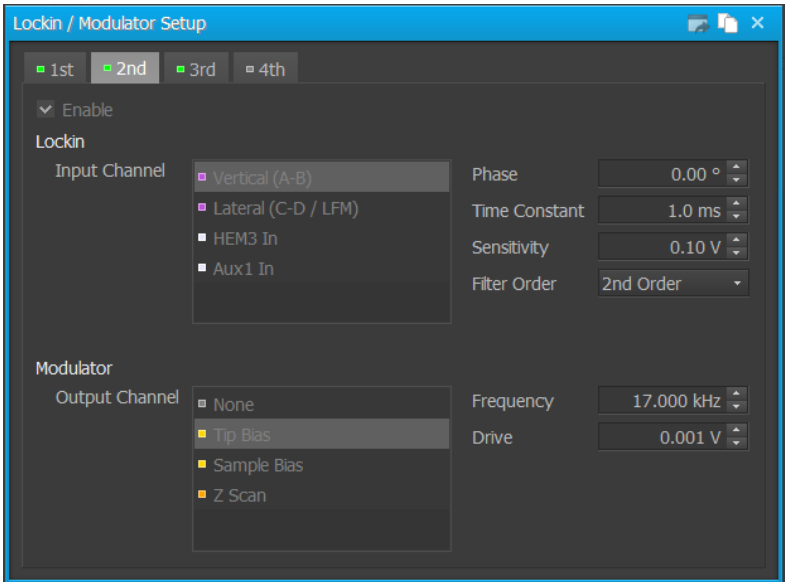
Figure 5-4-1 PowerScript Window

Following are the PowerScript Window buttons and descriptions of their functions:

Button	Description
Open	Opens a script in the PowerScript Window
Explorer	Opens the Windows Explorer location where the displayed script is located
Save	Saves the current script
Save as	Saves the current script under a new filename
Clear	Clears the scripting display
Copy All	Copies the displayed script to the clipboard
Help	Opens the SMARTSCAN scripting API helpfile
Run	Runs the displayed script
Clear	Clears the Output script display

5-5. Internal Lock-In

Internal lock-in amplifiers are software controllable using Lock-in/Modulator Setup. Lock-in amplifiers identify the amplitude and phase shift of the input signal at a particular frequency.



Phase 0.00 °
Time Constant 1.0 ms
Sensitivity 0.10 V
Filter Order 2nd Order
Frequency 17.000 kHz
Drive 0.001 V

Figure 5-5-1 Internal lock-in config window

To adjust the Reference Frequency of each Lockin Amp. you can adjust the Frequency of the Modulator with the same number as shown below. The same number of Lock-in Amp. and Modulator will have the Modulator operating Frequency as the Reference Frequency of Lock-in Amp. If you only want to use Lock-in Amp. instead of Modulator, you just need to set the Output Channel of Modulator to None and change the Frequency.

5-5-1. Lock-in Config

Lock-in Selection Tab

The lock-in tabs toggle the parameter page for the corresponding lock-in amplifier. Four lock-in amplifiers tabs are available. Once an input channel is opened and associated with a lock-in amplifier, the box on the Lock-in tab will turn green. If a measurement mode requires a lock-in amplifier, the input channel will be configured automatically in the software. Lock-in 1st is reserved for non-contact mode.

Input Channel

This indicates the input channel used in the lock-in, resulting in amplitude and phase determined at the frequency of interest. Input channel selections are **None**, **Vertical (A-B)**, **Lateral (C-D/LFM)**, **HEM3 In**, and **Aux1 In**. **HEM3** referes to the head extension module port on the left side of the AFM. **Aux1** refers to the BNC connection at the back of the controller labeled **Aux1 In**. Table 5.1 details available signal settings.

Phase

This field indicates the phase setting of the lock-in amplifier. Values between 0 and 180 degrees can be entered. Adjusting the phase will adjust the output of the lock-in amplifier phase-sensitive detector.

Time Constant

This field's value represents the time constant of the lock-in amplifer. Values between 0 and 1000ms can be entered. The time constant reflects how slowly the output responds, and thus the degree of output smoothing. Larger time constants correspond to a greater degree of output smoothing.

Filter Order

This drop-down menu allows selecting the filter type of the lock-in amplifier. Available choices are **First Order**, **Second Order**, or **None**. Filter order affects the dynamic reserve of the lock-in amplifier. Higher order filtering increases smoothing of the output signal.

5-5-2. Modulator Config

Modulator Selection Tab

The modulator selection tabs toggle the parameter pages for the corresponding modulator (reference signal for the lock-in amplifier). Two independent modulation channels are provided. 1st is used primarily for non-contact mode.

Target

This field allows selecting the signal that lock-in will reference. Selecting the target specifies the reference frequency AND adds the appropriate sinusoidal signal to the channel. A complete list of available signals can be found in Table 5.1. Signals are automatically configured for measurement modes which require a lock-in amplifier. Tip Bias is automatically selected in EFM. Sample Bias is automatically selected in SCM. ZScan is automatically selected in SICM.

Frequency

This field is used to set the oscillation modulation frequency.

Drive

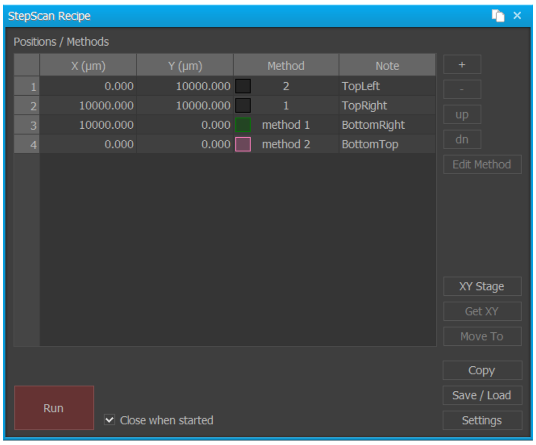
This field is used to set the oscillation drive amplitude.

Lock-in	**1**	**2**	**3**	**4**
Input Channel	None Vertical (A-B) Lateral (C-D.LFM) HEM3 In Aux1 In	None Vertical (A-B) Lateral (C-D.LFM) HEM3 In Aux1 In	None Vertical (A-B) Lateral (C-D.LFM) HEM3 In Aux1 In	None Vertical (A-B) Lateral (C-D.LFM) HEM3 In Aux1 In
Modulator Config	None, NCM Amplitude	None, Tip Bias, Sample Bias, Z Scan	None, NCM Amplitude	None, Aux1 Out

Table 5.1 Input channels and modulators

5-6. StepScan

Clicking the **StepScan** button in the sidebar will open the StepScan Recipe window, which allows programming routes to an image and moving to a new location within the movement of the motorized XY stage for automatic imaging. The StepScan Recipe window is shown in Figure 5-6-1.



	X (µm)	Y (µm)	Method	Note
1	0.000	10000.000	■ 2	TopLeft
2	10000.000	10000.000	■ 1	TopRight
3	10000.000	0.000	🟩 method 1	BottomRight
4	0.000	0.000	🟪 method 2	BottomTop

☑ Close when started

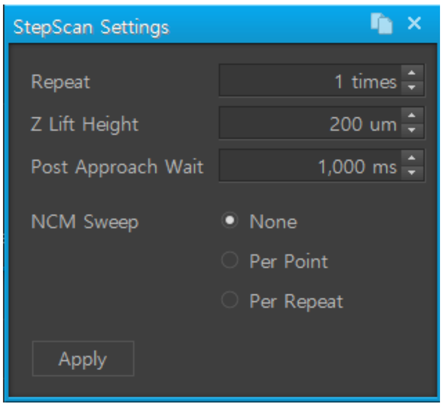
Figure 5-6-1. StepScan Recipe window

5-6-1. Postions and Methods

The Position/Methods area includes X and Y positions for the measurement location and the method used to acquire the image. The method determines scan sizes, scan rates, and gain parameters used to acquire the image. The buttons on the righthand side of the Positions/Methods area are used to manipulate the data points. A description the buttons' functions follows:

Button	**Description**
+	Adds a new point to the list
-	Deletes the highlighted point from the list
Up	Moves the highlighted point up on the list
Dn	Moves the highlighted point down on the list
Button	**Description**
Edit Method	Opens the Method Parameter Controls window
XY Stage	Opens the XY Stage Control window
Get XY	Changes the XY coordinates of the highlighted point to the current XY stage coordinates
Move To	Moves to the coordinates of the highlighted point
Copy	Copies the script used to run StepScan onto the clipboard
Save/Load	Opens the Presets window
Settings	Opens the StepScan Settings window

The StepScan Settings window provides additional options for the StepScan automated imaging process. The StepScan Settings window is shown in Figure 5-6-2.



Repeat 1 times
Z Lift Height 200 um
Post Approach Wait 1,000 ms
NCM Sweep ● None ○ Per Point ○ Per Repeat

Figure 5-6-2. StepScan Settings window

Settings	Description
Repeat	Repeats the step/scan recipe. The full step/scan recipe can be repeated up to 10 times.
Z Lift Height	Displays lift height after each measurement
NCM Sweep	Performs a frequency sweep during the recipe run
Post Approach Wait	
NCM Sweep	
None	Does not resweep the frequency during the recipe run
Per Point	Resweeps frequency after each point in the recipe
Per Repeat	Resweeps frequency after each repeat of the run
Apply	Applies settings to the step/scan recipe

5-6-2. Method

The Method Parameter Control window allows control of the scan area, scan rate, scan channels, scan options, Z servo, and bias of the acquired image. To add a measurement method to the Positions/Method area, right-click on the **Method** cell for the data point and choose the appropriate method.

To edit the measurement method, click **Edit Method**, which opens the StepScan Method window, shown in Figure 5-6-3.

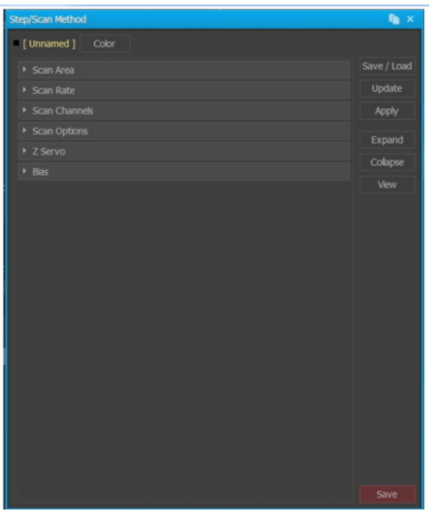
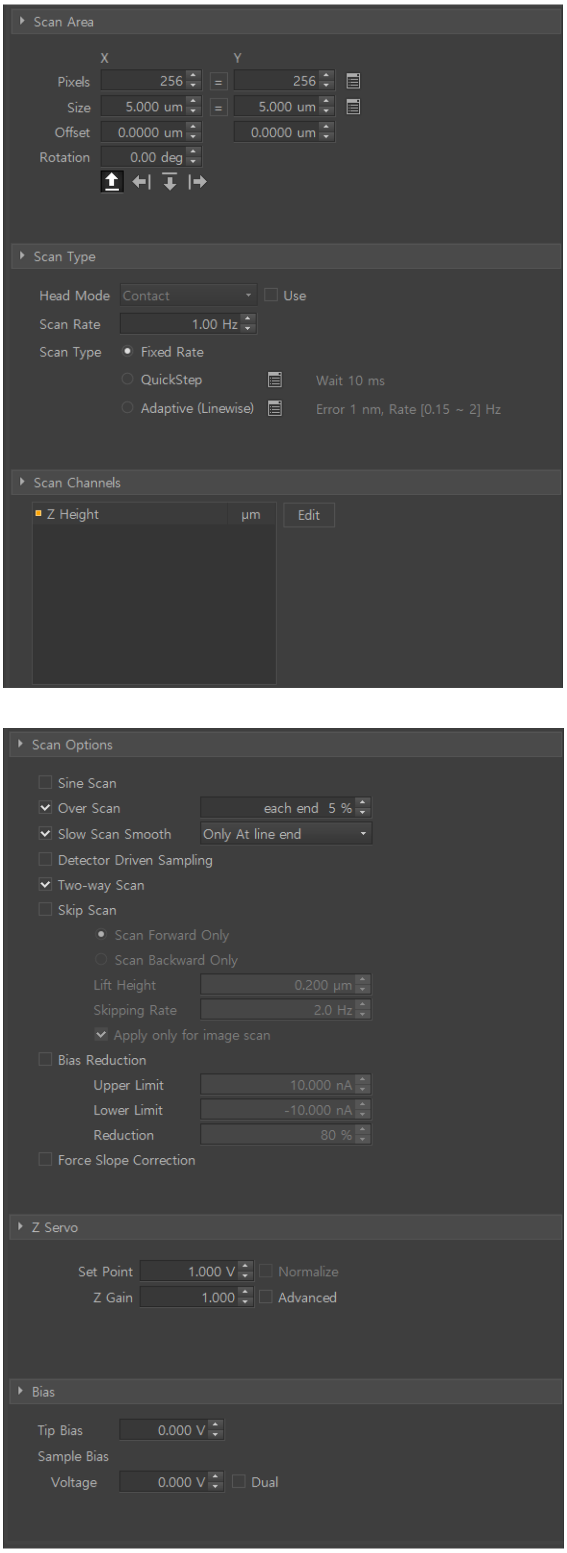


Figure 5-6-3. StepScan Method window



Scan Area

X Y

Pixels 256 = 256

Size 5.000 um = 5.000 um

Offset 0.0000 um 0.0000 um

Rotation 0.00 deg

Scan Type

Head Mode Contact ☐ Use

Scan Rate 1.00 Hz

Scan Type ● Fixed Rate

○ QuickStep Wait 10 ms

○ Adaptive (Linewise) Error 1 nm, Rate [0.15 ~ 2] Hz

Scan Channels

Z Height µm Edit

Scan Options

☐ Sine Scan

☑ Over Scan each end 5 %

☑ Slow Scan Smooth Only At line end

☐ Detector Driven Sampling

☑ Two-way Scan

☐ Skip Scan

● Scan Forward Only

○ Scan Backward Only

Lift Height 0.200 µm

Skipping Rate 2.0 Hz

☑ Apply only for image scan

☐ Bias Reduction

Upper Limit 10.000 nA

Lower Limit -10.000 nA

Reduction 80 %

☐ Force Slope Correction

Z Servo

Set Point 1.000 V ☐ Normalize

Z Gain 1.000 ☐ Advanced

Bias

Tip Bias 0.000 V

Sample Bias

Voltage 0.000 V ☐ Dual

Figure 5-6-4. Expanded method sections

To save the measurement method, click **Save/Load**, which opens the Presets window. Click **New**, and then and name the saved method preset. The buttons on the StepScan Method window are as follows:

Button	Description
Save/Load	Opens the Preset window
Update	Copies current scan parameters into the method
Apply	Copies method parameters into the current settings
Expand	Expands each section of the method
Collapse	Collapses all sections of the method
View	Opens a dialog window

5-7. Current Amplifier

5-7-1. Type

The current amplifier is used for C-AFM or STM mode for this system. It can be also used for SSRM mode for other system such as NX-Hivac. From this menu, you can select the type of current amplifier for your NX system. There are two types of current amplifier: Internal and external. Internal amplifier is divided into two options, DC and AC mode. Select one according to the type of amplifier you are using for C-AFM or STM. The external amplifier requires an external current amplifier with a power supply and head extention module.

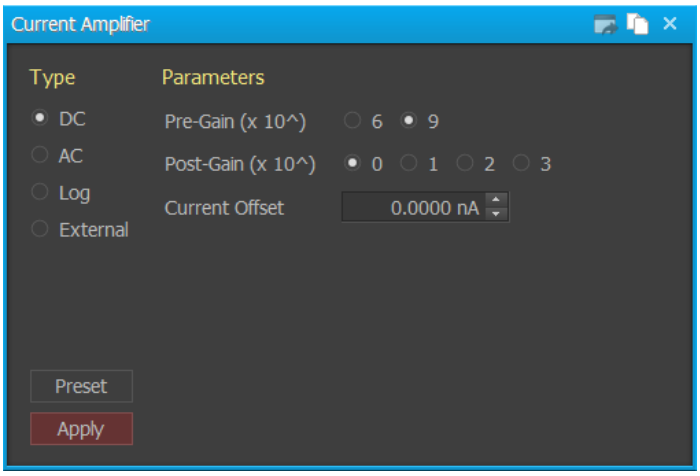
5-7-2. Internal Current Amplifier

Selecting **DC** applies amplification to DC signal, while selecting **AC** applies amplification to AC signal.

Pre- and Post- Gain

The Pre-Gain and Post-Gain parameters determine the overall gain for the amplifier. Effective gain settings are as follows:

	Pre Gain = 6	Pre Gain = 9
Post Gain = 0	6	9
Post Gain = 1	7	10
Post Gain = 2	8	11
Post Gain = 3	9	12



● DC
○ AC
○ Log
○ External

Pre-Gain (x 10^) ○ 6 ● 9
Post-Gain (x 10^) ● 0 ○ 1 ○ 2 ○ 3
Current Offset 0.0000 nA

Figure 5-7-1. Internal Current Amplifier

Current Offset

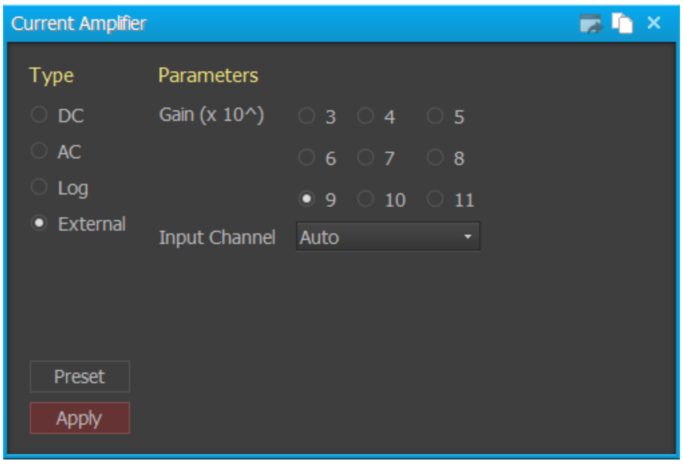
This control adds the selected current offset to the measured value.

5-7-3. Log Amplifier

This option is use for SSRM head mode in NX-Hivac system.

5-7-4. External Current Amplifer

The NX system can be used with an external current amplifier option. Selecting **External** provides access to the External Curent Amplifier parameters, described below. Figure 5-7-2 shows the user interface for the External Current Amplifier.



○ DC
○ AC
○ Log
● External

Gain (x 10^) ○ 3 ○ 4 ○ 5
○ 6 ○ 7 ○ 8
● 9 ○ 10 ○ 11
Input Channel Auto

Figure 5-7-2. External Current Amplifier

Gain

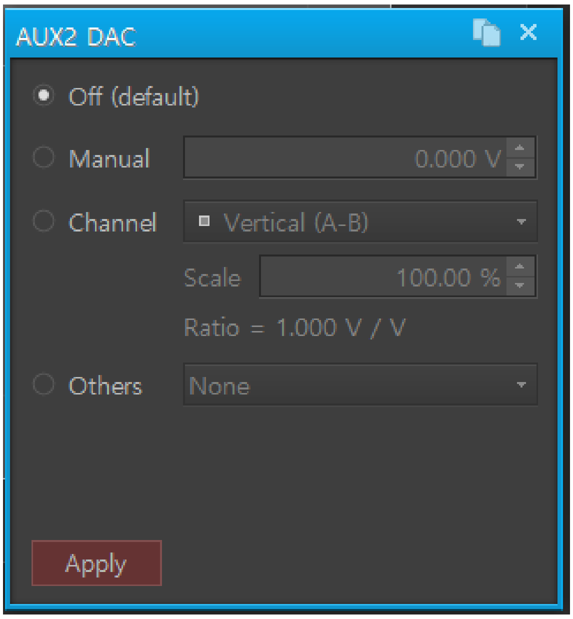
The gain setting for the External Current Amplifier must match the gain setting on the hardware in order to display the proper current units.ㅂ ㅈ

Input Channel

This control allows selecting the aux BNC input used to connect the current amplifier to the controller. **Auto** will automatically set the monitored channel depending on the imaging mode selected.

5-8. Aux DAC

You can change the output voltage of the aux DAC connector (AUX2 OUT) on the back panel of the NX control electronics by dragging the pointer on the adjustment knob or directly entering the voltage in the supplied field.



AUX2 DAC

● Off (default)

○ Manual 0.000 V

○ Channel Vertical (A-B)

Scale 100.00 %

Ratio = 1.000 V / V

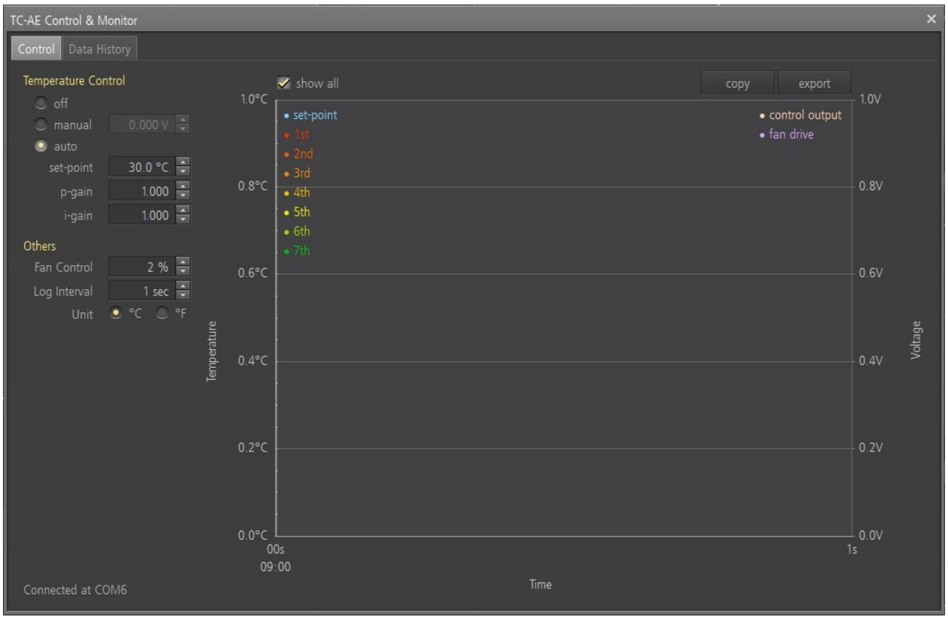
○ Others None

Figure 5-7-3. Aux DAC

5-9. TC-AE

The temperature-controlled acoustic enclosure (TC-AE) control is available for systems equipped with the acoustic enclosure with temperature control option. For more information about the TC-AE option, please consult the TC-AE manual. If the option is available and connected properly, the connection port will be displayed at the bottom left-hand corner of the TC-AE window. A “not connected” message will appear at the bottom if the option is unavailable. The temperature control unit must be turned on and connected prior to starting the SmartScan operating software.

Figure 5-8-1 shows the TC-AE control and monitor window. The interface is divided into two main areas accessed using the Control and Data History tabs.



TC-AE Control & Monitor

Temperature Control
○ off
○ manual 0.000 V
● auto
set-point 30.0 °C
p-gain 1.000
i-gain 1.000

Others
Fan Control 2 %
Log Interval 1 sec
Unit ● °C ○ °F

☑ show all

Connected at COM6

Figure 5-9-1. TC-AE Control & Monitor

5-9-1. Control

The Control tab displays the control interface used to set the desired temperature inside the acoustic enclosure and the parameters used to achieve this temperature. A temperature plot is provided for real-time monitoring of inside temperature.

Temperature Plot

Temperature Plot can display the temperature of the sensor inside the acoustic enclosure, as well as fan and voltage outputs. The signals listed on the left are displayed as temperatures and use the left side Y axis. The signals listed on the right are displayed as voltages and use the right side Y axis. The data is saved to the log file C:\Park Systems\SMARTSCAN\log|TC-AZ.db.

- Legend

  The legend is located at the upper right/left corner of the temperature monitor plot. Items in the legend can be toggled on and off by clicking on them. The items representing hidden data are shown in a strikethrough font. The signals displayed in the legends are as follows:

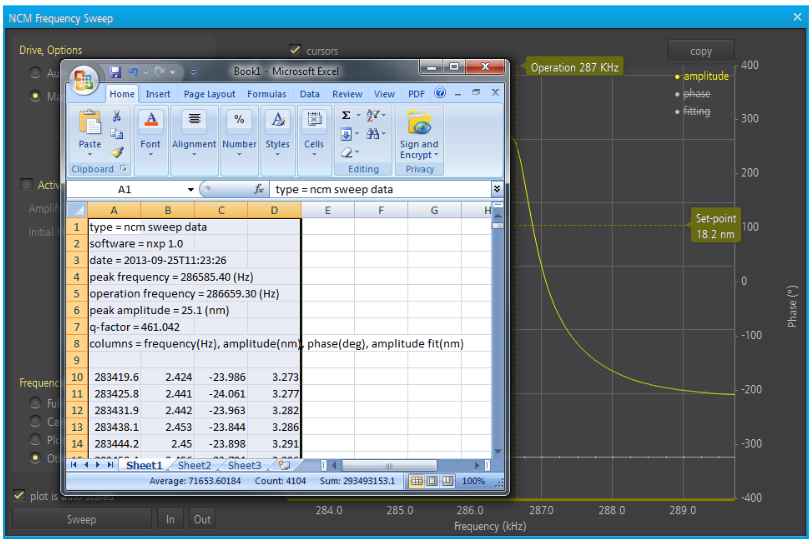
  - Upper left
    - SetPoint—target temperature for inside of the enclosure
    - Sensor temperature(1st~7th)—real-time temperature of the sensor (up to 7 sensors can be displayed)
  - Upper right
    - Fan Drive—Voltage applied to the cooling fan
    - Control Output—Voltage applied to Peltier heater/cooler

- Show all

  When this option is checked, the temperature plot will display all possible signals.

- Copy

  This option copies the signal display on the screen to a clipboard as text. You can paste (**Ctrl+V**) copied data to other programs, e.g., text editors or spreadsheets.



A1 type = ncm sweep data

type = ncm sweep data
software = nxp 1.0
date = 2013-09-25T11:23:26
peak frequency = 286585.40 (Hz)
operation frequency = 286659.30 (Hz)
peak amplitude = 25.1 (nm)
q-factor = 461.042
columns = frequency(Hz), amplitude(nm), phase(deg), amplitude fit(nm)

	A	B	C	D
10	283419.6	2.424	-23.986	3.273
11	283425.8	2.441	-24.061	3.277
12	283431.9	2.442	-23.963	3.282
13	283438.1	2.453	-23.844	3.286
14	283444.2	2.45	-23.898	3.291

Average: 71653.60184 Count: 4104 Sum: 293493153.1

Figure 5-9-2. Copying TC-AE data

- Export

  This option exports the signal display to a text file.

Parameter Controls

- Temperature control (three modes):
  - Off: Turns off the temperature control capability by setting the output voltage and fan speed to 0.
  - Manual: Manually sets the control output voltage to the Peltier device. Values from -10V to +10V can be entered.
  - Auto: Provides automatic temperature control, allowing the enclosure to be kept a desired setpoint temperature. Feedback parameters (P-Gain and I-Gain) as well as fan speed (Fan Control) must be adjusted to effectively reach the desired temperature.
- SetPoint: Target temperature for the inside of the acoustic enclosure. This temperature is feedback controlled.
- P-Gain: Proportional gain of temperature control feedback. Values between 0 and 10 can be entered. The P-Gain parameter adjusts the temperature based on the current error (the difference between the current temperature and the setpoint temperature).
- I-Gain: Intergral gain of temperature control feedback. Values between

0 and 10 can be entered. The I-Gain parameter adjusts the temperature based on the accumulation of past errors.

Others

- Fan Control: Fan speed control. Values between 0 and 100% can be entered. This parameter is set as a percentage of the maximum fan speed.
- Log Interval: Interval at which the data is collected and diplayed. Values from 1 to 100s can be entered.
- Unit: The temperature unit can be displayed in ºC or ºF by selecting the corresponding temperature scale.

Start button

Clicking **Start** begins the acquisition and display of temperature control data.

5-9-2. Data History

Temperature Plot

The features of the temperature plot under the Data History tab are identical to the plot in the Data History tab.

Data History Table

Temperature log files are displayed in the Data History table. Clicking on a specific data I/D will highlight the line in the table and display the saved temperature log in the temperature plot.

Refresh

Refreshes the Data History table.

5-10. Support

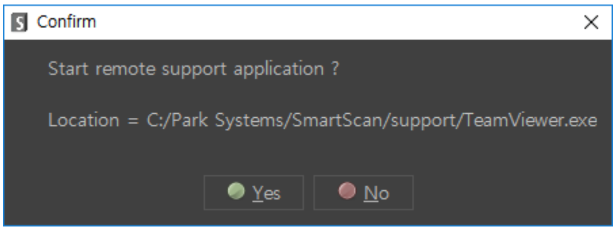
The **Support** button launches remote control software to provide a Park Systems service or applications engineer access to the computer in order to troubleshoot, `test, and run the the Park SmartScan operating software.

NOTE!

An internet connection is required for remote support.

To access remote support, contact your local Park Systems technical support group to arrange a remote support session. Launch the session by clicking **Support**.

A dialog box will open confirming your request to launch the remote control software. Confirming the request launches the remote control software.



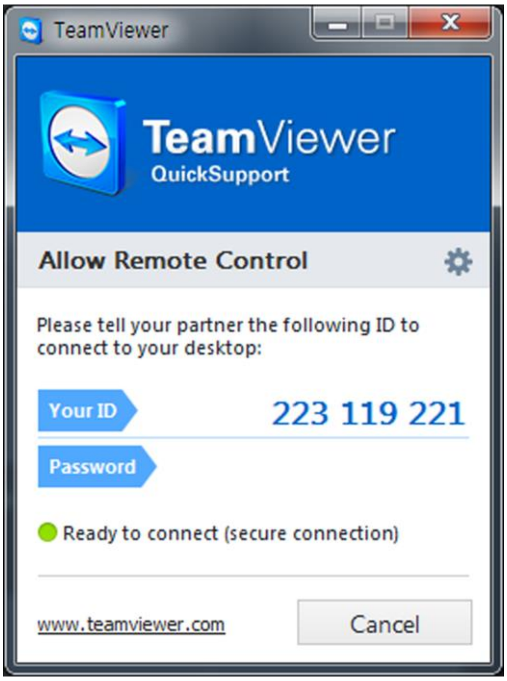
Start remote support application ?

Location = C:/Park Systems/SmartScan/support/TeamViewer.exe

Figure 5-10-1. Remote control confirmation dialog

The system/IP address is assigned a unique user I/D which must be provided to the Park System engineer to allow access.

To end the support session, click the **Cancel** button in the lower right corner or close the Teamviewer support window using the **X** at the top right corner.



Please tell your partner the following ID to connect to your desktop:

Your ID 223 119 221

Ready to connect (secure connection)

Figure 5-10-2. Teamviewer support window

Chapter 6. Auto Mode

You can access the auto mode workspace by clicking the **Auto** mode tab or by clicking **SmartScan ▼** and then **Auto**. Figure 6-0-1 shows the auto mode workspace with each view area labeled. These view areas are described below.

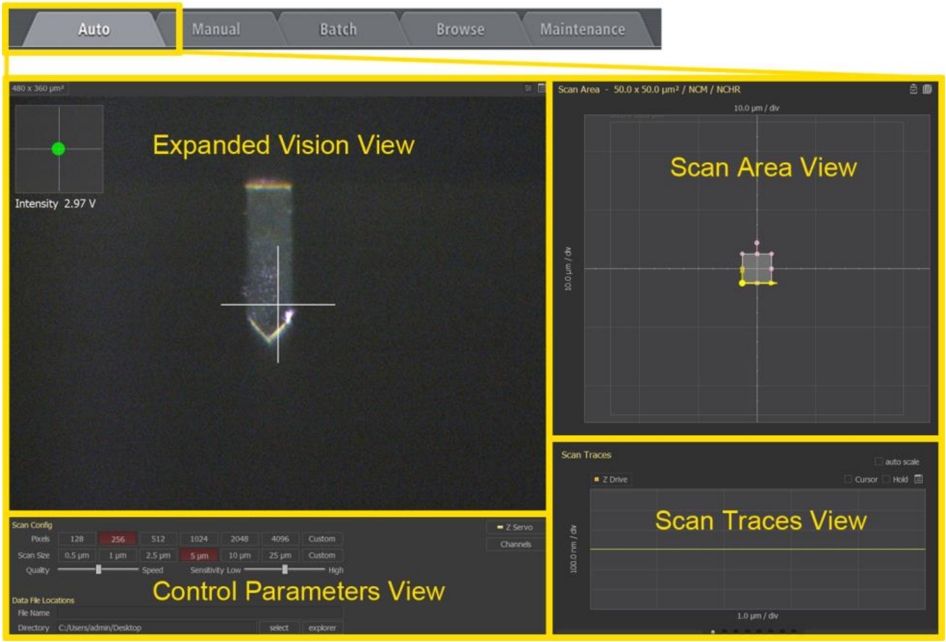


Figure 6-0-1. Auto mode workspace

6-1. Expanded Vision View

SmartScan supports viewing of the optical camera. Expanded Vision View is available in auto mode and measurement mode. Expanded Vision View is located in the upper-left corner of the SmartScan interface. Expanded Vision View provides features to monitor and control the AFM. Monitors are highlighted in Figure 6-1-1. Controls are highlighted in Figure 6-1-2.

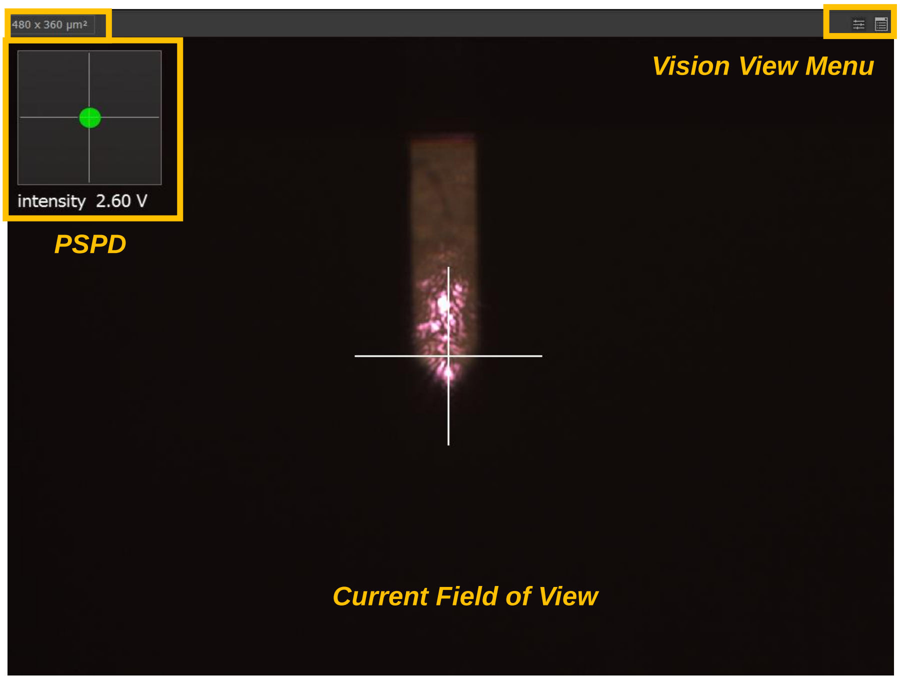


Figure 6-1-1. Current field of view

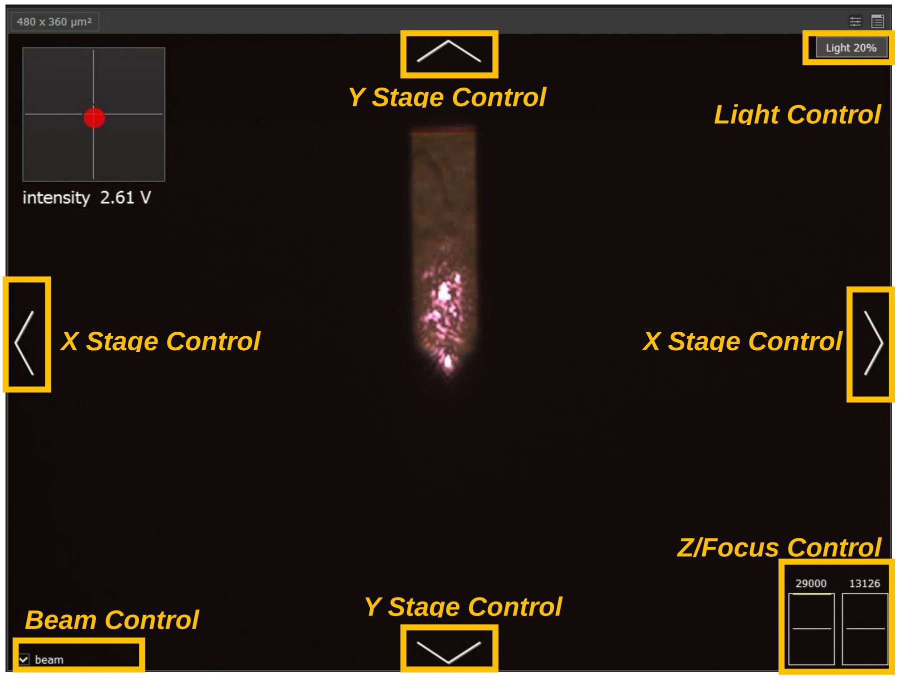


Figure 6-1-2. Field of view controls

6-1-1. Current Field of View

SmartScan's field of view can be adjusted by clicking on the current view label. Three choices for field of view will appear in a drop-down menu.

The field of view will depend on the configuration of the NX AFM. The default setting for the NX10 is as follows :

- 480 x 360 μm^2 / Large
- 384 x 288 μm^2 / Medium
- 300 x 225 μm^2 / Small

The change in the field of view is a digital magnification of the image. Field of view changes do not actually change the resolution, so zooming in too much will result in pixilation. The dimensions of the current field of view are displayed. If there is an issue with the camera, a numerical field of view size will not be displayed; instead the letters FOV will appear.

6-1-2. PSPD

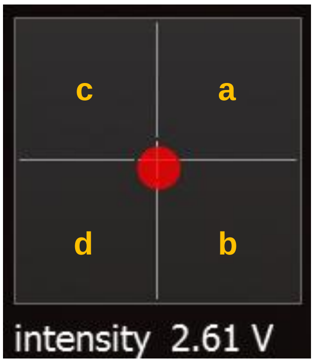


Figure 6-1-3. Quad-cell PSPD

The quad-cell PSPD can detect vertical as well as lateral deflection of the laser beam of the cantilever. The quad-cell PSPD has four cells as shown in Figure 6-1-3. You can get information about both surface height (AFM) and surface friction (LATERAL) during scanning by monitoring laser deflection.

The vertical deflection of the cantilever is measured as the difference between the upper cells (A=a+c) and the lower cells (**B**=b+d) of the quad-cell PSPD and provides the information about the sample's topography.

A-B signal=Topographic information= (a+c)-(b+d)

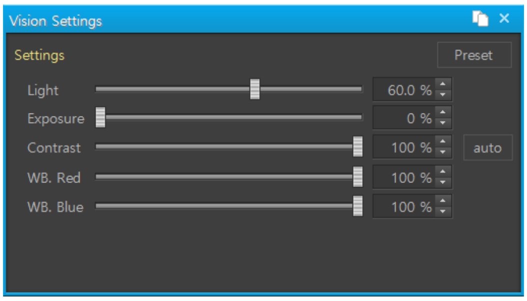
The lateral deflection of the cantilever is measured as the difference between the left cells (D=c+d) and the right cells (C=a+b) of the quad-cell PSPD and provides frictional information.

Lateral signal=C-D signal=Frictional information= (a+b)-(c+d)

In order to perform an approach and take an image, in general you should make the value of the A-B signal smaller than ±0.3V (the red point should be positioned at the center (crosshair) of the quad-cell PSPD display) and the value of the A+B signal—in other words, the laser total intensity should be greater than 2V. You can adjust the A-B signal and the intensity signal mechanically using the PSPD adjustment screws on the head (please refer to the User’s Manual). When properly centered, the laser will turn from red to green. The value of the A+B signal is called the signal intensity and is displayed at the bottom of the PSPD graphic.

6-1-3. Vision Settings

The **Vision Settings** button (☰) opens the Vision Settings dialog window, which contains controls for light and camera settings. Figure 6-1-4 shows the Vision Settings window. Light, exposure, contrast, red white balance, and blue white balance can be controlled using sliders, entering a percentage in the text field, or by using up/down arrows. The bottom of the Vision Settings window provides camera information, including camera type and frames per second.



Light 60.0 %
Exposure 0 %
Contrast 100 %
WB. Red 100 %
WB. Blue 100 %

Figure 6-1-4. Vision Settings window

- **Light**

  Alter the intensity of the LED light source by dragging the slider or directly entering the intensity level. Values from 0-100% can be entered.

- **Exposure**

  Adjust the CCD camera's exposure time by dragging the slider or directly entering the a value from 0% to 100%.

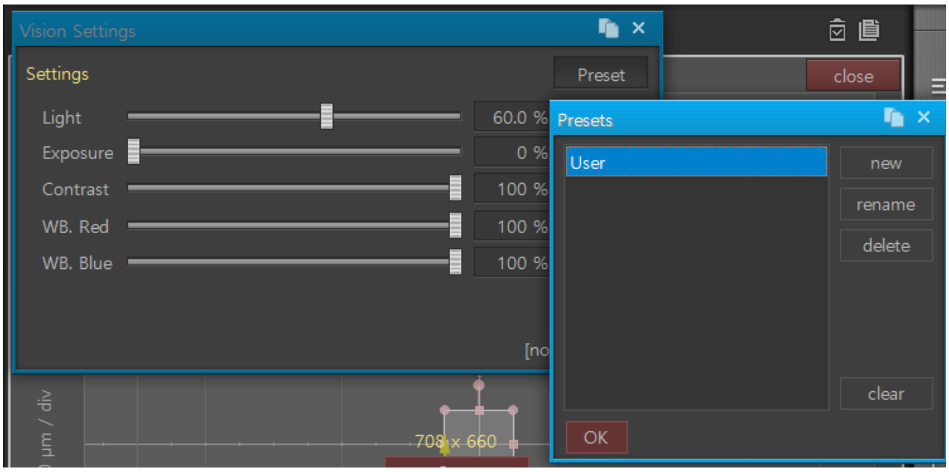
- **Camera Contrast**

  Adjust the CCD camera's contrast by dragging the slider or directly entering a value. The **Auto** button will automatically set the camera contrast for the display. Slider control and text field entry are disabled when Auto is used.

- **White Balance (Red, Blue)**

  The two scrollbars labeled **WB.Red** and **WB.Blue** can be used to adjust the color in the RGB color space in the red and blue axes, respectively, by dragging the scroll bar or entering a value directly. Clicking **Auto** will automatically set the white balance for the display. Slider control and text field entry are disabled when Auto is used.

Presets



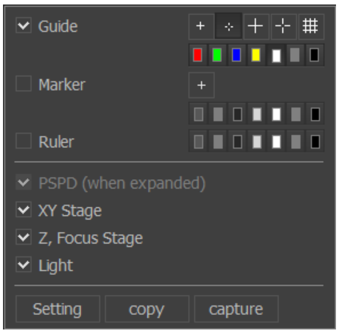
Light 60.0 %
Exposure 0 %
Contrast 100 %
WB. Red 100 %
WB. Blue 100 %

Figure 6-1-5. Presets window

Clicking the **Preset** button in the upper left corner of the Vision Settings window will open the Presets window. In this window, the current vision settings can be saved and recalled at a later time.

6-1-4. Options

Clicking the button open the Options box. The Options box allows toggling on and off optional features in the expanded field of view. Figure 6-1-6 shows the Options box.



- ☑ Guide
- ☐ Marker
- ☐ Ruler
- ☑ PSPD (when expanded)
- ☑ XY Stage
- ☑ Z, Focus Stage
- ☑ Light

Figure 6-1-6. Options box

6-1-3. Guide

When checked, this control adds a crosshair or grid lines to a view window. Guides aid in positioning the sample relative to the cantilever when measuring a particular area. Figure 6-1-7 shows the view window with and without guides.

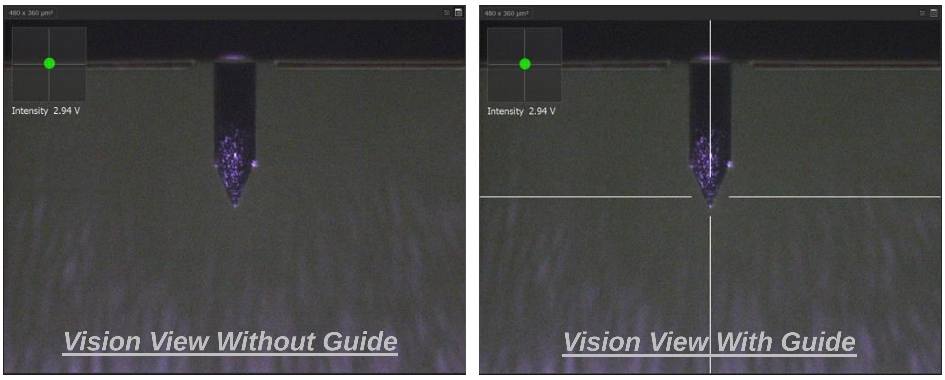
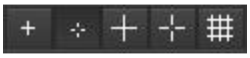
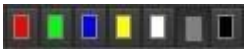


Figure 6-1-7. Vision View with/without guides

Guide type and color can be changed by clicking on the type and color desired. Crosshair positions cannot be changed or moved.

Available types: 

Available colors: 

6-1-4. Marker

When checked, the **Marker** feature will appear on the Vision View. The Marker is a circular object that can be resized by clicking on the object and dragging it to the desired size. The color of the object can also be adjusted based on the sample or background. Clicking on the object will display the horizontal and vertical diameters of the circular object. The Marker can be used to estimate objects in the Vision View. Figure 6-1-8 shows the Marker feature.

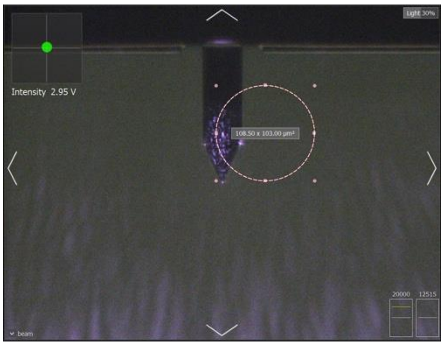


Figure 6-1-8. Vision View with Marker

6-1-4. Ruler

When checked, the **Ruler** feature will appear on the Vision View. The Ruler function displays a line that can be resized and relocated by dragging each endpoint. The distance between two points can then be calculated using the ratio of vision size and screen size. Figure 6-1-9 shows a selected ruler line measuring a cantilever approximately 147.42µm long.

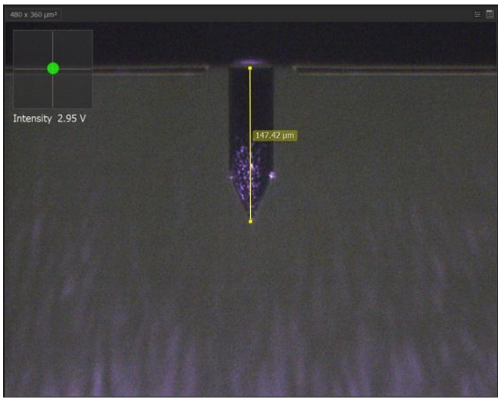
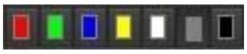


Figure 6-1-9. Ruler

The color of the ruler can be changed by clicking the appropriate color box.

Available colors: 

6-1-5. PSPD when expanded

When checked, this control displays the PSPD in the upper left corner of the expanded window. This option is displayed as default in auto mode.

6-1-6. XY Stage

When checked, this control displays the XY motorized stage controls at the edges of the Vision View.

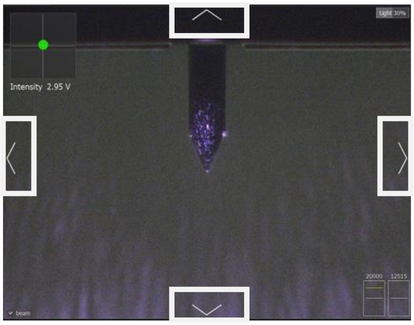


Figure 6-1-10. Vision View with XY stage controls highlighted

6-1-7. Z, Focus Stage

When checked, this displays the Z and focus stage controls in the lower right corner of the Vision window. Figure 6-1-11, shows the Z and focus stage controls.

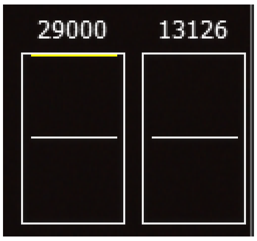


Figure 6-1-11. Z and focus stage pads

The Z and focus stage controls consist of two stage pads. The left-hand stage pad moves the Z stage stepper motor. The right-hand stage pad moves the focus stage stepper motor. The stage controls both direction and speed of stage movement. Clicking below the center line moves the Z and focus stage down. Clicking above the center line moves the Z and focus stage up. The farther away from the center line the stage pad is clicked, the faster the stage will move. Click and hold the pad to move the stage. Release the stage pad to stop movement.

6-1-8. Light

When checked, this control displays the light control in the upper right corner of the Vision window.

Holding the mouse cursor over the display will display a message indicating that the mouse wheel can be used to adjust light intensity. The display value will update in real time corresponding to the chosen light intensity. If the message does not appear, simply click on the display and begin adjusting with the mouse wheel.

6-1-9. Setting

Opens the Vision Settings window.

6-1-10. Copy

Copies the optical vision image on to the clipboard. The copied image does not include any guides or rulers.

6-1-11. Capture

Saves the optical vision image in C:\Park Systems\SMARTSCAN\Vision. Clicking this button will add a folder link to the saved image in the lower right corner of the Options window. The saved image does not include any guides or rulers.

6-1-12. XY Stage Control

X and Y stage control arrows appear on each side of the View window. The arrow direction denotes the direction of stage movement. Click and hold the arrow to move the stage. The stage moves at one speed, and the control is used to move the stage into the general area of interest. Releasing the arrow button will stop movement.

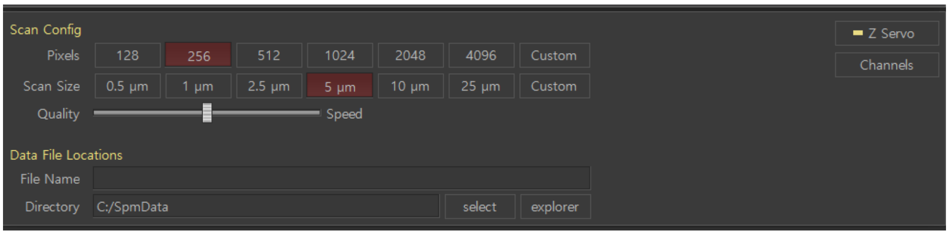
Once the desired location is within the field of view, the stage can be moved by double-clicking on the desired location. This will bring the location to the center of the feld of view indicated by the guide.

6-1-13. Beam Control

Clicking the beam control check box turns on and off the laser. This can be useful for viewing and positioning the sample without optical interference from the laser or for turning on the laser when the software has turned off the laser automatically.

6-2. Control Parameters View

The Control Parameters View is located in the lower left corner of the auto mode workspace. Located in the Control Parameters View are parameters used for scanning and saving data.



Directory C:/SpmData

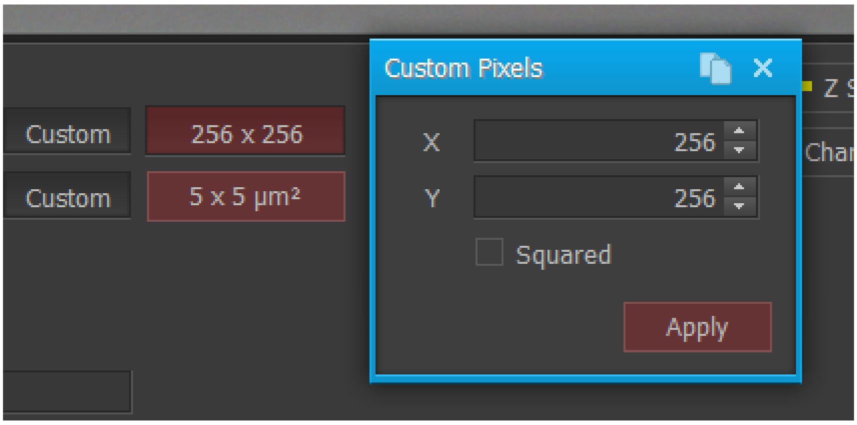
Figure 6-2-1. Control Parameters View

6-2-1. Scan Config

Scan Config provides setting for pixel resolution, scan size, and image quality.

Pixels

The image resolution is affected by the number of pixels in the image. Pixel resolution options are 128x128, 256x256, 512x512, 1024x1024, 2048x2048, and 4096x4096. Select the desired resolution by clicking the appropriate button. The current pixel resolution is highlighted. If a different or non-square pixel resolution is desired, clicking the **Custom** button will display an additional option next to the **Custom** button. Clicking the option will open a window that allows customizing the number of pixels in the image. Figure 6-2-1 shows the Custom window.



X 256

Y 256

☐ Squared

Figure 6-2-2. Custom pixel resolution

To set a custom resolution, enter the pixel range for X and Y independently. If the same value is desired for both X and Y, check **Squared**. Click **Apply** to apply the changes and close the dialog box.

Scan Size

The image scan size can be set using the **Scan Size** button presets. Preset scan sizes of 0.5µm, 1µm, 2.5µm, 5µm, 10µm, and 25µm can be chosen. Images will be the same dimension in both axes (slow scan direction and fast scan direction). If a non-square image or an image in a size not listed is desired, click the **Custom** button to add an additional option button. To change the value of the optional button, click the button to open the Custom dialog, and then set the scan size independently in the X and Y directions. See the Pixels section above for information on setting a custom-sized scan.

The Custom Pixel and Scan Size features can be used together to keep the pixel density consistent when acquiring rectangular images.

Quality

The **Quality** slider controls image quality. Sliding the bar toward Speed will increase the time it takes to acquire the image, but may decrease the overall quality of the image. Sliding the bar toward Quality will improve the overall quality of the image but increase the total scan time. By monitoring the Scan Area (Section 6-3) and Scan Trace (6-4), users can optimize the slider position for the best balance of quality and speed.

6-2-2. Date File Locations

File Name

SmartScan uses the filename in this field to name the saved image. Each data signal is saved as a separate file with the same file name but different file name suffixes. For example, an image named “FileName” would be written with the following default file structure:

FileName%1_%N_%G

Where %1 is the date written as YYMMDD, %N is the channel name, and %G is a sequential group number given to images as they are saved.

Note!

The structure written above is the default structure, but it can be adjusted by editing the manual mode config file.

Directory

Lists the directory where files are saved. The default directory is C:\spmdata.

Select

Opens a window to select a new directory.

Explorer

Opens the folder named in the Directory field in Windows Explorer.

6-2-3. Z Servo

Opens the Z Servo Configuration box. The Z servo controls feedback to the Z scanner. In contact mode, the force between the tip and sample is maintained by the Z servo. In non-contact mode, the distance between the tip and sample is maintained by the Z servo.

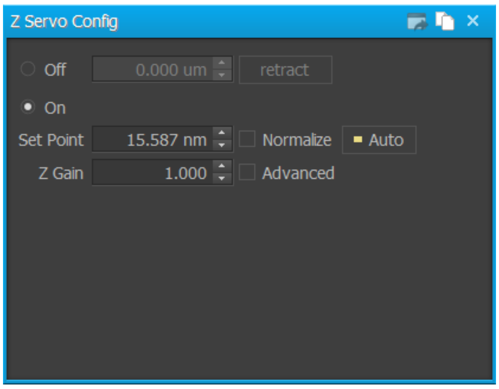


Figure 6-2-3. Z Servo Config

Off

This turns off Z servo feedback. This will stop movement of the Z scanner and hold the position of the tip. With the Z servo turned off, the software will not compensate for any movement or change due to thermal drift or deviations from the setpoint.

Once the Z servo is off, the text field will be active. The value displayed corresponds to the current scanner position. The center of the scanner range is given the value 0µm. Extension of the scanner from its center point results in a negative number. Retraction from center point generates a positive number.

Retract

This option retracts the scanner from the surface. The exact value will depend on the individual scanner.

On

On turns on the Z servo so that the software actively monitors the PSPD signal to compensate for deviations away from the set point.

SetPoint

This is the reference value for Z servo feedback. The Z servo is set so that the set point is maintained. In contact mode, the set point is in units of force. The force is measured by the deflection measured on the PSPD of the tip as it contacts the surface. See Contact Mode in the User’s Manual for more information.

In non-contact mode, the set point is in units of length. The set point is a measure of the amplitude of cantilever oscillation. As the cantilever nears the surface. the oscillation amplitude decreases. The system maintains a constant oscillation amplitude and hence a constant distance above the sample surface. See Non-Contact Mode in the User's Manual for more information.

Normalized

The **Normalized** check box changes the set point from a value specified in force or length units to a value specified by voltage from the PSPD.

Z Gain

Z Gain controls the **Proportional** and **Integral** servo settings used in imaging. Values from 0-20 in arbitrary units can be entered. The default value, 1, should be set for auto mode.

Advanced

When checked, the **Z Gain** parameter is replaced with four gain parameters: **+Z Gain**, **-Z Gain**, **P Gain**, and **I Gain**. Each of these numbers is factored separately in conjuction with the error signal to drive the Z scanner.

Note!

When you deselect the **Advanced** servo button, the PI gain changes to default values (P:1, I:1) and Z servo gain is set by the previous Z servo gain. Use caution when checking this box.

- **Z Servo Gain+/**-

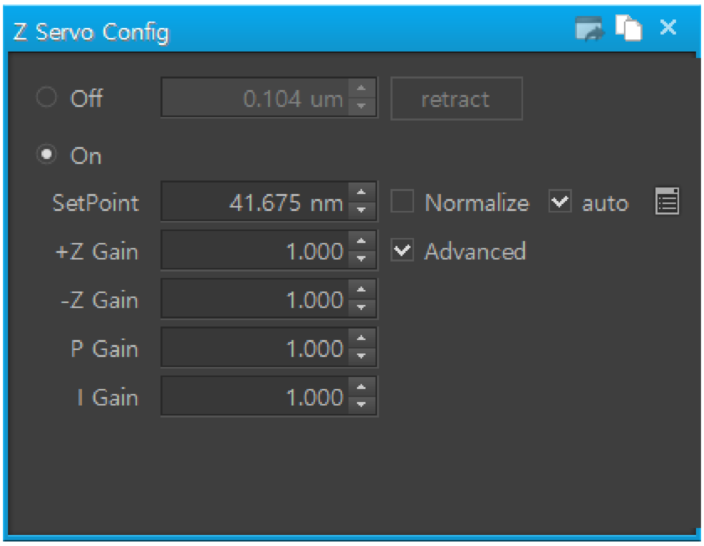
  When using Z servo gain, this multiplies the error signal according to the Z servo gain value for Z servo response time. These Z servo gain fields determine the value by which an error signal is amplified. A positive Z servo gain value amplifies the positive error signal, while a negative Z servo gain value amplifies the negative error signal. If the **Equal Gain** button is selected, the Z Servo Gain- value is set to equal the + value. Otherwise, the + and – gains can be set to different values. This can be useful for samples with steep variations, where a higher Z Servo Gain- value can help trace steep dropoff sample features.

- **P Gain**

  When using proportional gain, or P gain, this multiplies the error signal by a default scalar, then by the constant specified in the P Gain field to produce the Z scanner signal. A P gain of 1 is identical to SmartScan's behavior without Advanced Servo.

- **I Gain**

  When using integral gain, or I gain, this takes the integral of the error signal and multiplies it by a scalar, then by the specified I gain. A I gain of 1 is identical to SmartScan's behavior without Advanced Servo.



Z Servo Config

○ Off 0.104 um retract

● On

SetPoint 41.675 nm ☐ Normalize ☑ auto

+Z Gain 1.000 ☑ Advanced

-Z Gain 1.000

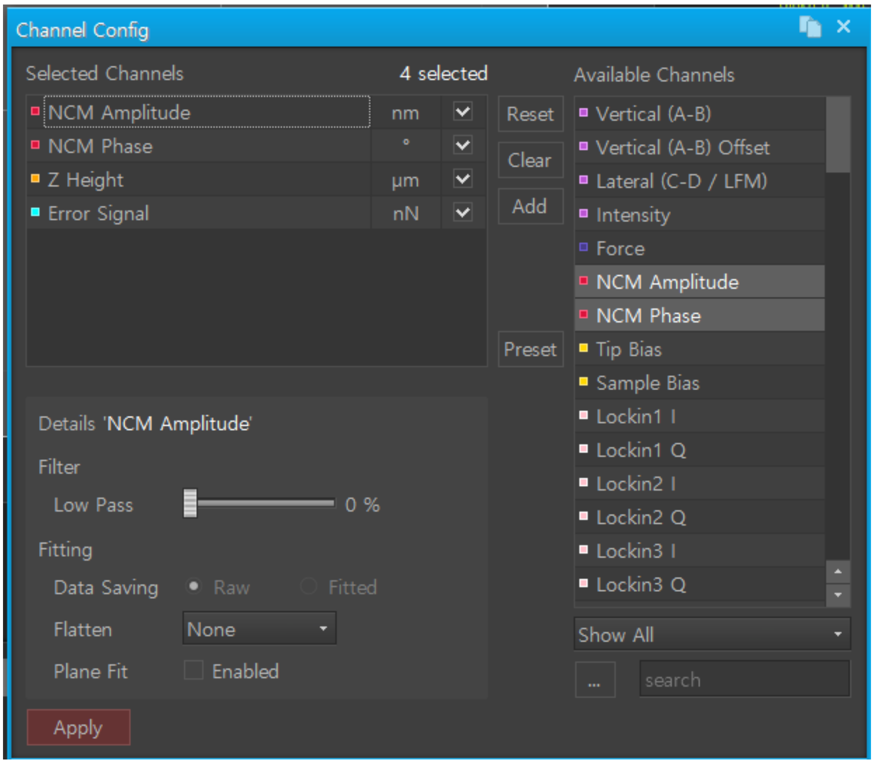
P Gain 1.000

I Gain 1.000

Figure 6-2-4. Advanced check box

6-2-4. Channels

This opens the Channel Config Window. The Channel Config window allows choosing data channels to monitor and record while scanning. It provides filters and flattening algorithms that can be added to the signal and saved with the data. The Channel Config window consists of three main sections: a) Selected Channels, b) Details, and c) the Channels Panel.



NCM Amplitude	nm	☑
NCM Phase	°	☑
Z Height	µm	☑
Error Signal	nN	☑

Details 'NCM Amplitude'

Filter

Low Pass 0 %

Fitting

Data Saving ● Raw ○ Fitted

Flatten None

Plane Fit ☐ Enabled

Figure 6-2-5. Channel Config window

Selected Channels List

The Selected Channels List provides a listing of the data channels that will be collected during a scan. The total number of channels is displayed in the upper left corner. Up to eight channels can be selected. An error message will be displayed if the number of channels chosen exceeds eight.

The **Unit** drop-down menu enables you to select the units that are used to display the signal channel on the Scan Traces View. Depending on the type of signal you are collecting, you can select from an appropriate list of units for the signal in the Unit field.

The unit next to the channel name indicates the unit used to specify the data. Once the channel name is highlighted, clicking the unit name will provide the ability to change the unit. Most units can be changed to “V”.

Adding a channel

Channels can be added to the list by double-clicking them from the Channels and Presets list or by highlighting the channel and clicking **Add**.

Deleting & resetting a channel

Channels can be deleted from the list by double-clicking on them or by clicking the check box corresponding to the input on the right side of the channel name.

Clicking an individual channel highlights the channel and displays channel details in the area below. And, clicking the **CLEAR** button deletes all the channels from the list. On the other hand, clicking **RESET** button undo previous operation on the Selected Channel list.

Low Pass Filtering

The **Filter** scale adjustment bar enables you to select the time interval (from 0 to 100%) used to replace each data pixel with averaged value from the collected data. An increase in the number corresponding to the pixel means that more sampling data points are averaged to obtain each data pixel.

The filter is applied during a scan and permanently affects your data. When surface features are hidden by high-frequency noise, the filter decreases the effect of such high-frequency contributions.

Data Saving

When using the Flatten and Plane Fit functions, you can select the raw data or the Fitted data to save. This feature is only available when Flatten or Plane Fit is enabled.

Flattening

The **Flatten** drop-down menu allows you to specify how much flattening is applied to your data as it is collected. In addition to **None**, which does not affect your data, there are 4 options: **Offset Adjust**, **Line**, **2nd Order**, and **3rd Order**.

Line, 2nd Order, and 3rd Order use the same basic principle. A curve of the specified order is fitted to each line of data acquired, and is then subtracted from that line.

Offset Adjust is a data processing routine that adds or subtracts an offset to each line of data relative to the average offset of the surrounding line(s) of data. Offset Adjust is especially useful when the sample is quite uniform in that the probe tip does not experience sharp slopes or valleys after the first line of data is acquired in the slow scan direction. Offset Adjust is recommended for relatively flat samples with fine structures and uniform features. Offset Adjust is not recommended for samples with large surface height differences.

Plane Fit

To apply an automatic slope correction to an image after it is acquired, select the **Plane Fit** check box. A first order flattening will be applied to the data. Plane Fit will compensate for the tilt of the sample surface relative to the sample scan plane.

Presets

Figure 6-2-5 shows the preset channels panel. Clicking **Preset** button will show a short list of predetermined channels for each mode as shown in Figure 6-2-4.

The preset channels can be customized by clicking **New** to create a new preset, **Rename** to rename an existing preset, **Delete** to delete a preset, or **Clear** to remove all the preset.

Any signal can be added to the Selected Channels List by double-clicking the channel and the clicking **OK** to apply the changes. These signals are monitored in real time on the Scan Traces View. Maximum of eight signals can be listed and monitored for image pixel resolution ranging to 4096×4096.

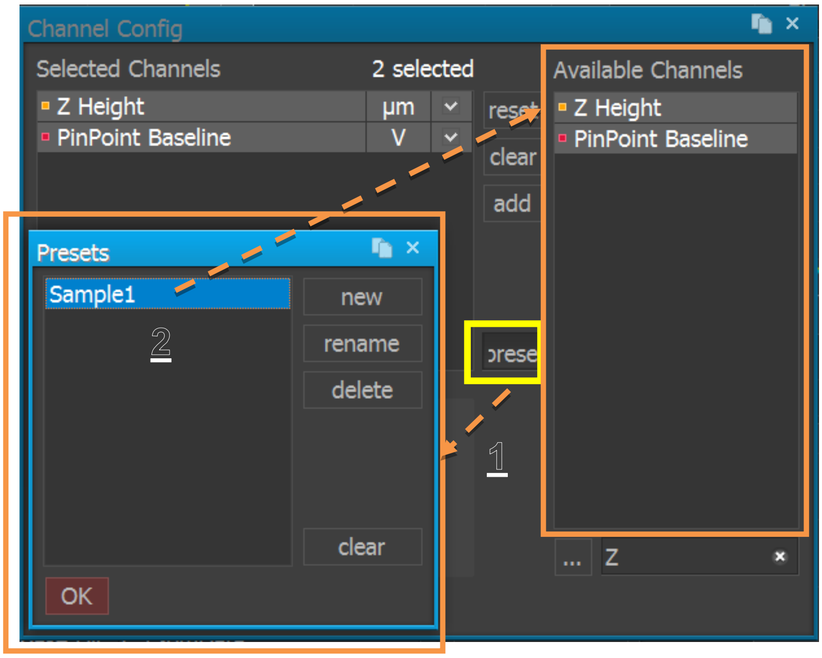


Figure 6-2-5. Preset Channels Panel

By clicking (...), a summary of channel category will appear (see Figure 6-2-6a). Then, clicking **More Specific** will show a list of available Mode (see Figure 6-2-6b). Channel search features can also be found at the bottom right of the window as shown in Figure 6-2-6c.

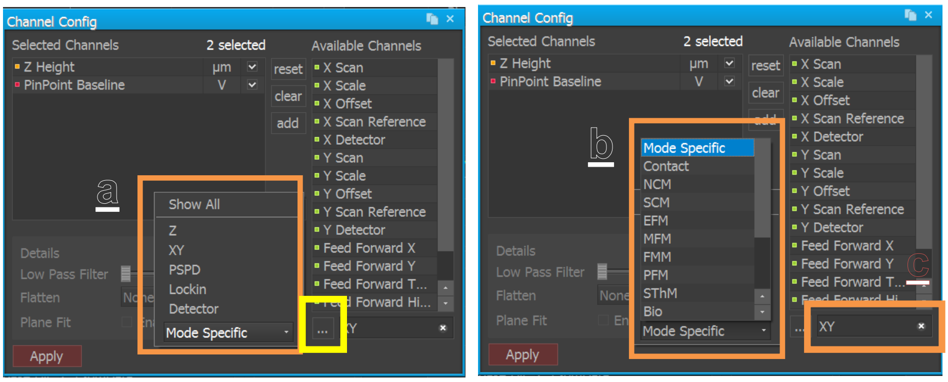


Figure 6-2-6. Channel List and Mode

6-3. Scan Area View

You can easily set a scan size and scan location for the scan in the Scan Area View. Also, the image can be monitored during scan, and the previously acquired image is monitored. For more information about the Scan Area View, refer to Section 8.1

6-4. Scan Traces View

The Scan Traces View is an oscilloscope window that can be used to display selected signals in real time. Up to eight signals can be displayed. Toggle between the different available signals using the radio button page indicator (● ○ ○ ○ ○ ○ ○ ○). For information about Scan Trace View controls, see Section 8.2.

Chapter 7 Manual Mode

You can convert to Manual mode by selecting the **Manual** tab or by clicking **SmartScan▼->Manual**. The workspace changes to reflect measurement-related tasks, displaying Vision View, Parameters Control View, Monitoring View, Scan Area View, Setup View, and Results View.

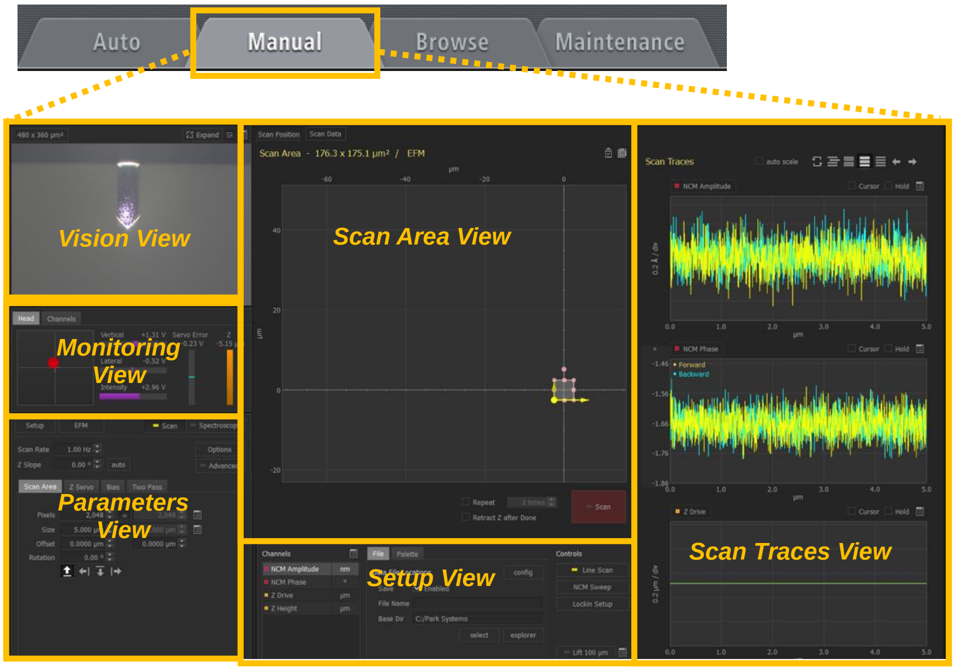
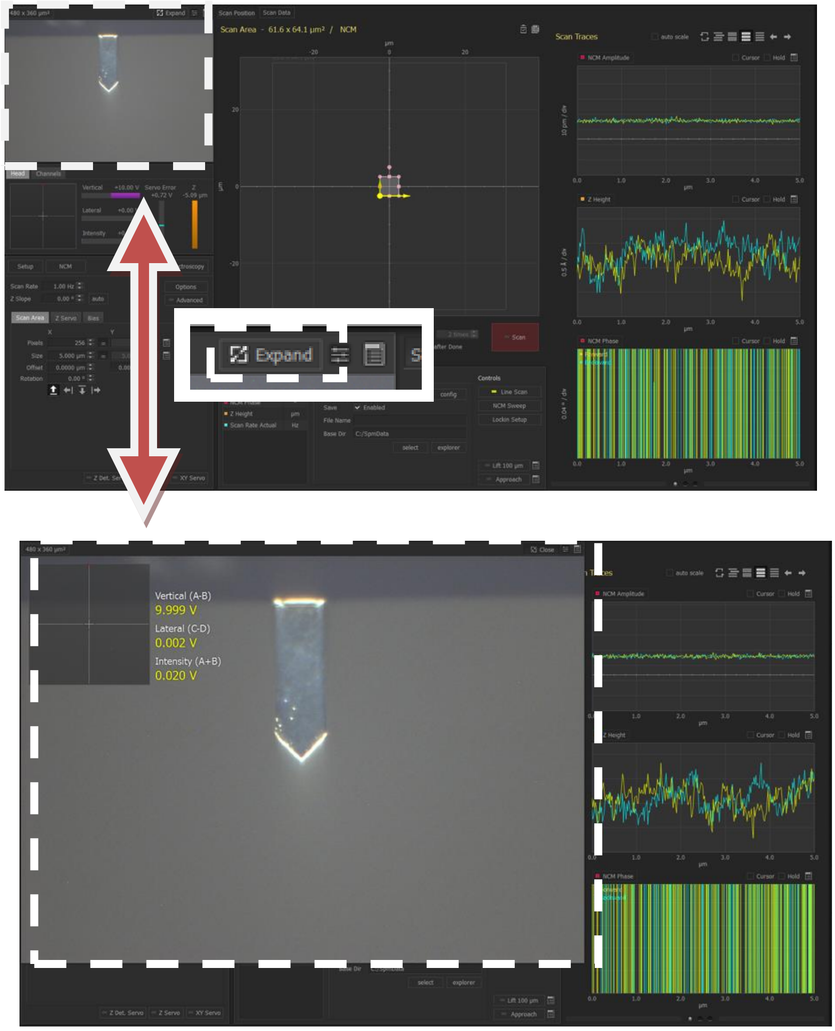


Figure 7-0-1. Manual Mode Workspace

7-1. Vision View

The Vision View displays the optical view from the digital camera. The camera can be focused on the cantilever or sample. Focus on the cantilever to align the beam onto the cantilever. Focus on the sample to locate the general area for imaging.

The Vision View can also be used to control a) light strength, b) turning the beam on/off, c) the XY stage, and d) the Z/focus stage. Clicking **Expand** (Expand) will expand the Vision View to allow the user to easily see the optical image. Refer to Section 6.1 for more information about the Vision View controls and the expanded Vision View.



Vertical (A-B)
9.999 V
Lateral (C-D)
0.002 V
Intensity (A+B)
0.020 V

Figure 7-1-1. Vision View and expanded Vision View

7-2. Monitor View

The Monitor View displays useful information during measurement. The Monitor View has three tabs: **Head**, **Channels**, and **Event**.

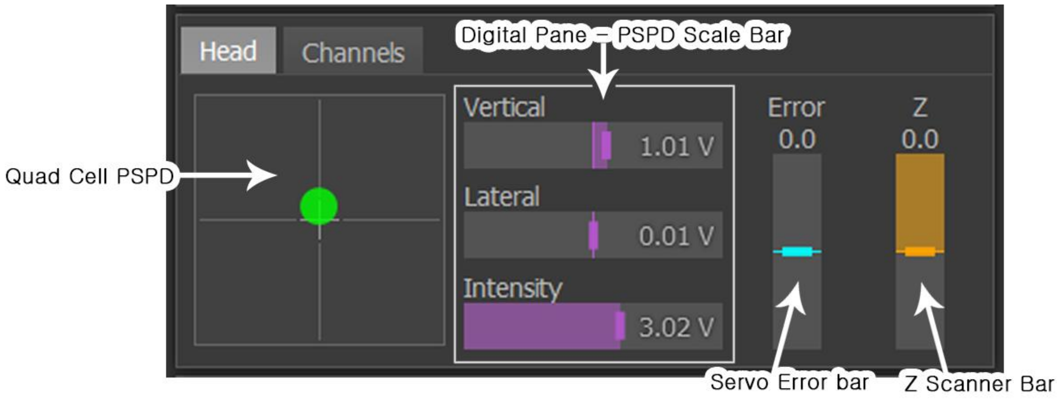


Figure 7-2-1. Monitor View

7-2-1. Head Tab

As shown in Figure 7-2-1, the **Head** tab contains a visual representation of the quad-cell PSPD (position-sensitive photo detector) and three related scale bars (**Vertical**, **Lateral**, **Intensity**) with the value in voltage units, as displayed above. The **Head** tab also contains a servo error bar and a Z scanner bar, which display the status of the feedback loop and the Z scanner in real time.

Panel	**Function**
Quad Cell-PSPD	Shows the position of the reflected laser beam on the PSPD so that you can monitor the deflection of the cantilever.
Vertical	Monitors the vertical PSPD signal, such as cantilever deflection, amplitude of cantilever vibration, or tunneling current, depending on your experimental setup.
Lateral	Monitors the lateral signal, which is related to the change in the surface friction on a sample surface.
Intensity	Monitors the intensity of the reflected laser beam on the PSPD.
Panel	**Function**

Servo Error Bar	Graphically displays the value of the servo error signal from the PSPD relative to the set point value. The value of the servo error signal is represented by the aqua-green bar.
Z Scan Bar	Graphically displays the Z extension of the piezoelectric scanner within its total range. The value of the Z extension is represented by an orange bar. The working range of the Z scanner is represented by this bar during each scan line.

Quad-cell PSPD and Scale Bars

The quad-cell PSPD can detect vertical as well as lateral deflection of the laser beam of the cantilever. The quad-cell PSPD has four cells as shown in Figure 7-2-2. You can get information about both surface height (AFM) and surface friction (LATERAL) during scanning by monitoring laser deflection. The vertical deflection of the cantilever is measured as the difference between the upper cells (A=a+c) and the lower cells (B=b+d) of the quad-cell PSPD and provides the information about the sample’s topography.

A-B signal=Topographic information=(a+c)-(b+d)

The lateral deflection of the cantilever is measured as the difference between the left cells (D=c+d) and the right cells (C=a+b) of the quad-cell PSPD and provides frictional information.

Lateral signal=C-D signal=frictional information=(a+b)-(c+d)

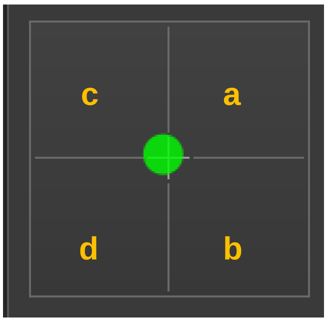


Figure 7-2-2. Quad-cell PSPD

In order to perform an approach and take an image, in general you should set the value of the A-B signal smaller than ±0.3V (the red point should be positioned at the center (crosshair) of the quad-cell PSPD display) and the value of the A+B signal (in other words, the laser total intensity) greater than 2V. You can adjust the A-B signal and the intensity signal mechanically using the PSPD adjustment screws on the head (please refer to the User's Manual for more information).

Servo Error Bar

The servo error bar graphically shows the values of the servo error signal from the PSPD relative to the set point value, the reference signal for the feedback loop.

During a scan, deflection of the cantilever changes as the tip responds to surface topography. The Z feedback loop works to keep this deflection constant during a scan by adjusting the Z position of the scanner. The deflection sensor monitors the amount of cantilever bending and sends a deflection signal to the feedback electronics. There, the deflection signal is compared to a reference signal (deflection at the set point) and an servo error signal is generated. This servo error signal is used to generate a feedback signal, which is sent to the Z scanner so that it causes the scanner to extend or retract. This feedback signal can also be used to generate an image of the sample surface.

Figure 7-2-1 shows the servo error bar. The aqua-green portion represents the value of the servo error signal, and the position at 0V represents the set point value. The feedback loop is optimized when the servo error signal bar matches the set point value.

Z Scanner Bar

The Z scanner bar monitors the extension or retraction of the Z scanner in response to feedback voltage. The orange portion of the Z scanner bar represents the extension of the piezoelectric Z scanner within its total allowable range of motion. The upper end of the Z scanner bar represents the scanner's position when it is fully retracted. The lower end of the Z scanner bar represents the scanner's position when it is fully extended.

Initially, the Z scanner bar is gray, indicating that the Z scanner is fully retracted. After you enter a set point value, the Z scanner bar fills with orange color to the lower end of the Z scanner bar. This means that the Z scanner bar is fully extended and is ready to approach the sample surface.

Once tip approach is complete, you will see that half of the Z scanner bar is filled with orange. During scanning, when the probe tip encounters peaks on the surface, the Z scanner retracts (the orange bar moves toward the upper end of the Z scanner bar). When the tip encounters valleys on the sample surface, the Z scanner extends (the orange bar moves toward the lower end of the Z scanner bar).

The Z scanner bar always represents the Z scanner’s maximum range of motion. Thus, depending on the Z scanner range, its relative motion is scaled differently. When the Z scanner is moving in a small range, the change of the Z scanner bar is relative to that small range, rather than the whole range.

The center of Z scanner bar is 0. As the Z scanner moves up from the center, it retracts and moves in the positive direction (+). As the Z scanner moves down from the center, it extends and moves in the negative direction (-). The value on the top of the Z scanner bar indicates the current Z scanner position.

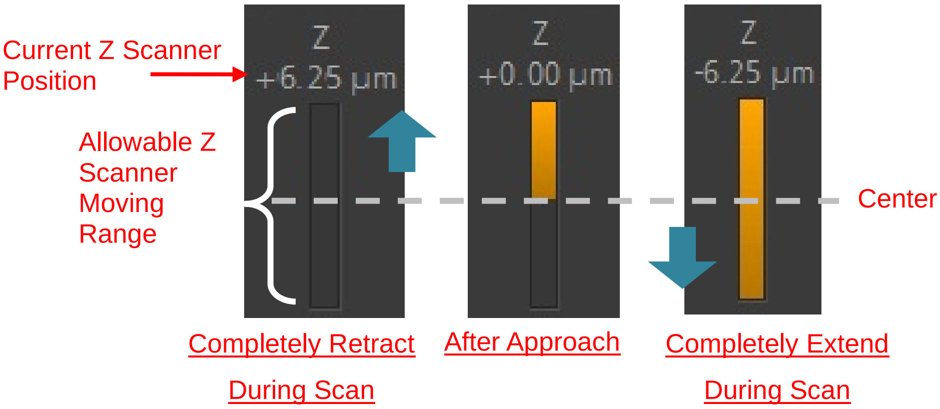

Current Z Scanner Position
Allowable Z Scanner Moving Range
Z
+6.25 µm
Z
+0.00 µm
Z
-6.25 µm
Center
Completely Retract During Scan
After Approach
Completely Extend During Scan

Figure 7-2-3. Z scanner bar

7-2-2. Channels Tab

In the **Channels** tab, you can select several input signals (up to six) and monitor them through digital panels in real time.

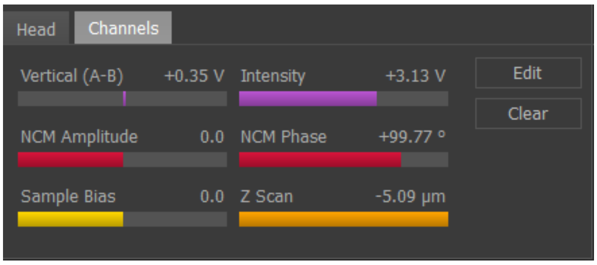


Figure 7-2-4. Channels tab

Edit

Edit opens the Channel List dialog to select signals to be monitored through the digital panel. Check the box on the right side of the the desired signal, and then click **OK** in the Channel List dialog to display the signals in the **Channels** tab.

Clear

Clicking **Clear** removes all signals displayed in the **Channels** tab.

7-3. Parameters View

At the top of the Parameters View are four buttons that toggle hardware and software features.

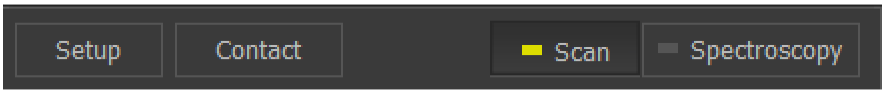
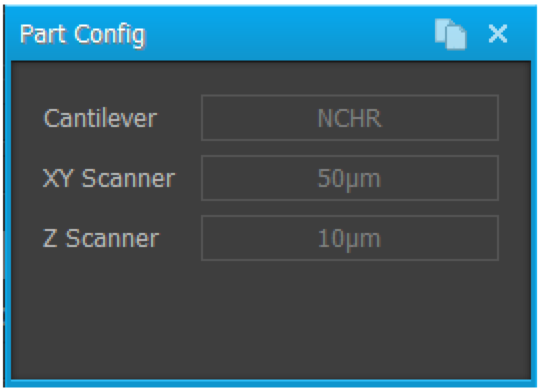


Figure 7-3-1. Software and hardware feature toggle buttons

7-3-1. Setup

The **Setup** button opens a hardware Part Config window. This window displays the type of cantilever, XY scanner, and Z scanner the system is using. Each field specifies a value the software uses while imaging. The cantilever file introduces spring constant and freqeuncy range information. The XY Scanner and Z Scanner values are used to calibrate scanners for accurate measurement. Figure 7-3-2 shows the Part Config window. To activate the Part Config button, **Line Scan** must be turned off.



Cantilever NCHR

XY Scanner 50μm

Z Scanner 10μm

Figure 7-3-2. Part Config

7-3-2. Head Mode

The **Head Mode** button displays a drop-down menu listing available scanning modes. The number of modes will vary for each system.

7-3.3 Scan and Spectroscopy

The **Scan** and **Spectroscopy** buttons toggle the workspace layout between scan mode and spectroscopy mode. The active mode is indicated by the yellow indicator light. Refer to Chapter 8 for more information on scan mode. Refer to Chapter 9 for more information on spectroscopy mode.

Chapter 8. Scan Control

Scan Control, located on the **Manual** tab, provides full scan control of the AFM. Clicking the **Scan** button in the Parameters View will activate scan control. The workspace setup includes the Vision View, Monitoring View, Parameters View, Scan Area View, and Scan Traces View. The Vision View and Monitoring View are shared between the Scan and Spectroscopy controls. All other view panels are specific to Scan Control. The Parameters View is used for setting up a scan and acquiring an image. The Scan Area View can be used to set the scan region and display the acquired image in real time. The Scan Traces View is used for monitoring a trace line in real time. The Setup View identifies which channels to acquire and where the files are saved.

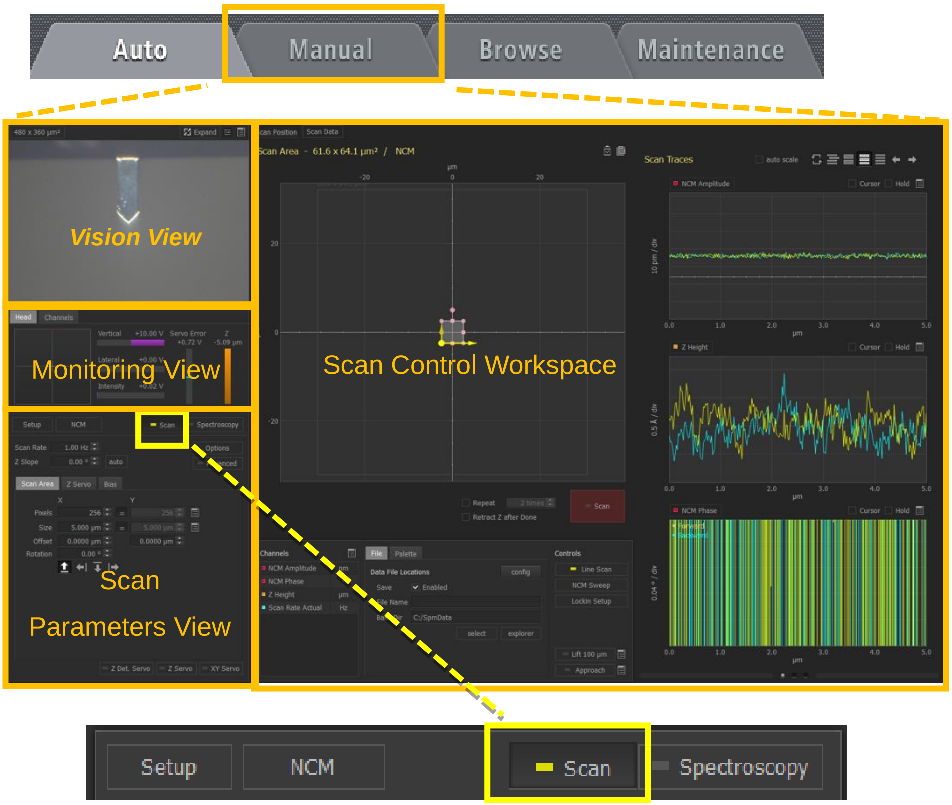


Figure 8-0-1. Scan mode interface

The **Manual** tab of the Spectroscopy control includes:

- Vision View (see Section 6-1)
- Monitoring View (see Section 7-2)
- Scan Parameters View (see Section 8-3)
- Scan Control Workspace (see Chapter 8)

The Scan Control Workspace is further separated into three main areas: the Scan Area View, Scan Traces View, and Setup View (see Figure 8-0-2).

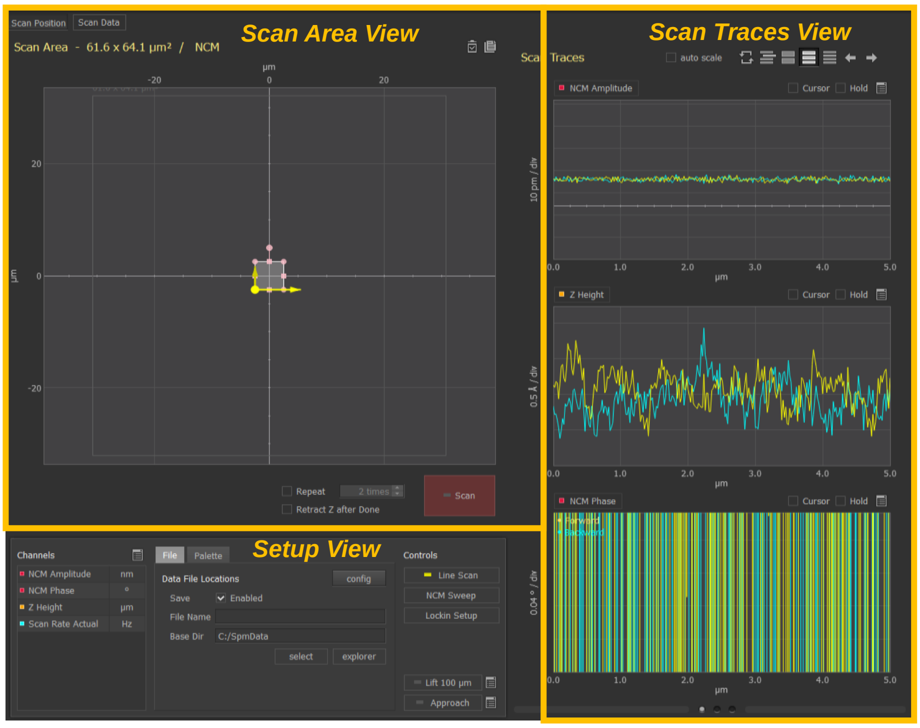


Figure 8-0-2. Scan Control workspace

8-1. Scan Area View

The Scan Area View is divided into two sections: Scan Position and Scan Data. Clicking the **Scan Position** or **Scan Data** button at the top of the screen will toggle between the two views.

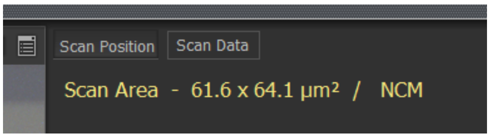


Figure 8-1-1. Toggle buttons for Scan Position and Scan Data

8-1-1. Scan Position View

You can easily set a scan size and scan location for the scan in the Scan Area View. Also, the image can be monitored during scan, and the previously acquired image can be monitored.

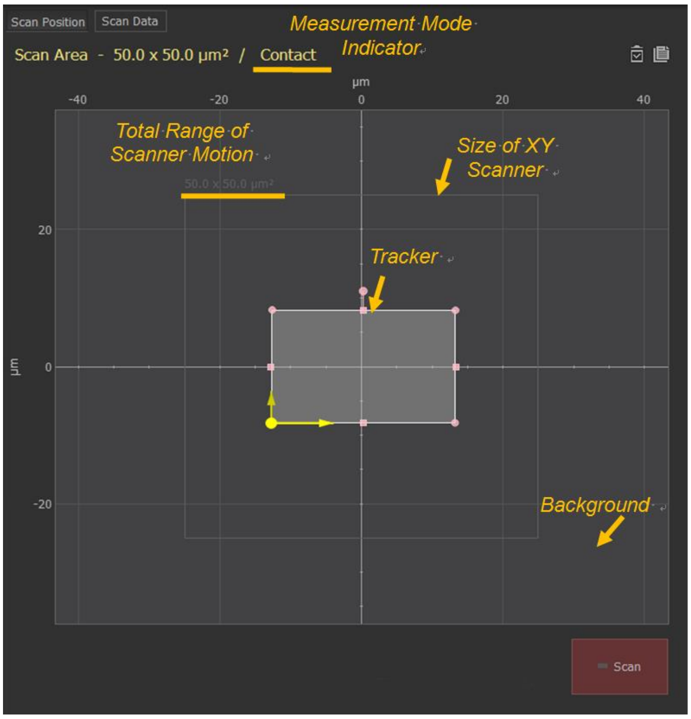


Figure 8-1-2. Scan Area View

Tracker

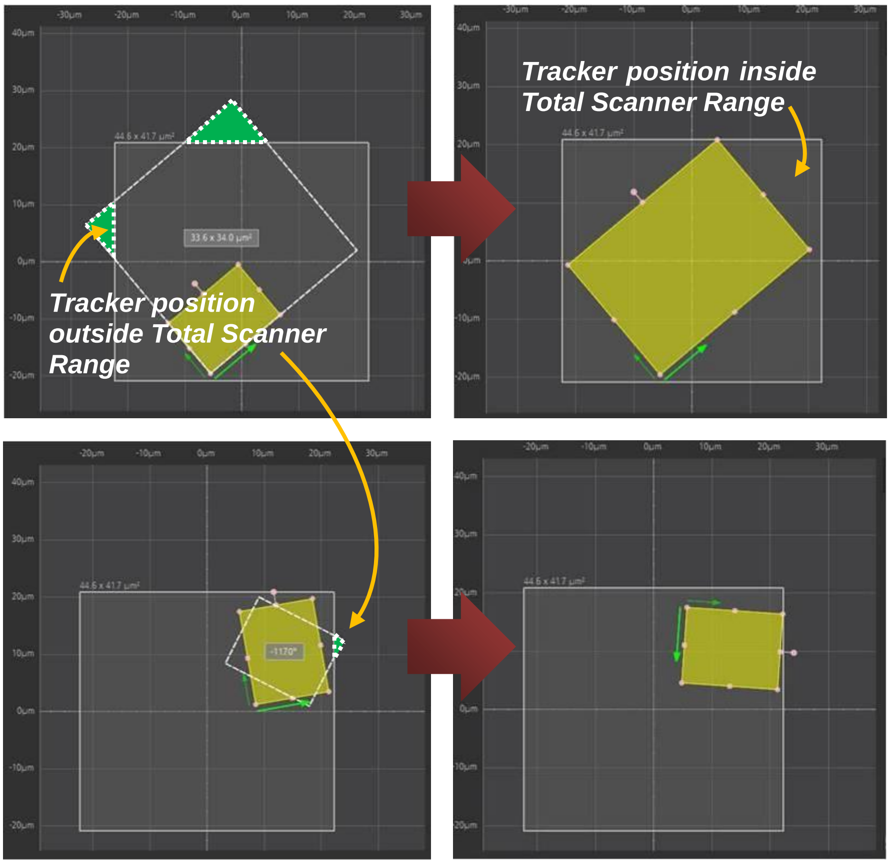
The tracker is the yellowish-green-bordered rectangle which indicates the desired scan size and location for a follow-up scan. The Tracker is displayed the current measured size and Offset.

You can specify a new scan size by enlarging or reducing the size of the Tracker. Also, you can move the scan location by moving the tracker from one place to another and/or by rotating the tracker. As you change the size of the tracker, scan size is continuously corrected in the Scan Size field. As you move the tracker to a new location or rotate to another direction, the scanner coordinates are continuously corrected in the Offset X/Y or Rotation fields.

Although it is easier to change the scan size and move and/or rotate to a new scan location using the Tracker, sometimes you need a specific scan size or scan location. In such cases, you can specify a particular scan size in the Scan

Size field, scanner coordinates in the Offset X, Y fields, and/or a particular scan direction in the Rotation field. This method is more precise than arbitrarily dragging the Tracker.

The total range of scanner motion is denoted by a white box in the Scan Area View. SmartScan will not allow the Tracker to be placed outside of this area. If the Tracker is rotated or moved by offset to a position outside of the total range of scanner motion, the Tracker position will be adjusted so the Tracker will remain inside the scan range.



Tracker position inside Total Scanner Range

Tracker position outside Total Scanner Range

Figure 8-1-3. Bounding the scan area

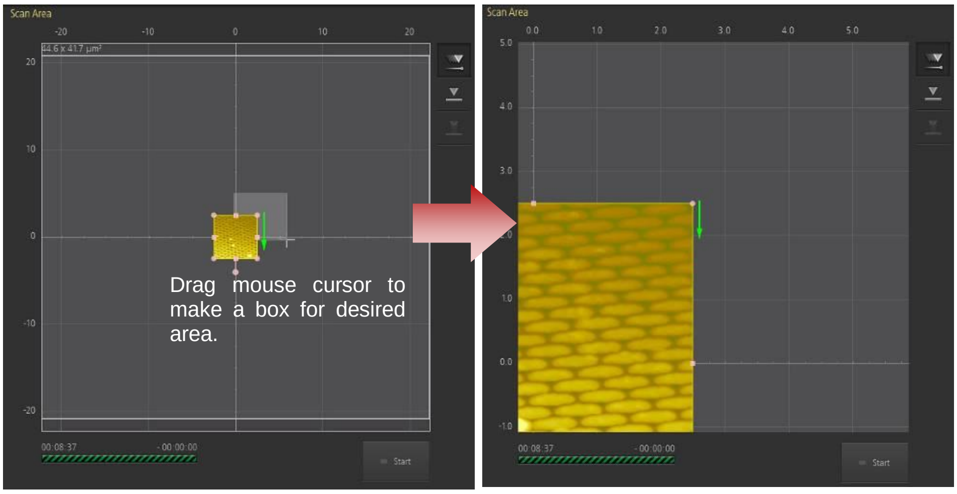
Thus, if you want to take a scan near the edge of the scanner's range, you should lift the tip and move the XY stage in the desired direction.

Note!

The Scan Area View does not represent the previous screen after you use the XY stage to position a follow-up scan.

Zooming in to the Scan Area

If you want to magnify a certain region, click and drag the mouse cursor to select the desired area. Magnification of the area does not affect scan size or scan area.



Drag mouse cursor to make a box for desired area.

Figure 8-1-4. Zooming in to the scan area

Alternatively, the scan area can be magnified by placing the mouse cursor in the scan area, left-clicking on the desired area for magnification, AND

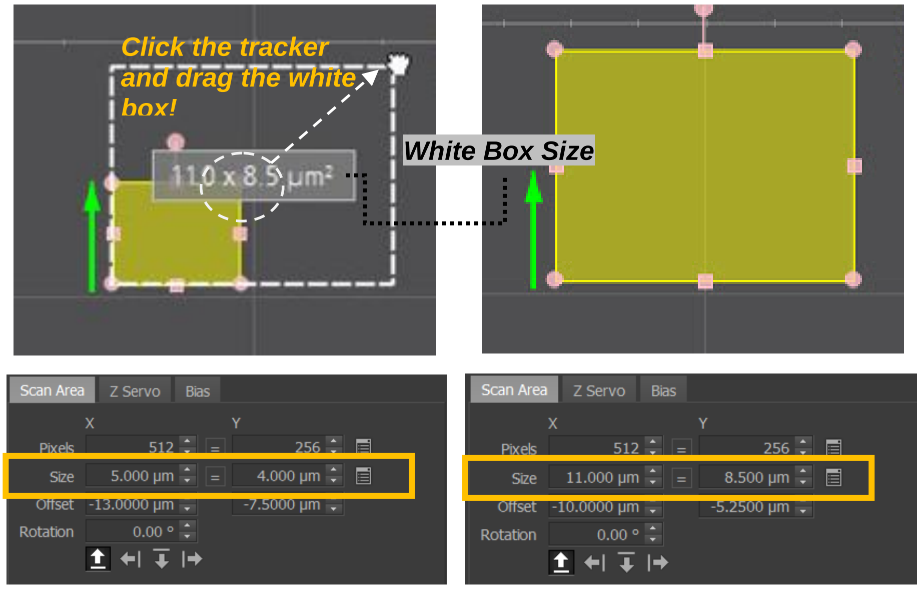
a) pressing the **+/-** key on the keyboard OR

b) using the mouse wheel to adjust the magnification

To zoom out, double-click anywhere on the scan area.

Changing the Scan Size

Place the mouse pointer on one of the pink dots located at the four corners of the Tracker. The mouse pointer will change to a hand (see circled area in Figure 8-1-5) and the white preview tracker box will appear. Click and drag the hand to increase or decrease the preview box until you reach the desired scan size. As you change the size of the preview Tracker, scan size is continuously updated in the Scan Size field in the Parameters Control View and also on the Tracker.



Before:
Pixels X 512, Y 256
Size X 5.000 µm, Y 4.000 µm
Offset X -13.0000 µm, Y -7.5000 µm
Rotation 0.00 °

After:
Pixels X 512, Y 256
Size X 11.000 µm, Y 8.500 µm
Offset X -10.0000 µm, Y -5.2500 µm
Rotation 0.00 °

<Before> **<After>**

Figure 8-1-5. Increasing (above) and decreasing (below) scan size

Pink dots located on the sides the Tracker can be used to adjust the sides of the Tracker and scan size independently.

Size Change Hot Key Controls

Hot key size change controls provide added control when changing the scan size by dragging the corner of the tracker.

Click+Drag+Shift	Preserves scan size aspect ratio
Click+Drag+Ctrl	Preserves the center point of the scan
Click+Drag+Alt	Does not snap scan size to the grid

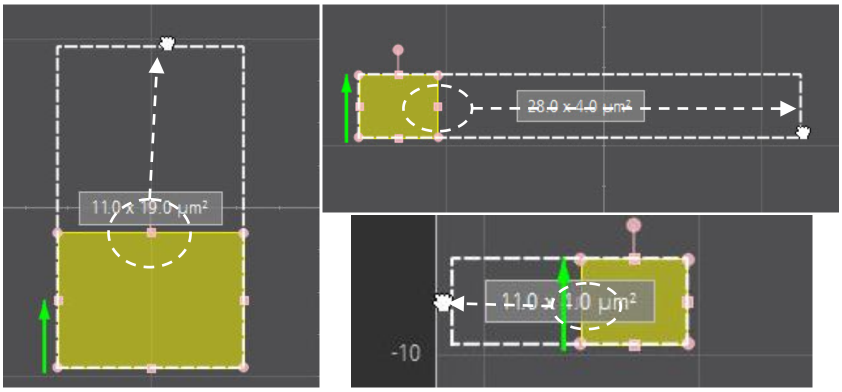
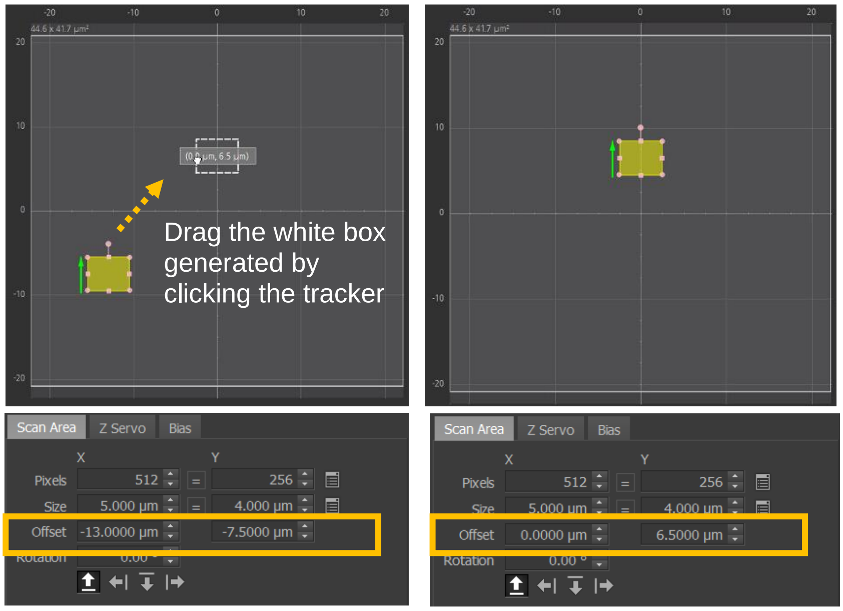


Figure 8-1-6. Tracker side adjustment

Changing the Scan Location

Place the mouse pointer at the center of the Tracker. The cursor will change to a hand, and the white preview tracker will be displayed. Click and drag the white box until you reach the desired scan location. As you drag the Tracker, the scanner coordinates (X, Y) are continuously corrected in the Offset X,Y fields. Figure 8-1-7 shows the procedure to move the Tracker to another location.



Drag the white box generated by clicking the tracker

Pixels 512 = 256
Size 5.000 µm = 4.000 µm
Offset -13.0000 µm -7.5000 µm
Rotation 0.00 °

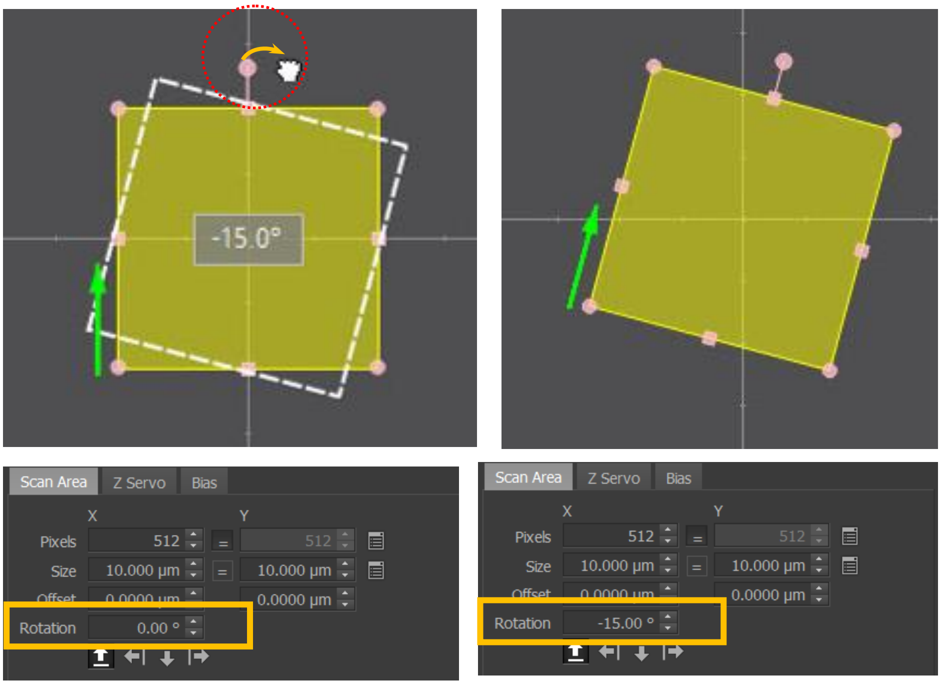
Pixels 512 = 256
Size 5.000 µm = 4.000 µm
Offset 0.0000 µm 6.5000 µm
Rotation 0.00 °

<Before> **<After>**

Figure 8-1-7. Changing scan location in the Scan Area View

Rotating the Scan Area

Place the mouse pointer on the handle of the Tracker marked with the circle in Figure 8-1-8. The handle will change to a hand and the white preview tracker box will be displayed. Rotate the tracker to the desired orientation. You will notice that the scan direction is changed to the corresponding angle of the rotated tracker in the Scan Area View. The precise rotation angle is updated in the Rotation field of the Parameters Control window. Figure 8-1-8 shows how to rotate the tracker in the Scan Area View. The first scan line is marked as a green arrow below the expected first scan line to avoid any confusion.



Pixels 512 = 512
Size 10.000 µm = 10.000 µm
Offset 0.0000 µm 0.0000 µm
Rotation 0.00 °

<Before>

Pixels 512 = 512
Size 10.000 µm = 10.000 µm
Offset 0.0000 µm 0.0000 µm
Rotation -15.00 °

<After>

Figure 8-1-8. Rotating the scan area

Scanning an Image

To begin acquiring a scan, click the brown **Scan** button at the lower right corner of the the Scan Area View. As the scan is acquired, the Tracker displays the acquired image line by line. When the measurement is completed, the Tracker control outline is generated again. Acquired images are displayed in the background as imaging continues. To remove an image from the collection, select the image and press the **Delete** key.

Smooth

Applies a mathematical interpolation to the scan data before it is displayed. **Smooth** is visible only while an image is being acquired.

Change

Selects the data to be displayed in the Scan Area View from the selected channels acquired. The acquired channels can be selected in the Setup View (see Section 8-3). **Change** is visible only while an image is being acquired.

Fit

Adjusts the acquired image to fit inside the Scan Area View. **Fit** is visible only while an image is being acquired.

Full Color

Readjusts the color scaling to the maximum pixel range. **Full Color** is visible only while an image is being acquired.

Data Information

Double-click on the acquired image to display the Data Information window. Figure 8-1-9 shows an example of the Data Information window. This window displays all acquired data related to the data channel and its saved location.

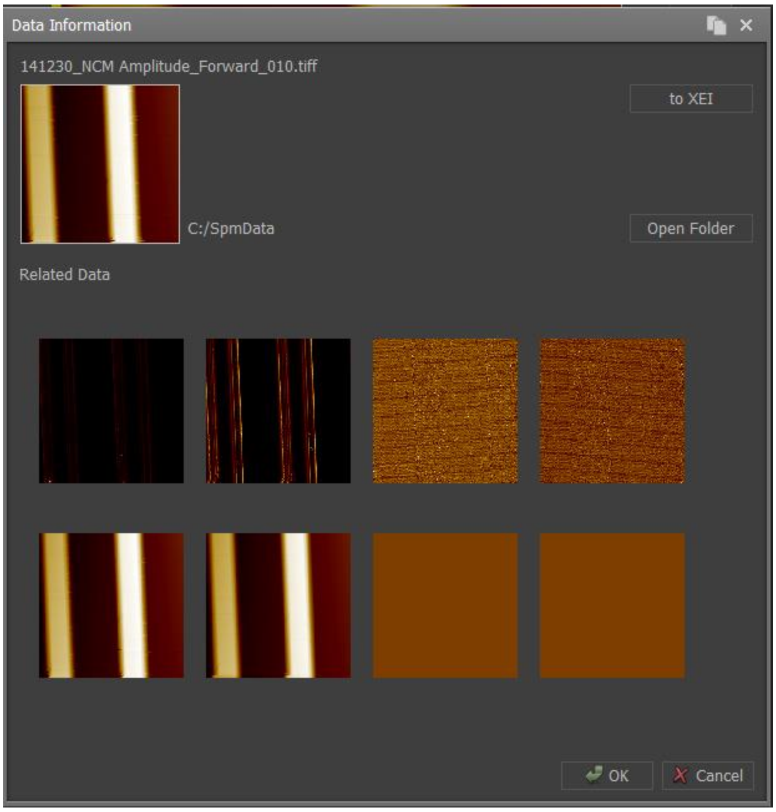


Figure 8-1-9. Data Information window

The **to XEI** button will send the data file at the top left of the window to XEI. To send any other data file, click the **Open Folder** button and then double-click the appropriate image from the Explorer window.

8-1-2. Displaying Scan Data

Clicking the **Scan Data** button toggles the Scan Data View. The Scan Data View displays acquired data, thumbnails, and scan traces. Acquired data in this view can be displayed in a custom arrangement for efficient operation. The Scanning Data dialog for each channel, which is obtained through the image during the scan and trace line, can be viewed in more detail.

The main area of the Scan Data View displays the acquired image and scan trace, as shown in Figure 8-1-10.

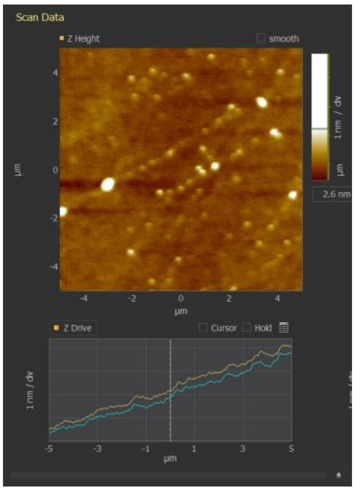
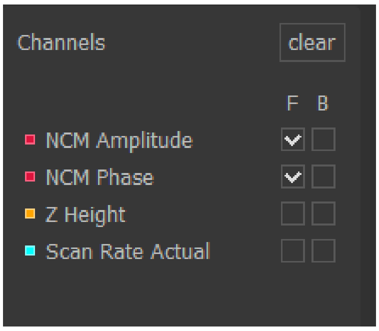


Figure 8-1-10. Scan Data

Adding Channels to the Scan Data View

Channels can be added to the Scan Data View by checking the box next to the channel name in the workspace. Check boxes under **F** indicate a forward scan direction. Check boxes under **B** indicate a backward scan direction. Figure 8-1-11 shows the channel selector. To clear all check boxes, click the **clear** button.



	F	B
NCM Amplitude	☑	☐
NCM Phase	☑	☐
Z Height	☐	☐
Scan Rate Actual	☐	☐

Figure 8-1-11. Channel selector

Changing the Signal in the Scan Trace

The signal displayed in the Scan Trace can be changed by clicking the signal name. See Section 8-2, Scan Traces View for more information about the Scan Trace oscilloscope graph.

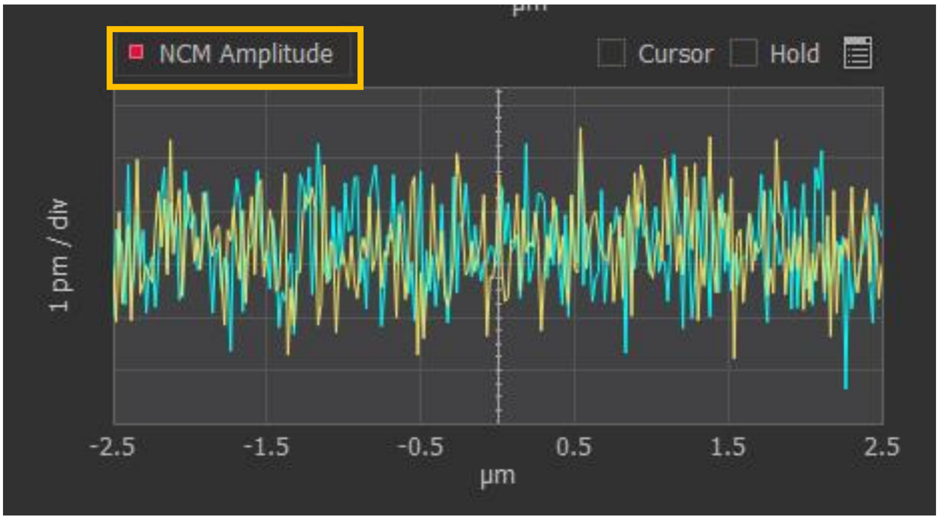


Figure 8-1-12. Scan Trace oscilloscope window

Viewing Data Thumbnails

Thumbnails of all data being acquired during the scan are displayed at the bottom of the screen. Double-clicking the thumbnail will add the data to the Scan Data View. If the signal is already checked, double-clicking the thumbnail will bring the signal onto the display by advancing the Scan Data page. Previous and next pages can be viewed using the page indicator radio buttons (○ ○ ○ ●) located below the oscilloscope views.

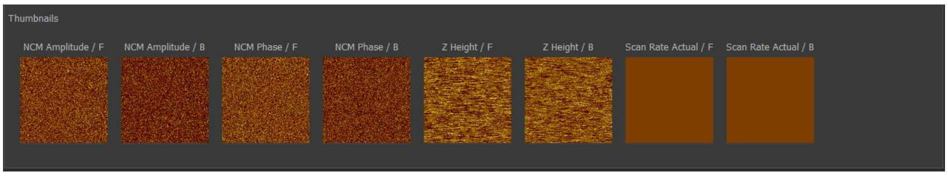


Figure 8-1-13. Data thumbnails

8-2. Scan Traces View

The Scan Traces View is an oscilloscope window that can be used to display selected signals in real time. Signals can be viewed only when the line scan is turned on. Figure 8-2-1 shows the Scan Traces View.

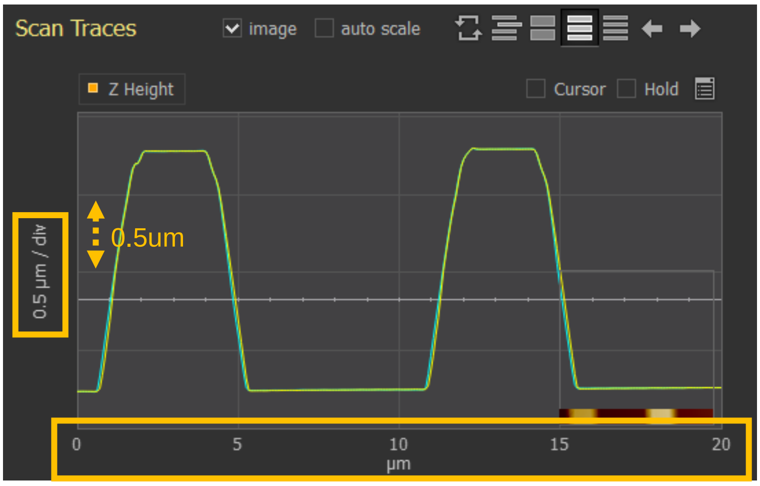


Figure 8-2-1. Scan Traces View

The oscilloscope screen is divided by gray grid lines on a dark gray background by two-dimensional X and Y coordinates. On the point that meets each grid, the distance in the vertical direction displays the distance between each division, while the distance on the horizontal axis displays an absolute scale.

Signals displayed on the oscilloscope screen are obtained along the fast scan direction. The signal obtained from the forward scan direction is represented by a yellowish trace line on the oscilloscope screen. An aqua-blue trace line that represents the signal obtained from the backward scan direction will also be displayed on the screen. To remove either the forward or the backward trace signals from the oscilloscope screen, hold the mouse button on the upper left corner of the oscilloscope screen. The forward and backward legends will appear. Clicking the text will toggle the trace display. An inactive trace will be grayed out and displayed in a strikethrough font. See Figure 8-2-2, which has the forward trace removed from the display, for an example.

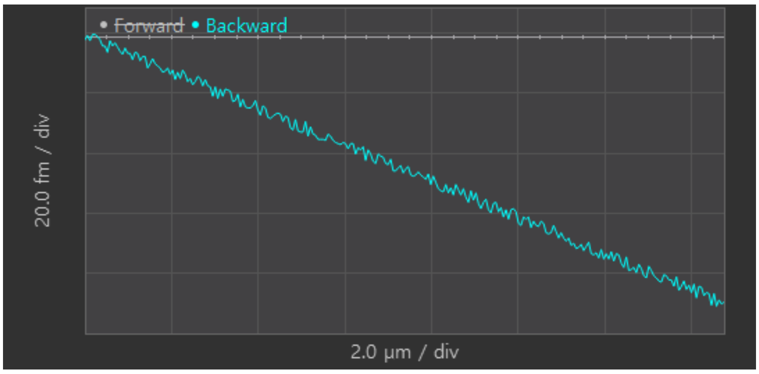


Figure 8-2-2. Removing traces from a view

8-2-1. Auto Scale

☐ auto scale

Auto Scale continuously rescales the vertical division and horizontal scale of the oscilloscope screen to maximize the signal displayed. Auto scaling applies to all oscilloscope screens. Individual auto scaling can be applied by clicking the button and choosing **Auto Scaling**.

8-2-2. Rescale

This option rescales all plots simultaneously. Double-clicking on each plot automatically rescales the display so that the peak-to-peak maximum of the data fits on the screen. The scale can also be controlled manually by using the mouse wheel. The vertical axis on the screen may be rescaled accordingly.

8-2-3. Relocate

After clicking this icon, relocate each plot by clicking and dragging it to the desired location.

8-2-4. Add/Delete Plots

Determine the number of plots (two to four) shown on one screen with these icons. Up to eight plots can be displayed at one time. The plots will appear on different pages depending on the number of plots selected.

8-2-5. Previous/Next

⬅ ➡ Displays the previous or next pages of the Scan Traces View. The number of pages is indicated by the radio buttons at the bottom of the Scan Traces View.

8-2-6. Signal Name List

■ Height The Signal Name list displays a list of signals you can monitor on the oscilloscope display. When you click the field button, a list of signals will appear (see highlighted area in Figure 8-2-3) that are currently selected in the Channel Config dialog. Depending on your selection, their units may be different. For more details about the Channel Config dialog, see Section 8-3-1, Channels.

Up to two channels can be added to each scan trace. To add a second channel, click **Add 2nd Channel** from the Signal Name List. A second field button will appear to the right of the original button. The second channel can be chosen from the second field button. To remove the channel, click **Remove** from the list under the appropriate signal.

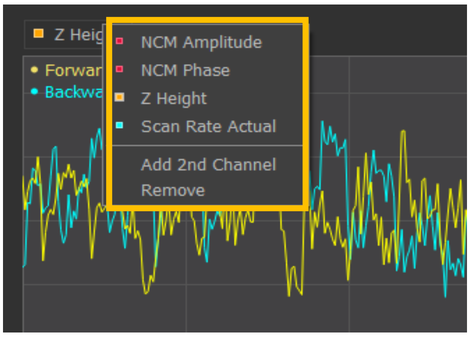


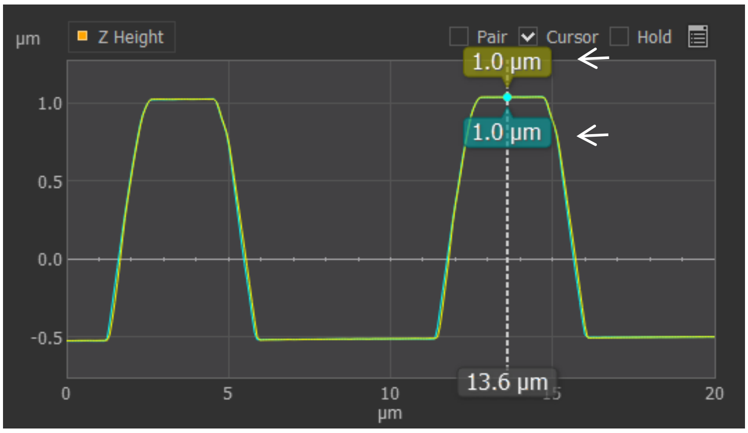
Figure 8-2-3. Input signals

8-2-7. Cursor

☐ cursor When you check the **cursor** check box, a white vertical line will appear on the oscilloscope screen. The value of the forward signal will appear in yellowish green, while the value of the backward signal will appear in aqua near the point where the line crosses the signal. At the bottom of the line is an indicator with the position of the line in the fast scan direction.

When the **cursor** check box is checked, a **Pair** check box will appear. Clicking on this box will cause a second white line to appear on the oscilloscope screen.

The signal can be measured between the pair of white vertical lines. Values for the absolute difference between the two lines is displayed for the Y value of the forward signal (yellowish green), the Y value for the backward signal (aqua), and the X value of the fast scan direction (white). X and Y always refer to the Scan Trace View, where X is the displayed horizontal axis and Y is the displayed vertical axis. Figure 8-2-4 shows single and paired cursors on the Scan Trace View.

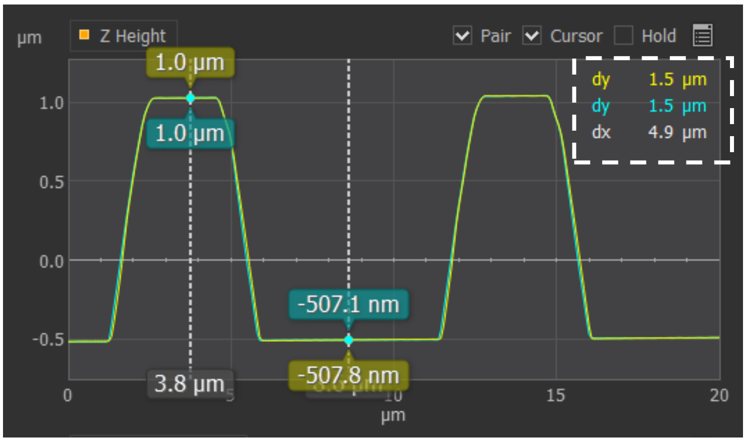


(Olive Color)

Height of a cursor on

(Aqua Blue Color)

Height of a cursor on retrace line



dy 1.5 μm
dy 1.5 μm
dx 4.9 μm

Distance between the two line cursors.

Figure 8-2-4. Single and paired cursors

8-2-8. Hold

The signal displayed on the oscilloscope screen continuously changes since the tip continuously scans the surface to obtain the signal. **Hold** captures the displayed signal so that you can easily analyze individual trace lines in the Scan Traces View. Checking the **Hold** check box will freeze the signal and prevent the trace from being updated as the scan progresses. This can be useful when measuring a particular feature or for comparing a previous line scan.

8-2-9. Menu

The **Menu** button opens a features list for the Scan Traces View. Figure 8-2-5 shows the menu box contents.

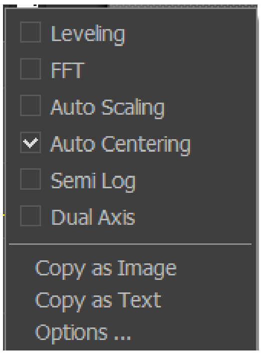


Figure 8-2-5. Scan Trace menu

Leveling

After you select this icon, you will see two white bars in the oscilloscope screen. You can use these bars to easily subtract the background slope. Point your mouse at each bar and the cursor will change to a left-right arrow. Drag each bar to two different points you believe to be at the same height. The slope of the trace line will change accordingly so that the two different points are brought to the same level. However, it will adjust line profile slope only on scan traces.

The width of the transparent strip extending from the centered line bar is a cursor average range. The trace line in the region is actually calculated by averaging the Y coordinates of the points within the cursor average range. This width can be easily adjusted by click and dragging the transparent strip.

FFT

The FFT button shows a one-dimensional FT (Fourier transform) of the signal in real time. This FT shows the information of the frequency of the trace line, on which a fast Fourier transformation has been performed. The FT signal is useful for determining the presence of external noise while measuring the sample surface with the NX system.

Auto Scaling

This feature auto scales the individual oscilloscope screen to rescale the vertical division to maximize the displayed signal. **Auto Scaling** will be checked automatically if the **Auto Scale** check box at the top of the Scan Traces View is checked.

Auto Centering

This feature adjusts the vertical scale to keep the signal in the center of the oscilloscope screen. **Auto Centering** is disabled if **Auto Scaling** is checked.

Semi Log

This feature adjusts the vertical scale to a semi log plot.

Dual Axis

Dual Axis adds a secondary axis on the left side of the oscilloscope screen.

Offset

This feature offsets the second signal from the first signal when displaying two signals.

Copy as Image

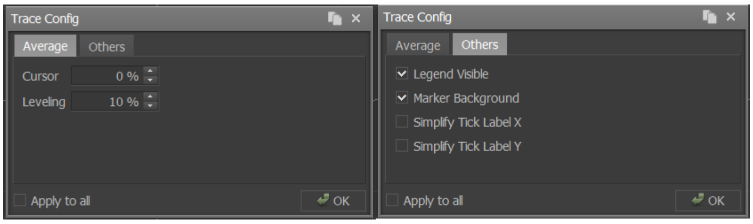
Use this to copy the oscillscope screen to the clipboard as an image.

Copy As Text

Use this to copy the oscilloscope screen to the clipboard as a text file.

Options

Options opens the Options dialog for trace configuration. Trace Config has two tabs: Average and Others. Figure 8-2-6 shows the Options dialog.



Cursor 0 %
Leveling 10 %
☐ Apply to all

☑ Legend Visible
☑ Marker Background
☐ Simplify Tick Label X
☐ Simplify Tick Label Y
☐ Apply to all

Figure 8-2-6. Scan Trace options window

The **Average** tab allows the user to customize the averaging bars for cursors used in the scan trace. The **Cursor** setting can be adjusted from 0 to 100%, where 100% is equal to the entire scan size. The default setting is 0% and provides a cursor measurement of a single point. Increasing the **Cursor** setting averages the cursor measurement to a percentage of the image scan size. Visual guides are added to the cursor to indicate the area being averaged for the measurement. The **Leveling** setting provides the same averaging capability for the leveling bars. The default setting is 10%.

The **Apply to All** check box applies the averaging values to all scan traces.

The **Others** tab provides options for customizing the scan trace graph. Options include:

Legend Visible	Displays the scan trace legend (forward and backward indicators)
Marker Background	Adds rectangular background color to the cursor measurement labels
Simplify Tick Label X	Simplifies the X axis label to a unit per division
Simplify Tick Label Y	Simplifies the Y axis label to a unit per division
Apply to All	Applies the scan trace customization to all scan traces

8-3. Setup View

The Setup View contains menu items such as **Palette**, **Channels**, **Approach**, **NCM Sweep**, and **Scan**. The Setup View is used to set frequently used operating parameters for scan measurement. The Setup View is divided into the **Scan** tab and the **Spectroscopy** tab. In this section, only the **Scan** tab is covered.

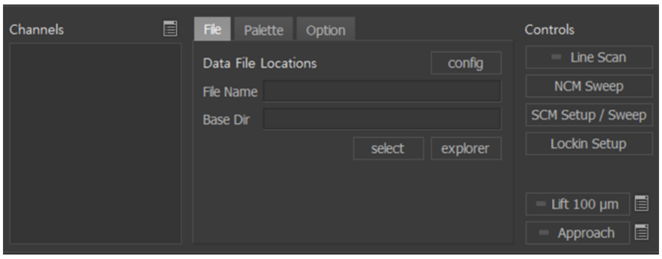
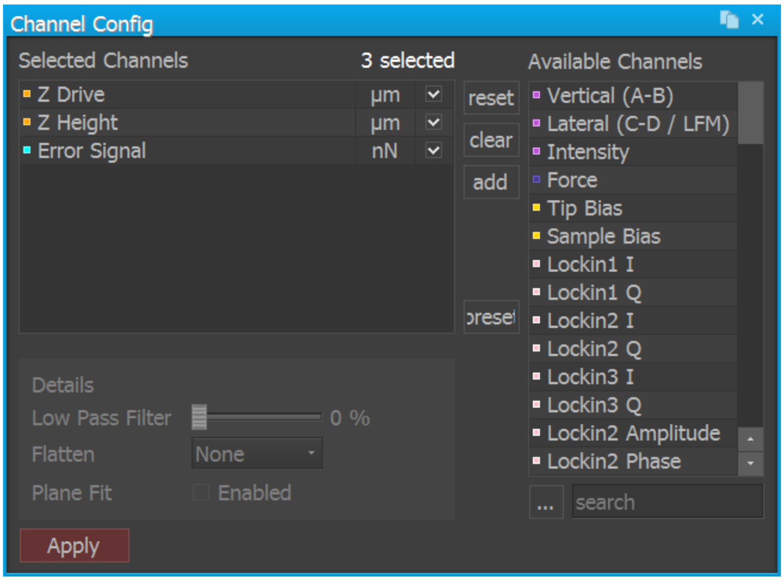


Figure 8-3-1. Setup View

8-3-1. Channels

This opens the Channel Config Window (see Figure 8-3-2). The Channel Config window allows choosing data channels to monitor and record while scanning. It provides filters and flattening algorithms that can be added to the signal and saved with the data. The Channel Config window consists of three main sections: a) Selected Channels, b) Details, and c) the Available Channels.



Z Drive µm ☑
Z Height µm ☑
Error Signal nN ☑

Low Pass Filter 0 %
Flatten None
Plane Fit ☐ Enabled

Figure 8-3-2. Channel Config window

Selected Channels List

The Selected Channels List provides a listing of the data channels that will be collected during a scan. The total number of channels is displayed in the upper left corner. A maximum of eight channels can be selected. An error message will be displayed if the number of channels chosen exceeds eight.

The *Unit* drop-down menu enables you to select the units that are used to display the signal channel on the Scan Traces View. Depending on the type of signal you are collecting, you can select from an appropriate list of units for the signal in the Unit field.

The unit next to the channel name indicates the unit used to specify the data. Once the channel name is highlighted, clicking the unit name will provide the ability to change the unit. Most units can be changed to “V”.

Adding a channel

Channels can be added to the list by double-clicking them from the Channels and Presets list or by highlighting the channel and clicking **Add**.

Deleting & resetting a channel

Channels can be deleted from the list by double-clicking on them or by clicking the check box corresponding to the input on the right side of the channel name.

Clicking an individual channel highlights the channel and displays channel details in the area below. And, clicking the **CLEAR** button deletes all the channels from the list. On the other hand, clicking **RESET** button undo previous operation on the Selected Channel list.

Low Pass Filtering

The **Filter** scale adjustment bar enables you to select the time interval (from 0 to 100%) used to replace each data pixel with averaged value from the collected data. An increase in the number corresponding to the pixel means that more sampling data points are averaged to obtain each data pixel.

The filter is applied during a scan and permanently affects your data. When surface features are hidden by high-frequency noise, the filter decreases the effect of such high-frequency contributions.

Data Saving

When using the Flatten and Plane Fit functions, you can select Raw data or Fitted data to save. In the Selected Channels, you can set the data you want to store differently as raw or Fitted..

Flattening

The **Flatten** drop-down menu allows you to specify how much flattening is applied to your data as it is collected. In addition to **None**, which does not affect your data, there are 4 options: **Offset Adjust**, **Line**, **2nd Order**, and **3rd Order**.

Line, 2nd Order, and 3rd Order use the same basic principle. A curve of the specified order is fitted to each line of data acquired, and is then subtracted from that line.

Offset Adjust is a data processing routine that adds or subtracts an offset to each line of data relative to the average offset of the surrounding line(s) of data. Offset Adjust is especially useful when the sample is quite uniform in that the probe tip does not experience sharp slopes or valleys after the first line of data is acquired in the slow scan direction. Offset Adjust is recommended for relatively flat samples with fine structures and uniform features. Offset Adjust is not recommended for samples with large surface height differences.

Plane Fit

To apply an automatic slope correction to an image after it is acquired, select the **Plane Fit** check box. A first order flattening will be applied to the data. Plane Fit will compensate for the tilt of the sample surface relative to the sample scan plane.

Presets

Figure 6-2-5 shows the preset channels panel. Clicking **Preset** button will show a short list of predetermined channels for each mode as shown in Figure 8-3-3.

The preset channels can be customized by clicking **New** to create a new preset, **Rename** to rename an existing preset, **Delete** to delete a preset, or **Clear** to remove all the preset.

Any signal can be added to the Selected Channels List by double-clicking the channel and the clicking **OK** to apply the changes. These signals are monitored in real time on the Scan Traces View. Maximum of eight signals can be listed and monitored for image pixel resolution ranging from 1×1 to 4096×4096.

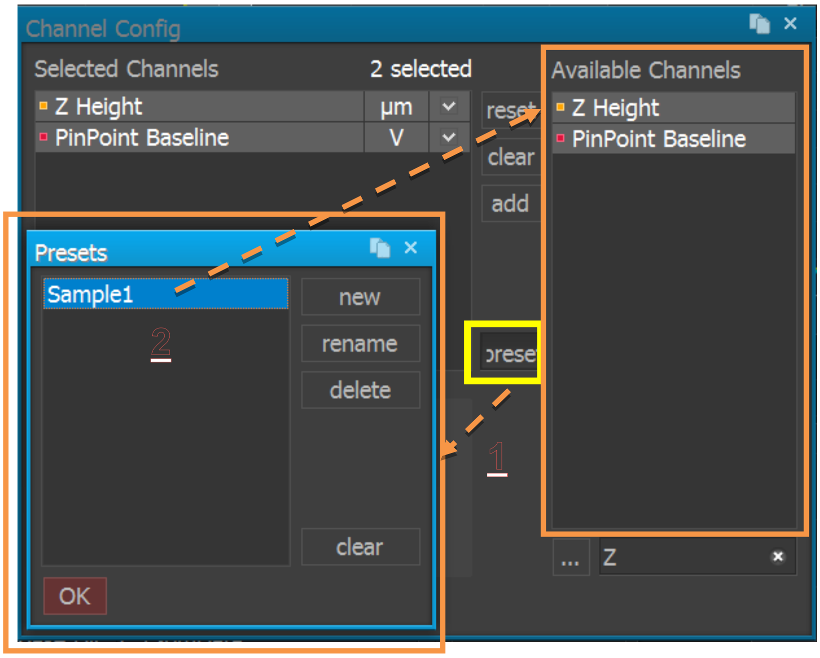


Figure 8-3-3. Preset Channels Panel

By clicking (...), a summary of channel category will appear (see Figure 8-3-4a). Then, clicking **More Specific** will show a list of available Mode (see Figure 8-3-4b). Channel search features can also be found at the bottom right of the window as shown in Figure 8-3-4c.

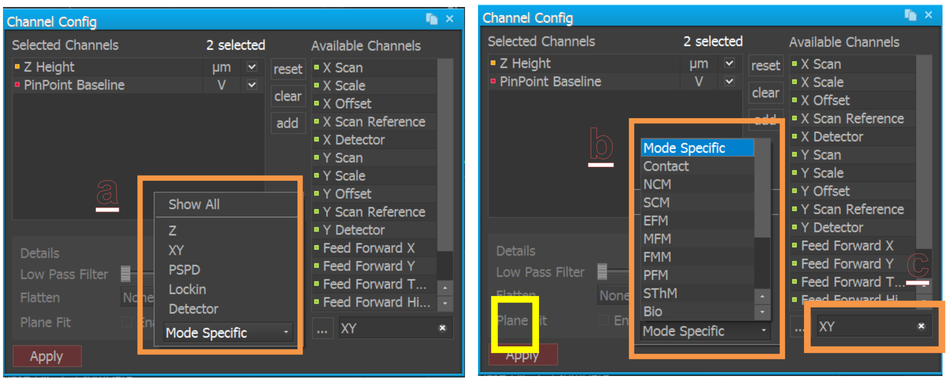


Figure 8-3-4. Channel List and Mode

8-3-2. File

File Name

SmartScan uses the filename in this field to name the saved image. Each data signal is saved as a separate file with the same filename but different filename suffixes. For example, an image with the file name “FileName” would be written by default as:

FileName%1_%N_%G

Where %1 is the date written as YYMMDD, %N is the channel name, and %G is a sequential group number given to images as they are saved.

Note!

The structure above is the default structure, but it can be adjusted by changing the manual mode config file.

Directory

Lists the directory where files are saved. The default directory is C:\spmdata**.**

Select

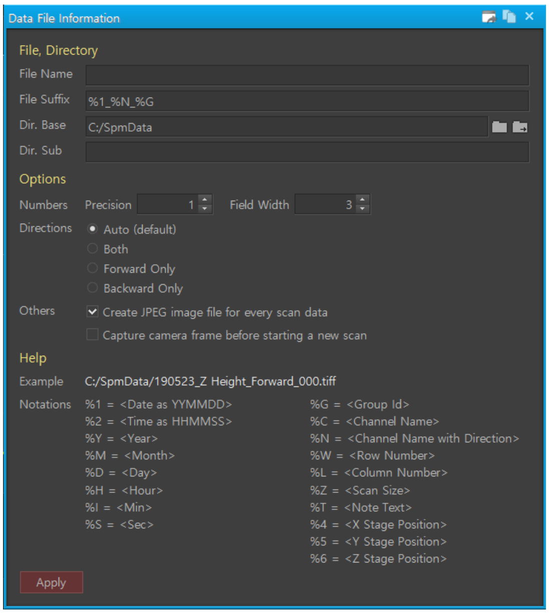
Opens a window to select a new directory.

Explorer

Opens the folder named in the Directory field in Windows Explorer.

Config

The **Config** button opens the Data File Information window. This window displays filename and directory information in addition to displaying the suffix configuration as described above (see File Name). Figure 8-3-5 shows the Data File Information window. Also, there are two options that can be seen in this window: **Save JPEG Image File** and **Save Camera Frame before Scan Start**. Checking the first box will automatically save JPEG Image file together with TIFF file during scanning. On the other hand, checking the second box will automatically capture and save the image in Camera frame or the Vision view before scanning.



File Name:
File Suffix: %1_%N_%G
Dir. Base: C:/SpmData
Dir. Sub:

Numbers: Precision 1, Field Width 3
Directions:
● Auto (default)
○ Both
○ Forward Only
○ Backward Only
Others:
☑ Create JPEG image file for every scan data
☐ Capture camera frame before starting a new scan

Example: C:/SpmData/190523_Z Height_Forward_000.tiff

Notations:
%1 = <Date as YYMMDD>
%2 = <Time as HHMMSS>
%Y = <Year>
%M = <Month>
%D = <Day>
%H = <Hour>
%I = <Min>
%S = <Sec>
%G = <Group Id>
%C = <Channel Name>
%N = <Channel Name with Direction>
%W = <Row Number>
%L = <Column Number>
%Z = <Scan Size>
%T = <Note Text>
%4 = <X Stage Position>
%5 = <Y Stage Position>
%6 = <Z Stage Position>

Figure 8-3-5. Data File Information window

File Suffix: %1_%N_%G_%Z

Where

%1 = Date as YYMMDD

%N = Channel Name with Direction

%G = Group Number

%Z = Scan Size

Example:

C:/SpmData/150825_Z Height_Forward_0001_2.000x3.000

From the example above, the number of decimal places in Z% or Scan size can be adjusted by changing the value in the **Number Precision**. The value can be varied from 0 to 10, and the default value is 1.

If Number Precision is 3, %Z = 2.000x3.000

If Number Precision is 2, %Z = 2.00x3.00

The number series in G% or Group number can also be changed by varying the value in the **Number Field Width**. The value can be adjusted from 1 to 10, and the default value is 3.

If Number Field Width is 4, %G = 0001

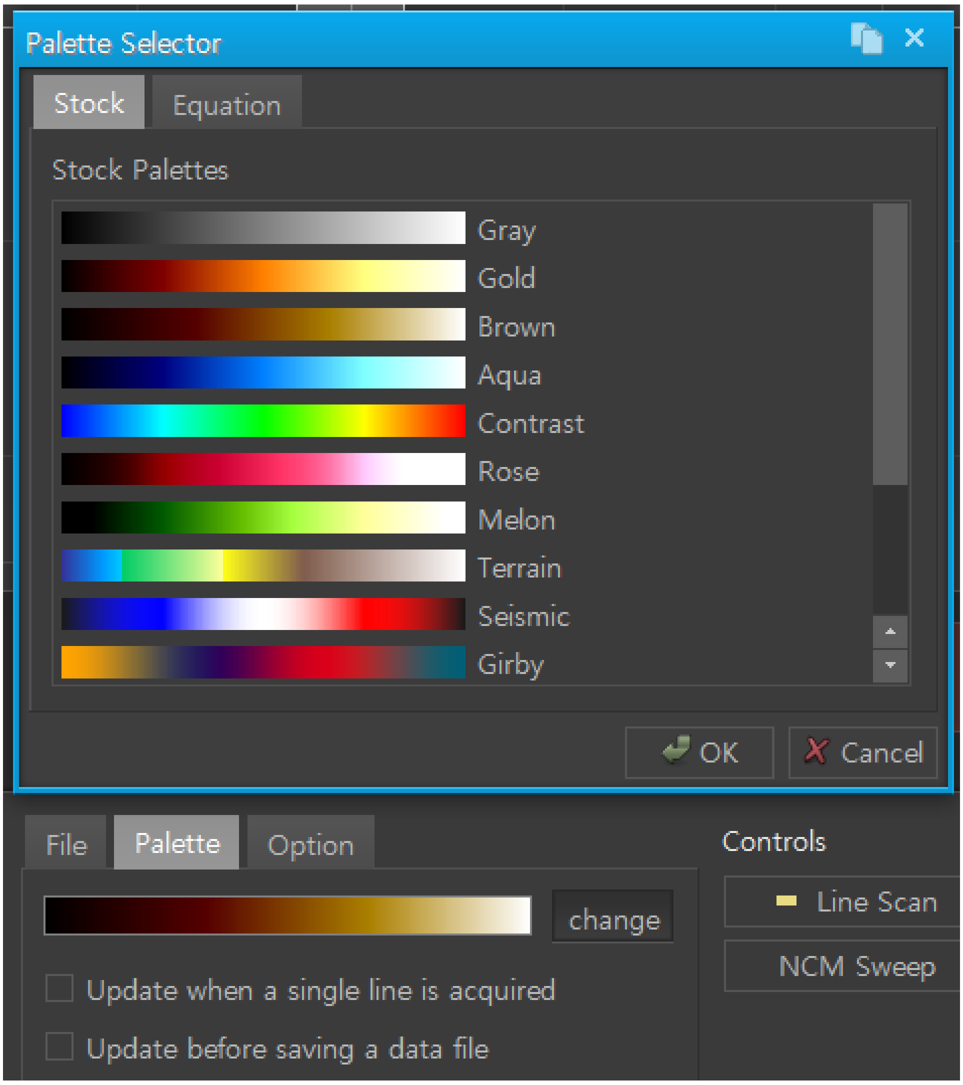
If Number Field Width is 5, %G = 00001

8-3-3. Palette

Use **Palette** to choose the color palette for the saved image. The current color palette is displayed. To change the palette, lick the palette to open the Pallete Selector. Palletes can be chosen from pre-loaded stock palletes, using a user defined equation, or by ASE Import.

Stock

To choose a stock palette, highlight the desired palette and then click the **OK** button under the **Stock** tab. The new palette will be displayed under the **Palette** tab. Figure 8-3-6 shows an example using the Melon palette.

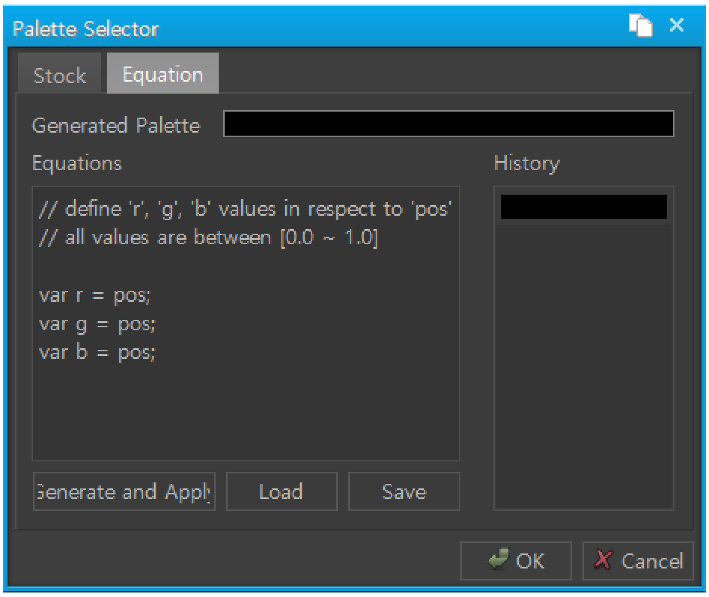


☐ Update when a single line is acquired

☐ Update before saving a data file

Figure 8-3-6. Changing the image paletteEquation

Generated Palette	Script written after the generated palette display
Equations	Spatial coding for generating the palette
History	Show cumulative display for the generated palette; this data has not yet been saved
Generate and Apply	Displays the History panel to generate a palette from the script written in the Equations panel
Load	Loads the generated palette
Save	Saves the selected palette to the hard disk
OK	Confirms the generated palette for the palette selection
Cancel	Stops the operation and closes the Palette Selector dialog



```
// define 'r', 'g', 'b' values in respect to 'pos'
// all values are between [0.0 ~ 1.0]

var r = pos;
var g = pos;
var b = pos;
```

Figure 8-3-7. Equation Palette Selector

Update when a single line is acquired

This feature is that Color leveling whenever the each line update when the scan.

Update before saving a data file

This feature is intended for the whole Color leveling before save the image.

8-3-4. Options

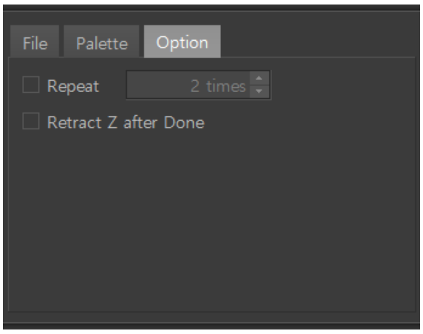


Figure 8-3-8. Option view

Repeat

Checking the **Repeat** check box will activate the text display to the right. Enter a number between 2 and 1000 to repeat the scan the specified number of times.

Retract Z after Done

Checking the **Retract Z after Done** check box will lift the cantilever away from the sample 100μm using the Z stage control once the image has been acquired.

8-3-5. Controls

Line Scan

Line Scan repeatedly scans the first line in the chosen parameters. Using Line Scan, it is possible to adjust the parameters for the sample before acquiring the image. Line Scan is active when the yellow light is turned on. Line scan is inactive when no light appears on the **Line Scan** button.

NCM Sweep

NCM Sweep is available for non-contact-mode-based scanning modes. The **NCM Sweep** button opens the NCM Frequency Sweep window. See Section 5.3 for more information about the NCM Frequency Sweep window.

SCM Setup/Sweep

SCM Setup/Sweep is available when SCM scanning mode is chosen. The **SCM Setup/Sweep** button opens the SCM Frequency Sweep window. See the SCM Manual for more information about the SCM Frequency Sweep window.

Lock-in Setup

The **Lock-in Setup** button opens the Lock-in/Modulator Setup window. See Section 5-5 for more information about Configuration Setup.

Lift-100um

This function allows users to move the Z stage in incremental steps by selecting a desired step size. The lift height value can be adjusted by choosing a preset number (10, 20, 50, 100, 200, 500, 1000, 2000, 5000) in the Selection dialog, which can be displayed by clicking the ▤ icon.

Approach

Approach moves the tip toward the sample automatically with controlled velocity until the value of the reference signal reaches the Set Point value of the Parameters Control View. To take an image, it is necessary to bring the tip very close (from a few angstroms to hundreds of angstroms) to the sample surface so that the tip can interact with the sample surface.

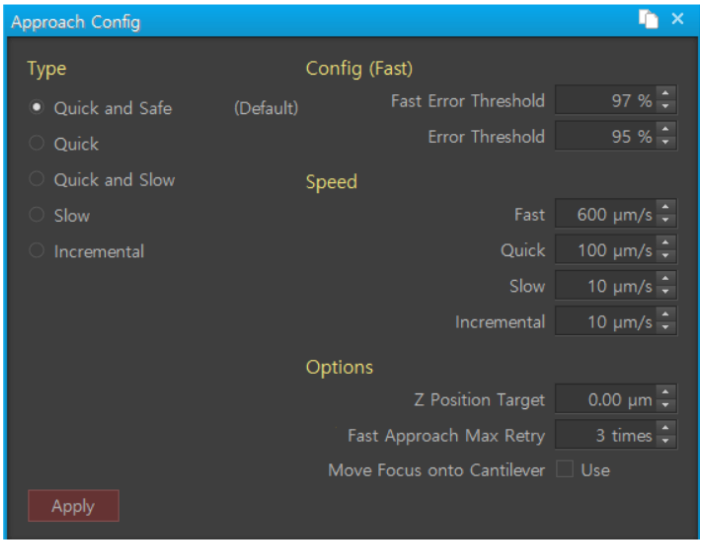
There are several things you must do before beginning an auto approach:

- Load a sample and a tip
- Make sure the sample is directly under the tip
- Make sure the probe head is turned on
- Check the alignment of the PSPD

Before performing an auto approach, you should lower the tip to just above the sample surface using the Z stage pad in the Z/Focus dialog. Then click **Approach** to perform an auto approach. Approach is automatically completed when the value of the reference signal reaches the set point value.

The Approach List dialog, which can be displayed by clicking ▤ on left of the **Approach** button, is used to select the approach type that will be used to control the motion of the Z scanner during the approach process. In general, the approach parameters are optimized by default based on your hardware configuration and do not need to be adjusted. However, the approach type may be changed using this dialog.

The Approach Config dialog is shown in Figure 8-3-9. By default, the **Quick and Safe** option is selected.



Approach Config

Type

● Quick and Safe (Default)
○ Quick
○ Quick and Slow
○ Slow
○ Incremental

Config (Fast)

Fast Error Threshold 97 %
Error Threshold 95 %

Speed

Fast 600 µm/s
Quick 100 µm/s
Slow 10 µm/s
Incremental 10 µm/s

Options

Z Position Target 0.00 µm
Fast Approach Max Retry 3 times
Move Focus onto Cantilever ☐ Use

Figure 8-3-9. Approach Config dialog

- **Type**

  There are five available approach types: Quick and Safe, Quick, Quick and Slow, Slow, and Incremental. The velocity of the tip's approach speed for each of the approach types and error threshold settings can be found to the right of the Type selector.

  - Quick and Safe

    The Quick and Safe approach type moves the tip rapidly until it reaches the error threshold point, after which the Incremental approach method is used.

  - Quick

    The Quick approach type moves the tip toward the sample rapidly.

  - Quick and Slow

    The Quick and Slow approach type moves the tip rapidly until it reaches the error threshold point, after which the Slow approach method is used.

  - Slow

    The Slow approach type brings the tip close to the sample surface in continuous motor steps until the reference signal reaches the set point.

  - Incremental

    The Incremental approach method brings the tip close to the sample surface in incremental sets of motor steps. The system checks if the set point has been reached after each set of motor steps until the reference signal reaches the set point. The Incremental approach method converts to the Slow approach method when the tip recognizes the sample surface.

- **Config**
  - Fast Error Threshold

    Fast Error Threshold is active only in a non-contact-mode-based imaging mode using Fast Approach. This indicates the ratio of the servo error signal during approach divided by the servo error signal before approach. It determines when the switchover occurs and is used during the Fast Phase of the approach.

  - Error Threshold

    Error Threshold indicates the ratio of the servo error signal during approach divided by the servo error signal before approach. It determines when the switchover occurs. For example, in Quick approach, an error threshold of 1 effectively turns off Quick approach. An error threshold of 0 will effectively bring the Slow approach speed up to the value of the Quick approach, which will almost certainly result in tip, sample, and possibly Z scanner damage.

> WARNING!
>
> If the approach speed is too fast or the error threshold is too small, the cantilever can crash into the surface, which may damage both the tip and sample. Choose a value that is enough to be safe.

- **Speed**
  - Fast

    Fast Speed sets the velocity for the Fast Approach speed used during the Fast Phase of the approach.

  - Quick

    This sets the velocity for Quick approach.

  - Slow

    This sets the velocity for Slow approach.

  - Incremental

    Sets the velocity for Incremental approach.

- **Option**

  - Z Position Target

    This setting allows for the adjustment of the height of the Z scanner when the tip comes in contact with the sample surface. A zero value will set the scanner position in the center of the Z scanner bar, while positive and negative values will set the scanner in retracted or extended positions, respectively. Too great a positive value can limit Z scanner retraction, causing an unexpected crash between the tip and sample. On the other hand, too great a negative value an limit Z scanner extention, causing inaccurate feedback. Consider the Z scanner's available movement range when entering this value. When using the 15㎛ Z scanner, the Z scanner can retract and extend 7.5㎛ by the zero value after approach.

WARNING!

Do not enter a value in excess of the Z scanner's available range to avoid crashing the head into the sample and seriously damaging your system.

  - Fast Approach Max Retry

    In the case of Fast Approach, there is an internal action to check the NCM Amplitude before switching from the Quick method to the Incremental method. If the NCM amplitude information is different from what you expected, you will skip Z stepping back to Incremental and retry the Quick method approach, which adds up to how many times you want to allow this repetition.

- ○ Move Focus onto Cantilever

This function allows you to move focus to the cantilever before approaching it. This prevents the focus from shifting when you approach the sample for a scan.

An important thing to note is that the focus position must be taught to the tool by the user. For example, in Figure 8-3-9, the Save function is used to teach the hardware the user's desired focus location on the cantilever.

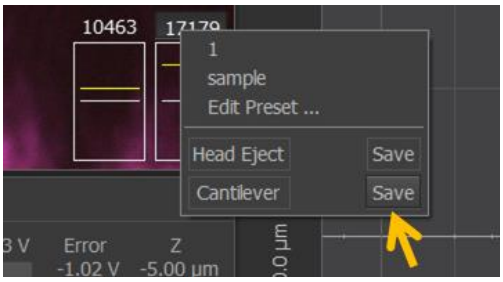
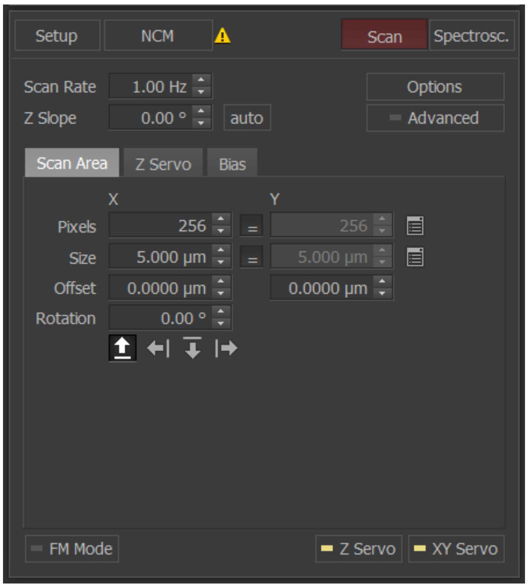


Figure 8-3-10. Saving Cantilever Postion

8-4. Parameters View on Scan Control

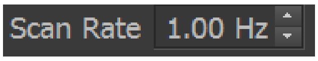
The Parameters View in Scan Control sets the operating parameters for the instrument. The Parameters View includes Scan Rate, Scan Area, Servo Feedback, and Bias information. Figure 8-3-11 shows the Parameters View.



Scan Rate 1.00 Hz
Z Slope 0.00 °
Pixels 256 = 256
Size 5.000 µm = 5.000 µm
Offset 0.0000 µm 0.0000 µm
Rotation 0.00 °

Figure 8-3-11. Parameters View on Scan Control

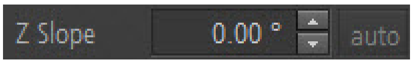
8-4-1. Scan Rate



Scan Rate 1.00 Hz

The Scan Rate field allows you to adjust the scan rate while an image is being generated or for the next scan. The scan rate is the frequency of the back-and-forth rastering of the sample. A 1Hz scan rate indicates that one line of data is collected per second. For better image quality, decrease the scan rate, which gives the feedback loop more time to respond to the surface topography. However, at slower scan rates, thermal drift (expansion or contraction caused by non-uniform scanner and sample temperatures) tends to cause distortion in an image. Since the scan rate depends on the scan size and the roughness of your sample, you should experiment and take images at various scan rates to determine the best setting for a particular sample.

8-4-2. Z Slope



Z Slope 0.00 °

In general, the sample surface is not flat relative to the scanning plane. Due to this, you should adjust the X and Y slope in the Slope field. The slope is a linear correction that is added digitally to the scanner’s X and Y position. These corrections to the scanner’s position eliminate a slight tilt or slope of the sample surface. The tilted signals on the Scan Traces View should be adjusted in both X and Y directions. You can remove most of the tilt by adjusting the slope. Acquired images will then be corrected to account for slope.

Clicking **Auto** will find a slope value that will minimize the slope of the current trace line.

In order to adjust the slope in the X or Y direction manually, switch to the appropriate fast scan direction and enter the number for the slope correction. You can also or increase or decrease the number in the Slope field using the spin button (⇕). Before you set the X slope parameter in the Slope field, X should be the fast direction. Likewise, after you select Y as a fast direction, you can set the Y slope parameter in the Slope field. The range of the slope parameter value is from -45 to 45 degrees. If the slopes cannot be adjusted in this range, the sample surface is excessively tilted and you should try to reload the sample on the sample holder.

In addition to adjusting the slope in the Slope field, there are two ways you can eliminate the intrinsic slope from an image. One method is to apply an automatic slope correction to an image by subtracting a planar correction. This can be performed by checking **Offset Adj.** or **Line Fit** in the Channel Config dialog. Another slope correction can be done in the image processing program, XEI, which supports the flattening process. For more details, please refer to the XEI software manual.

- **How to adjust the slope in the X and Y direction**

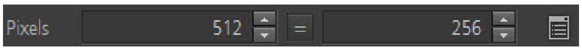
  Change the rotation of the XY scanner. Set the rotation to ±90° to change the fast scan direction. Enter a value in the text field, and then press the **Enter** key on your keyboard, use the spinner button with your mouse, or rotate the scan area box by clicking and dragging. Adjust the value until the signal trace becomes horizontal in the Scan Traces View.

Alternatively, you can press the **Auto** button next to the text field. This will automatically generate a slope value.

8-4-3. Scan Area

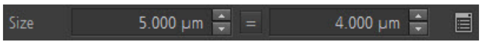
The **Scan Area** tab sets the parameters for the image scan size, pixel resolution, scan direction, and offset.

Pixels X, Y


Pixels 512 = 256

You can specify the resolution of an image by selecting the appropriate image pixel size from the Pixels field. The Pixels field enables you to select the number of data points used to collect an image. Clicking ▤ displays a dialog containing preset values (32×32, 64×64, 128×128, 256×256, 512×512, 1024×1024, 2048×2048, and 4096×4096). For the same scan area, a larger pixel size value will offer a higher lateral resolution, but image acquisition times will be longer. Thus, in order to increase the lateral resolution of an image, it is recommended to decrease the scan size while keeping pixel size constant.

Size X, Y



Size 5.000 µm = 4.000 µm

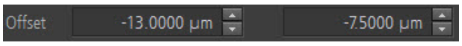
Size indicates the width of the scan. You can set the scan width by entering a value directly in the Size field. There are two Size fields, X and Y, but you only have to set the scan size once (usually, you will set the X scan size) since all scans are square. To perform a rectangular scan, click the **=** button, and the Y Size field will be enabled. The unit for the scan size, µm, is displayed in the Size field. The features you want to see in an image will determine the scan size. It is important to find the proper scan size related to the features of interest on the sample surface.

Click to display a dialog with preset data points (1×1µm^2, 2×2µm^2, 5×5µm^2, 10×10µm^2, 20×20µm^2, and 50×50µm^2).

The maximum available scan size is dependent on the range of the scanner. For example, using a 100µm scanner, the maximum scan size is 100µm. The resolution of the XY scanner and Z scanner, as well as external noise, affect the minimum allowable scan size.

Another way to select the scan size is in the Scan Area View. Setting the scan size in the Scan Area View will be explained in Section 9-1-1.

Offset X, Y

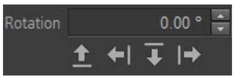


Offset -13.0000 µm -7.5000 µm

In the X and Y Offset fields, you can specify X and Y scanner coordinates for the next scan. The scanner coordinates are referenced to the center of the XY scanner. The coordinates at the center of the scanner are (0, 0). The X offset value is the scanner coordinate that moves from left to right in the optical microscope view. The Y offset value is the scanner coordinate that moves from bottom to top in the optical microscope view.

To set the specific offset values for X and Y, enter the desired X and Y coordinates in the X and Y Offset fields. In addition, you can change the X and Y scanner coordinates by dragging the tracker in the Scan Area View (see the previous section for more information).

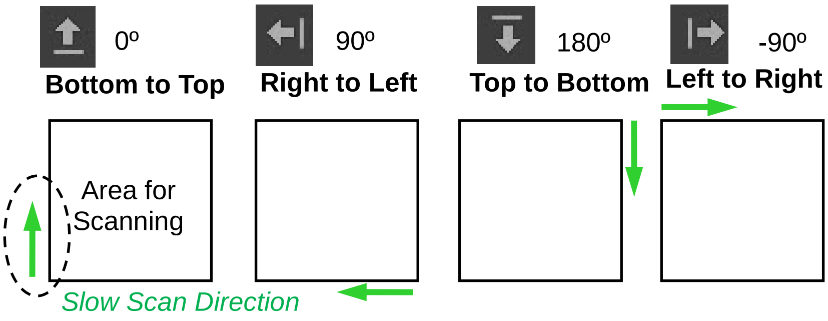
Rotation



Rotation 0.00 °

You can take an image in various scan directions by rotating the scan direction. You can change the scan direction in the Rotation field. In general, the rotated scan direction will not affect the image's features. The Rotation option is useful only when you want to take an image with a slightly different scan direction.

You may discover inconsistencies in the shape of the scanning tip when subsequent images are generated after changing the rotation angle of the scan direction. Also, you can distinguish between the "true" features on the sample surface and the "false" features in the image that may result from external noise or a tip effect. The true image is much the same at different angles, but a changed feature or image at a rotated angle is not "true." The Rotation degree may be varied from (-180) to (+180). Frequently used rotations (0 / -90 / 180 / -90) and scan directions can be easily set using the icon buttons shown below.



FM Mode

8-4-5. Z Servo

You can enable or disable feedback with the Z scanner servo by checking the **On**/**Off** radio button. **Off** turns off the Z scanner servo in this mode, and the scanner position is held constant at the position displayed in the text box. **On** turns the feedback on, and the scanner position is determined by the set point (see Figure 8-4-1).

- Off

This control turns off Z scanner feedback. Once the radio button is clicked, the text box will disply the last known scanner value. Extension of the scanner displays a negative number, while retraction of the scanner displays a positive number. The center of the scanner is defined as 0um. The **Retract** button will retract the scanner from the sample.

When **Servo** is checked, the feedback loop is active. When feedback is on, the Z scanner's motion matches the surface topography. The servo error signal is used to generate a feedback voltage, which is sent to the scanner, instructing it to extend or retract to generate an image of the sample surface. When feedback is on, the Height signal is used to generate an image of the sample surface.

When feedback is off, the servo error signal is primarily used to generate an image. In this case, the sample or the probe tip is not raised or lowered to minimize the error signal.

CAUTION!

If the Z scanner servo is off and tip is not raised enough, both tip and sample can be damaged.

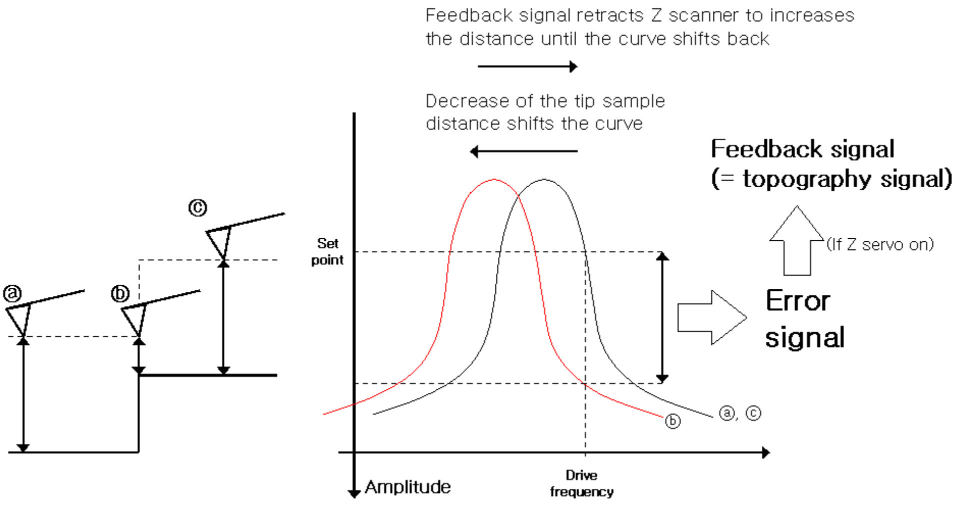

Feedback signal retracts Z scanner to increases the distance until the curve shifts back
Decrease of the tip sample distance shifts the curve
Feedback signal (= topography signal)
(If Z servo on)
Error signal
Set point
ⓐ
ⓑ
ⓒ
ⓐ, ⓒ
ⓑ
Amplitude
Drive frequency

Figure 8-4-1 Concept of the Z servo in NC-AFM

- Manual

When the Z scanner servo is deactivated, the text field on the left of the Manual combo box is displayed. You may manually extend or retract the Z scanner by entering a value in this field. You can monitor the position of the scanner with the Z scanner bar in the Monitoring View. The scanner extension is expressed in microns.

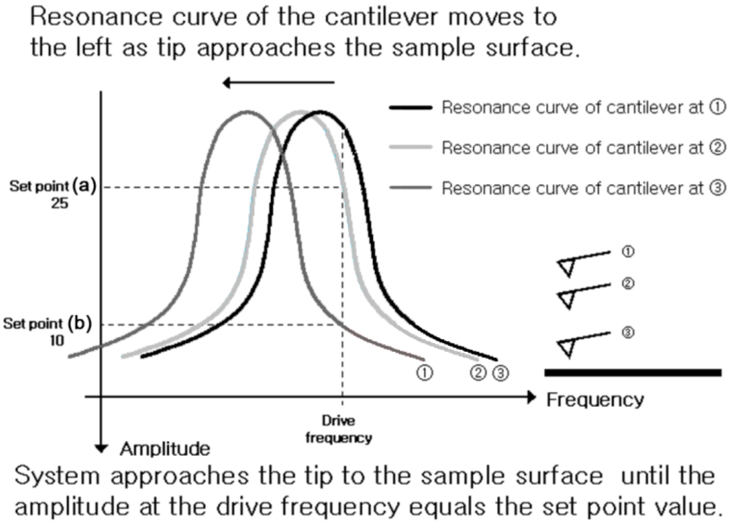
Set Point

The Set Point spinner allows you to specify the value of the reference signal of the feedback loop that is maintained during auto approach or scan. During an approach or scan, the system will send the feedback signal to the Z scanner in order to maintain a constant set point value.

The meaning of the set point value differs depending on the scan mode. In contact mode (AFM, LFM), the set point correlates to a value for the vertical force between the sample and the tip and is measured by looking at the cantilever’s deflection. In non-contact modes (NC-AFM, Tapping, MFM), the set point value correlates to a value for the amplitude of the cantilever vibration. In STM mode, the set point is a value for the tunneling current between the tip and the sample.

In any of the three cases mentioned above, the set point value is proportional to the tip-sample distance. As the set point value increases in contact mode and STM mode, the tip-to-sample distance decreases. On the other hand, as the set point value decreases in non-contact mode, the tip-to-sample distance decreases. Thus, the set point value can be understood as a measure of the tip-sample distance.

In order to protect the tip, you should not approach the tip too closely to the sample surface. If the tip is too close to sample, the tip may crash into the sample and damage both the tip and sample. Subsequent images taken after such a crash may produce incorrect information.



Resonance curve of the cantilever moves to the left as tip approaches the sample surface.

System approaches the tip to the sample surface until the amplitude at the drive frequency equals the set point value.

Resonance curve of cantilever at ①
Resonance curve of cantilever at ②
Resonance curve of cantilever at ③
Set point (a) 25
Set point (b) 10
① ② ③
Frequency
Drive frequency
Amplitude

Figure 8-4-2 Concept of the set point in NC-AFM

Normalized

Clicking the **Normalized** button converts the set point from a distance or force to a raw unit (voltage).

Advanced

When **Servo** is checked, the feedback loop is active. The feedback sensitivity is controlled by adjusting the Z servo gain.

The servo error signal is amplified by an appropriate factor controlling the +Z Gain value before the signal is sent to the scanner. The range of the Z gain value is from 0 to 20, in arbitrary units related to the Z scanner's range of motion.

A number of factors (such as scan rate, scan size, and sample topography) can affect the optimum value of the Z gain parameter. If the Z gain is too low, fine topographical features will be lost. If the Z gain is too high, the Z scanner will oscillate.

When **Advanced** is selected, the single Z Servo Gain item is replaced with four items: Z Servo Gain+, Z Servo Gain-, I Gain, and P Gain. Each of these numbers is factored separately in conjunction with the servo error signal to drive the Z scanner.

NOTE!

Unselecting Advanced, sets PI gain to default values (P: 1, I: 1)and Z Servo Gain is set by the previous + Z Gain. Use caution when changing this option.

- +/- Z Gain

  Using Z servo gain multiplies the servo error signal according to the Z servo gain value for Z servo response time (see Advanced, above). These Z gain fields determine the value by which a servo error signal is amplified. A positive Z servo gain value amplifies the positive servo error signal, while a negative Z servo gain value amplifies the negative servo error signal. If the **Advanced** button is disabled, only the +Z Gain field is activated, and adjusting the +Z Gain value controls the +/- Z gain values equally. Otherwise, the + and – gains can be set to different values. This can be useful for samples with steep variations, where a higher Z servo gain- value can help trace steep dropoff sample features.

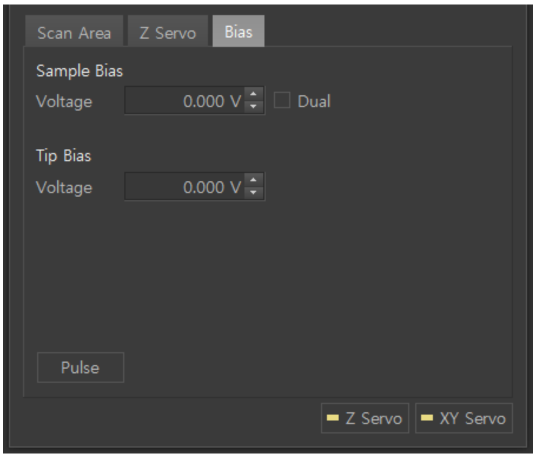
- P Gain

  Using proportional gain, or P gain, multiplies the servo error signal by a default scalar, then by the constant specified in the P Gain field to produce the Z scanner signal. A P gain of 1 is identical to SmartScan’s behavior without Advanced Servo.

- I Gain

  Using integral gain, or I gain, takes the integral of the servo error signal and multiplies it by a scalar, then by the specified I gain. An I gain of 1 is identical to SmartScan’s behavior without Advanced Servo.

8-4-6. Bias



Sample Bias
Voltage 0.000 V ☐ Dual

Tip Bias
Voltage 0.000 V

Figure 8-4-3. Bias tab

Sample Bias

The Sample Bias parameter sets the sample bias applied during a scan. The sample bias is the electric potential difference between the sample and the ground. The sample bias can be specified as a value from -10V to +10V.

“Dual” Sample Bias is an option that that is only applied for image acquisition. Its function is to apply different sample voltages according to the scan direction (e.g., FastScan forward or backward). The main purpose of doing so is to measure the dependence of two sample biases while performing C-AFM scans as well as to save on overall measurement time accordingly.

Tip Bias

The Tip Bias parameter sets the tip bias applied during a scan. The tip bias is the electric potential difference between the tip and the ground. The tip bias can be specified as a value from -10V to 10V. Depending on the modes available on your instrument, the tip bias can be applied manually or by the feedback system. To do so, **Manual** or **Servo** in this panel may be disactivated in the SmartScan software.

- Servo

  The lock-in is used for KPFM. When the tip bias servo is on, the system adjusts the tip bias automatically to minimize the difference in potential between tip and sample. The Gain field and **Phase Only** check box are activated when **Servo** is enabled.

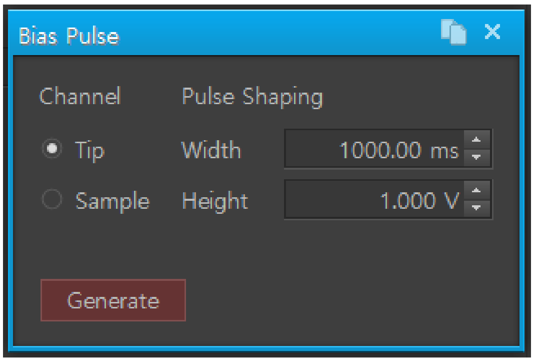
- Phase Only

  The tip bias feedback will only use the EFM phase signal.

- Servo gain

  Controls the sensitivity of feedback control

- Pulse Generation



Width 1000.00 ms

Height 1.000 V

Figure 8-4-4. Bias pulse generation

You can apply either tip bias or sample bias voltage. This function can be useful in SICM mode. For example, in SICM mode the probe used is a nano-pipette. When there are obstructions in or around the nano-pipette, an electrical shock can be applied to it to remove that substance, which may improve the quality of the probe and increase its imaging lifetime.

- Channel

  Use this to choose the sample/tip bias channel.

- Height

  Height determines the generated voltage. The value of the applied voltage can be entered directly.

- Width

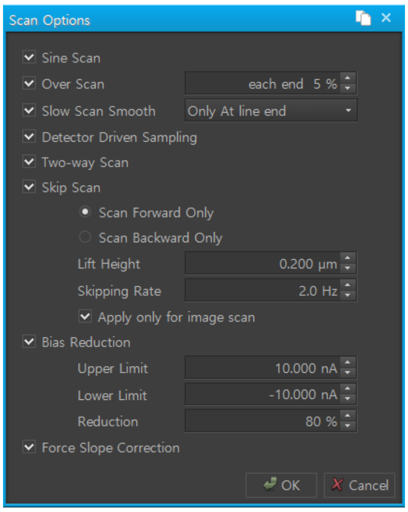
  Width determines the duration of the generated voltage (Height). The value of the duration of the applied voltage can be entered directly.

- Generate

  Generate applies input values to tip or sample bias.

8-4-7. Options

The following scan options are available in the Scan Options dialog shown by clicking the **Options** button:



☑ Sine Scan
☑ Over Scan each end 5 %
☑ Slow Scan Smooth Only At line end
☑ Detector Driven Sampling
☑ Two-way Scan
☑ Skip Scan
● Scan Forward Only
○ Scan Backward Only
Lift Height 0.200 μm
Skipping Rate 2.0 Hz
☑ Apply only for image scan
☑ Bias Reduction
Upper Limit 10.000 nA
Lower Limit -10.000 nA
Reduction 80 %
☑ Force Slope Correction

Figure 8-4-5. Scan Options dialog

Sine scan

If the **Sine Scan** option is active, the voltage applied to the piezo actuator of the XY scanner is in a sine waveform instead of the usual sawtooth waveform.

The piezo actuator expands as the applied voltage increases, and it contracts as the applied voltage decreases. Hence, the speed of the actuator's movement, which is the time derivative of the actuator's expansion and contraction, is proportional to the time derivative of the voltage applied to the actuator.

In ordinary cases, a sawtooth waveform has a constant derivative and thus there is a constant actuator speed. However, in the case of a sine waveform, the derivative is not constant and is almost zero when the applied voltage reaches the highest value. Thus the scanner does not move at constant velocity. The scanner moves slowly at both ends of each scan line and faster in the middle of each scan line, giving the scanner time to adjust its position before collecting the next line of data. On some samples, selecting **Sine Scan** may help to eliminate glitches at the ends of scan lines that result from abrupt directional changes of the probe.

Over scan

Over Scan can be selected to adjust the range of movement of the scanner in the fast scan direction beyond the selected scan size to be acquired. You can set the scanner's motion to a value greater than the image size by entering a percentage value for **Over Scan**. While scanning at the edge of a scan area, interactions between the tip and the sample or scanner instabilities at the scanner's turnaround point may produce streaks at the edge of an image. This problem can be eliminated by adjusting the overscan.

For example, if you specify a scan size of 20μm in the Scan Size field in the Parameters Control View, and an overscan value of 10%, the actual scan size used to collect the image will be 20μm+20μm×10%=22μm, but only 20μm of the 22μm image will be shown in the results scan trace and saved as data.

Slow Scan Smooth

Another method for dealing with artifacts created at the edges of the fast scan direction, checking this box introduces a sine wave into the movement of the tip at the turnaround points. This feature may be used independently or in conjunction with **Over Scan**, and can also be set from the Startup View in the Preferences dialog.

Detector-driven sampling

Detector-driven sampling image acquisition enhances the servo scan's performance by controlling the time intervals between sampling data points. In this case, data points are acquired when the detector outputs match the intended X, Y position of the scanner. However, when detector-driven sampling is not selected, data points are still taken at equal time intervals during the signal trace in the fast direction.

Two-way Scan

Two-way Scan automatically alternates the slow scan direction for successive images. This option is selected by default.

When this option is selected, if X is set as the fast scan direction, the slow scan direction, Y, alternates from bottom-to-top and top-to-bottom for successive images. If Y is selected as the fast scan direction, the slow scan direction, X, alternates from left-to-right and right-to-left for successive images.

In general, there is no significant difference in the images whether the **Two-way Scan** option is selected or not. However, in some cases, you may be able to distinguish effects that are due to tip anisotropy.

Skip scan

Skip scan does not scan in both directions (only scanning in the selected direction), lift the Z scanner in other direction to a designated height and the scanning speed moves faster at a set scan rate.

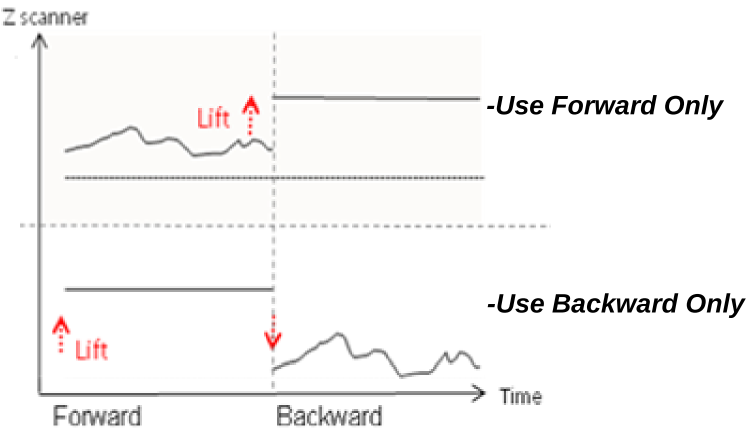


Figure 8-4-6. Skip scan

By changing **Lift Height** and **Skipping Rate**, you can select the lift amount and skip scan speed.

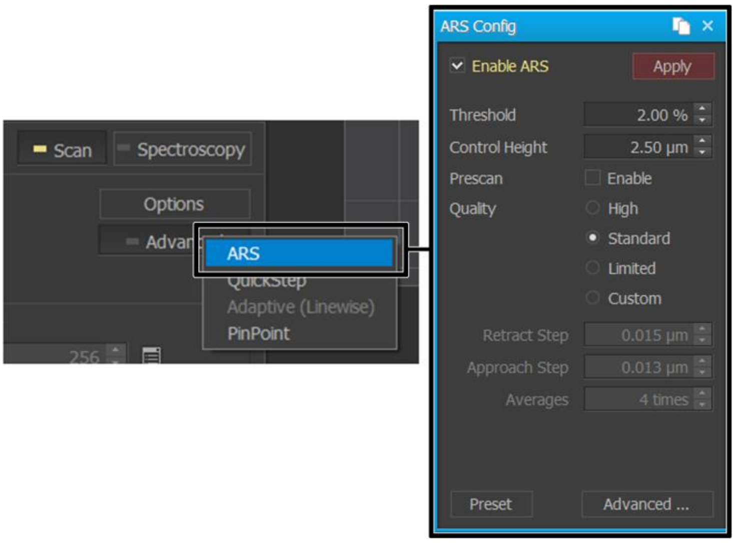
8-4-8. Advanced

The **Advanced Scan** button provides features for stepwise scanning, adaptive (Linewise) scanning, and PinPoint scanning.

When one of the advanced scan features is active, the yellow light will turn on and the Advanced label will display the name of the active scan feature (ARS, Adaptive, or PinPoint).

ARS mode config

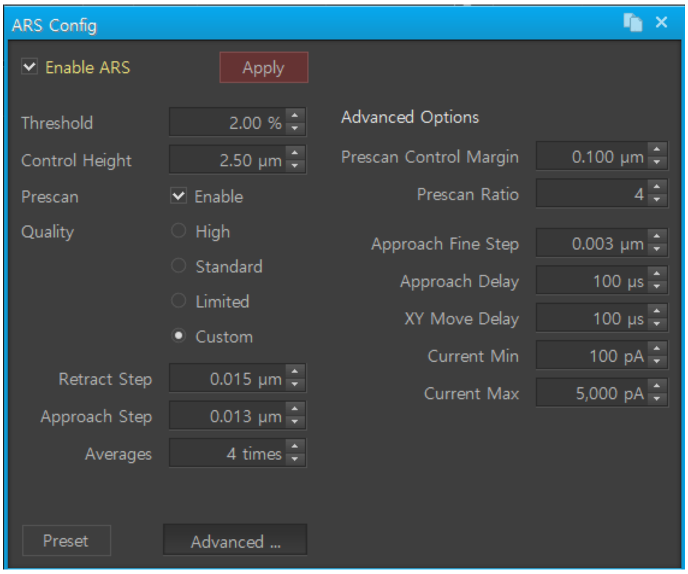
The image of a very delicate feature of a biological sample or cell which has a height of several microns, can be distorted by imaging with AC mode using continuous feedback. In approach-retrace scanning mode, continuous feedback is no longer used. Instead, to get every imaging pixel point, the nano-pipette’s linear approach and retract procedure is operated repeatedly on the sample surface while monitoring current signals. At first, when the nano-pipette is distant from the sample surface, reference current is measured. Secondly, the nano-pipette approaches until it reaches a height where 2.0 % current is reduced. When 2.0 % current reduction is achieved, the position of the Z scanner is recorded. Lastly, the nano-pipette is retracted far enough from the sample and then moves to next imaging point.



☑ Enable ARS
Threshold 2.00 %
Control Height 2.50 µm
Prescan ☐ Enable
Quality ○ High ● Standard ○ Limited ○ Custom
Retract Step 0.015 µm
Approach Step 0.013 µm
Averages 4 times

Figure 8-4-7. ARS Mode Config

Changin Head Mode top SICM Mode will add “ARS” to Advanced, as shown in Figure 8. (Does not appear in Advanced Window selection menu when not in SICM Mode. For Complicated details, click [Advanced…] and Advanced Options will expand to the right.

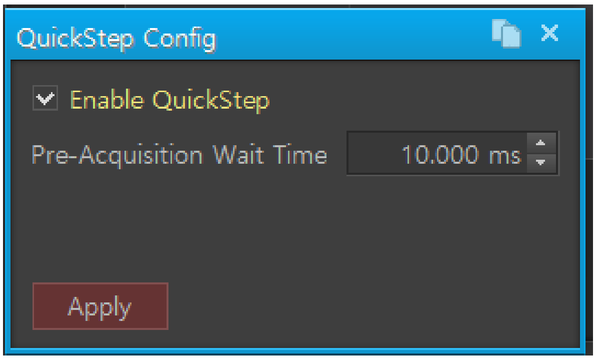


☑ Enable ARS
Threshold 2.00 %
Control Height 2.50 µm
Prescan ☑ Enable
Quality ○ High ○ Standard ○ Limited ● Custom
Retract Step 0.015 µm
Approach Step 0.013 µm
Averages 4 times

Prescan Control Margin 0.100 µm
Prescan Ratio 4
Approach Fine Step 0.003 µm
Approach Delay 100 µs
XY Move Delay 100 µs
Current Min 100 pA
Current Max 5,000 pA

Figure 8-4-8. ARS Mode setup

QuickStep Scanning



QuickStep Config

☑ Enable QuickStep

Pre-Acquisition Wait Time 10.000 ms

Figure 8-4-9. QuickStep Scan

Adaptive Scanning

This feature is active only for scanning modes utilizing a mechanical oscillation (NCM, tapping, EFM, MFM). Adaptive scan is a feedback system that acquires a new scan rate from the servo error signal.

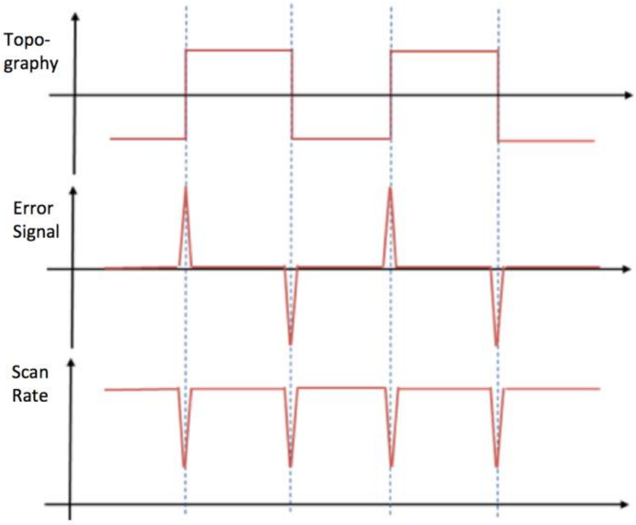
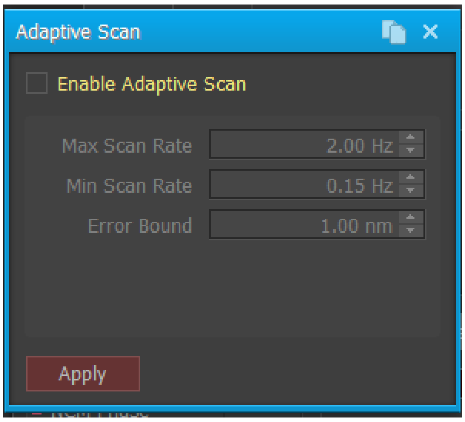


Figure 8-4-10. Scan rate feedback

For example, as shown in Figure 8-4-10, when topography encounters an edge, the servo error signal will start introducing peak or deep. In this case, the scan rate will be decreased, allowing slow scan. On the other hand, it will be increased when the servo error signal is close to zero.

There are three benefits from this function.

1. Scan rate will increase during imaging when encountering flat surfaces. Hence, imaging duration will be dramatically reduced.
2. Scan rate will decrease during imaging when encountering an edge. Hence, image quality will be dramatically enhanced.
3. Feedback parameters can be easily adjusted.



Adaptive Scan

☐ Enable Adaptive Scan

Max Scan Rate 2.00 Hz

Min Scan Rate 0.15 Hz

Error Bound 1.00 nm

Figure 8-4-11. Adaptive Scan setup

You can set the Adaptive Scan as follows:

1. Add servo error signal and scan rate for desired channels in the Channel Config dialog.
2. Click the **Adaptive** button in the Parameters control panel.
3. Check the **Adaptive Scan** check box to adjust the parameters for Adaptive Scan.
4. Set up Adaptive Scan parameters.
5. Click **OK** to apply the parameters to the scan rate.
6. Once active, Scan Rate in the Parameters View will be grayed out.
7. Adjust parameters accordingly by monitoring ‘Scan Rate and Servo error signals on the Scan Traces View.

Max/Min Scan Rate

Max Scan Rate and **Min Scan Rate** determine the maximum and minimum scan rate when the adaptive scan runs. When scan rate changes during Adaptive Scan, if the value is larger than **Max Rate** or smaller than **Min Rate**, **Max Rate** or **Min Rate** will be replaced with the applied scan rate.

Error Bound

Adaptive Scan changes the scan rate depending on servo error signal from previous line scan. Scan rate decreases when the error signal is greater than the error bound. The Error Bound acts as a limit to trigger the change in speed for adaptive scanning.

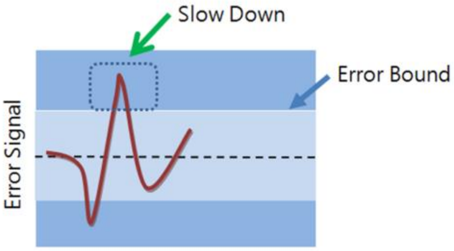


Figure 8-4-12. Error Bound

PinPoint Scanning

The PinPoint^{TM} mode developed by Park Systems acquires high-resolution topographical data and force-distance (F/D) data at each pixel concurrently in the entire scan area. Using PinPoint^{TM} mode, surface morphology as well as the quantitative nanomechanical properties (i.e., modulus, adhesion, deformation and dissipation) of the sample can be obtained all at once. The process is achieved using Park Systems's unique methodology, while measuring the morphology of the sample, the XY scanner halts at each data acquisition point and takes a rapid F/D curve with finely-controlled contact force, distance, and contact time between the tip and the sample. This makes evaluation of mechanical properties in materials a seamless operation for materials science professionals, creating reliable analysis at vastly improved levels of speed and accuracy.

In this Chapter, the basic operation procedure of PinPoint^{TM} mode will be explained, including sample and tip mounting, sensitivity calibration, force constant calibration, and PinPoint^{TM} mode parameter settings. Next, to give users a clear picture regarding the influence of cantilever stiffness on measured modulus results, three cantilevers with varying stiffness were used to image a standard PinPoint^{TM} mode polymer sample (consisting of polystyrene (PS) matrix with a nominal modulus of

2 GPa, and a low-density polyolefin (LDPE) with a nominal modulus of 0.1 GPa). Results demonstrated the capability of Park PinPoint^{TM} mode to differentiate the two surface domains with high fidelity.

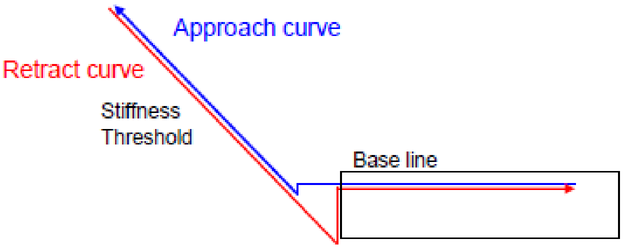
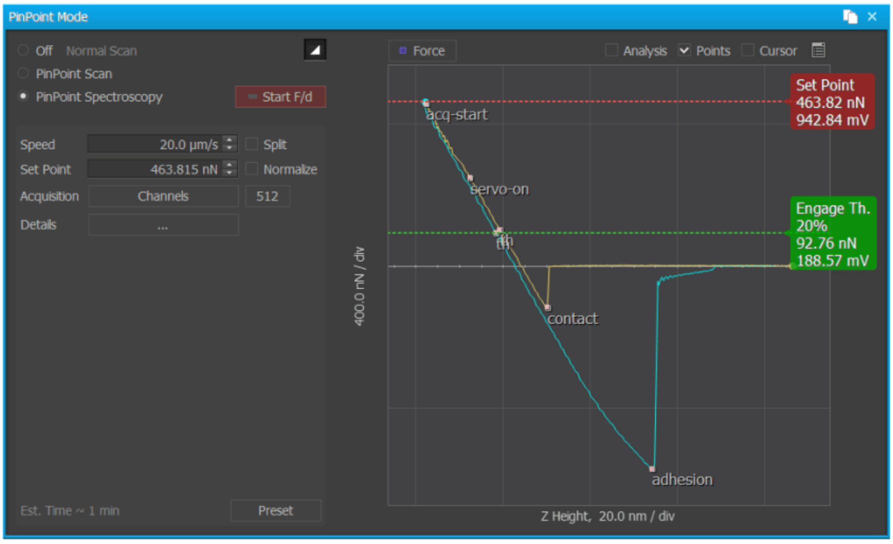


Figure 8-4-13. PinPoint mode channels on an F/d curve

For each F/d curve, the stiffness threshold can be calculated. Images can be created from F/d curve information corresponding to topography, stiffness, or secondary sources such as a current between tip and sample. In PinPoint mode, the cantilever approaches and retracts from the surface. As data is collected, the cantilever does not move during hold time, acquiring data, and moving the XY scanner. Figure 8-4-13 shows an F/d curve.

The PinPoint scanning control window is shown in Figure 8-4-14. PinPoint mode parameters can be applied to the data points of an entire image by toggling the radio button to **Scan**. PinPoint mode parameters can be applied to a single point by toggling the radio button to **Spectroscopy**.


PinPoint Mode

○ Off Normal Scan
○ PinPoint Scan
● PinPoint Spectroscopy

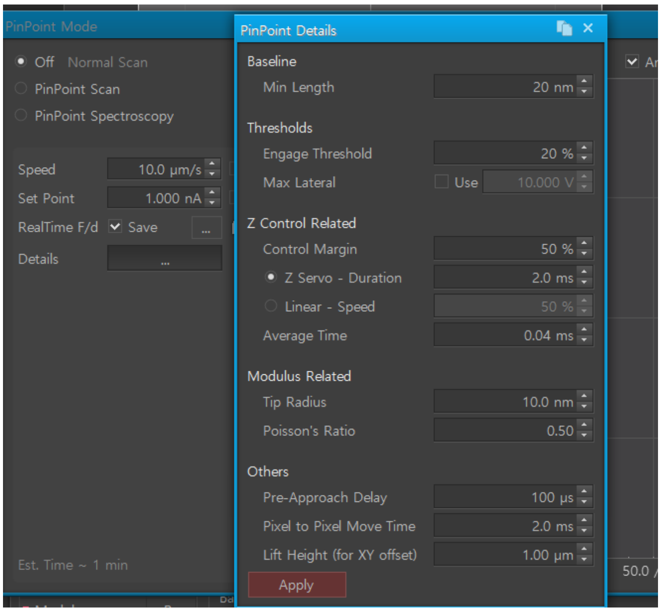
Speed 20.0 μm/s ☐ Split
Set Point 463.815 nN ☐ Normalize
Acquisition Channels 512
Details ...

Est. Time ~ 1 min

☐ Analysis ☑ Points ☐ Cursor

Set Point
463.82 nN
942.84 mV

Engage Th.
20%
92.76 nN
188.57 mV



● Off Normal Scan
○ PinPoint Scan
○ PinPoint Spectroscopy
Speed 10.0 µm/s
Set Point 1.000 nA
RealTime F/d ☑ Save ...
Details ...
Est. Time ~ 1 min

Min Length 20 nm
Engage Threshold 20 %
Max Lateral ☐ Use 10.000 V
Control Margin 50 %
● Z Servo - Duration 2.0 ms
○ Linear - Speed 50 %
Average Time 0.04 ms
Tip Radius 10.0 nm
Poisson's Ratio 0.50
Pre-Approach Delay 100 µs
Pixel to Pixel Move Time 2.0 ms
Lift Height (for XY offset) 1.00 µm

Figure 8-4-14. PinPoint scanning control window

To enable PinPoint scanning for an image, toggle the radio button to **Scan** and check the **Enable PinPoint** checkbox. Enabling PinPoint scanning will activate the parameter section discussed below. Once the parameters have been set for a particular sample, the setting can be saved and recalled using the **Preset** button.

To acquire a PinPoint mode image:

1. Select **Contact Mode**.
2. Select **Channel Config**.
3. Search for the PinPoint channels.
4. Choose **PinPoint** in the Details window.
5. Toggle the radio button to **Scan**.
6. Check **Enable PinPoint**.
7. Choose starting parameters.

The parameters for PinPoint mode are as follows:

- **Sample and Tip**

- Sample

A polystyrene – low-density polyolefin elastomer (PS-LDPE) sample is used in this User Guide as the PinPointTM mode standard calibration sample. PS-LDPE is a copolymer sample mounted on a 12 mm steel sample chunk. A blend of PS and LDPE were spin-cast onto a silicon substrate, creating a film with different modulus properties. PS with an elastic modulus of ~2 GPa serves as the matrix while PE is the low-density doping component with an elastic modulus of ~0.1 GPa.

- Tip

It is important to select a probe that can result in sufficient deformation of the sample while still retaining high force sensitivity. Therefore, both the force constant of the cantilever and the stiffness of the sample under study need to be taken into consideration when selecting probes. Below you can find Park's recommendation for probe selection.

Sample Modulus (E)	Probe	Nominal Force Constant
1 MPa < E < 20 MPa	SD-R30-CONT	0.2 N/m
10 MPa < E < 2 GPa	SD-R30-FM	2.8 N/m
1 GPa < E < 5 GPa	SD-R30-NCH	42 N/m

Figure 8-4-15. Force constant of the three cantilevers and suitable sample modulus range

- **Basic PinPoint^{TM} mode Operation**

This section includes the general procedure of performing a PinPoint^{TM} modeexperiment with Park SmartScan^{TM} (version RTM10d). In later sections, parameter settings and their influence on the measurements will be discussed.

1. **Instrument Setup**

   Set up your Park AFM system as you would for the ordinary Contact mode AFM. For detailed instructions, refer to your AFM User's Manual.

2. Z Height Calibration

The value for Z Height is the Z scanner movement determined by the system’s linearized sensor. Calibration of this setting should be done first. It is recommended to double-check your work after completing the calibration. For detailed instructions on how to do so, refer to the Maintenance section of AFM User’s Manual.

1) Before calibration, measure a standard sample with known height values and analyze the height of the sample with XEI.

2) Click “Maintenance”.

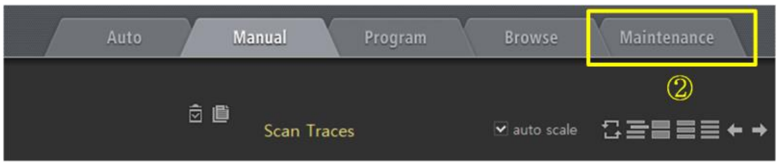
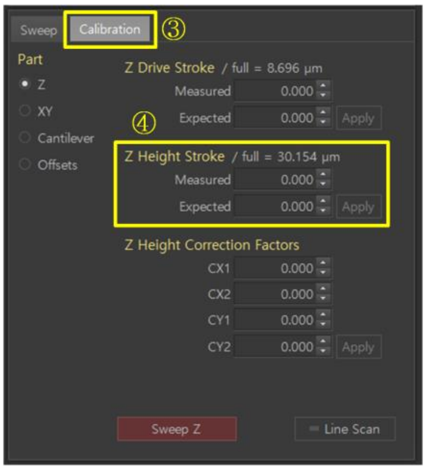


Figure8-4-15. Maintenance menu

3) Click “Calibration” and log in.

4) The Measured value is the height derived from the Z height calibration image. The Expected value is the height value reported for the known sample. After entering the Measured and Expected values, click “Apply” to adjust the calibration.



Z Drive Stroke / full = 8.696 µm
Measured 0.000
Expected 0.000

Z Height Stroke / full = 30.154 µm
Measured 0.000
Expected 0.000

CX1 0.000
CX2 0.000
CY1 0.000
CY2 0.000

Figure8-4-16. Z Height Calibration

3. A-B Sensitivity Calibration

To get accurate mechanical properties of the sample, the A-B sensitivity of the cantilever needs to be calibrated. A-B sensitivity is the calibration factor between the deflection of the cantilever and movement of the reflected beam on the position-sensitive photodiode (PSPD). In contact mode, this PSPD position is converted to a distance deflected by the cantilever using the A-B sensitivity calibration. The deflection is then converted to a force measured in Newtons using the spring constant of the cantilever.

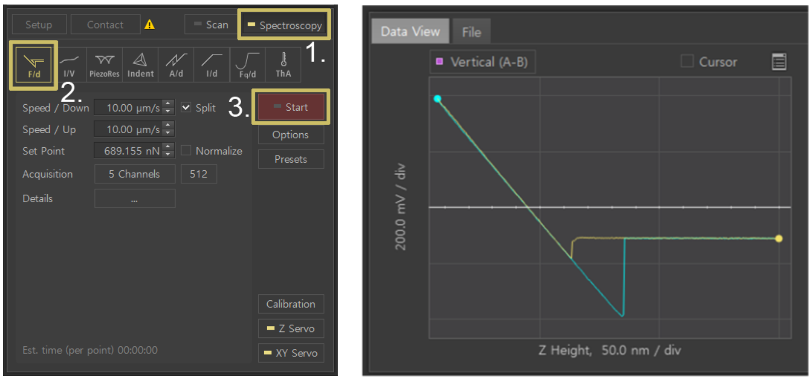
A-B sensitivity is obtained from the slope of the F/D (Force vs. Distance (Z scanner movement)) curve taken on a hard sample like bare silicon substrate following the procedure below:

1) Take an F/D curve (in contact mode) on a bare Si wafer sample with your cantilever. Click “Spectroscopy”

2) Click “F/D”.

Set the parameters for the F/D curve as follows (left panel of Figure 3):
Highest: 0.2 µm
Lowest: -0.2 µm
Speed: 0.20 µm/s
Force Corr.: Enabled
Force Limit: 0.3-0.5 V (you can set it to normalized value by checking “Normalize” in the “Z Servo” menu)
Hold Time: 0.000 sec
Acquisition: 4 Channels, 1024

3) Click “Start” to acquire an F/D curve. When finished, an F/D curve will be displayed in the “Data View” window, as in the right panel of Figure 8-4-17.



Speed / Down 10.00 µm/s ✓ Split
Speed / Up 10.00 µm/s
Set Point 689.155 nN ☐ Normalize
Acquisition 5 Channels 512
Details ...
Est. time (per point) 00:00:00

Figure 8-4-17. F/D curve parameters and a representative F/D

4) Click on the “Calibration – Cantilever Sensitivity”, which will lead you to the “Sensitivity Calibration” window, as see on the right of Figure 8-4-18.

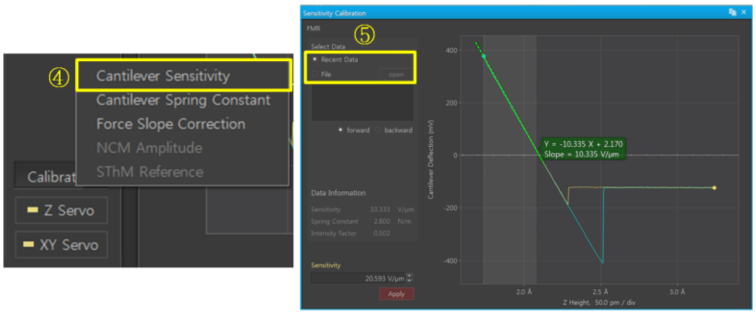
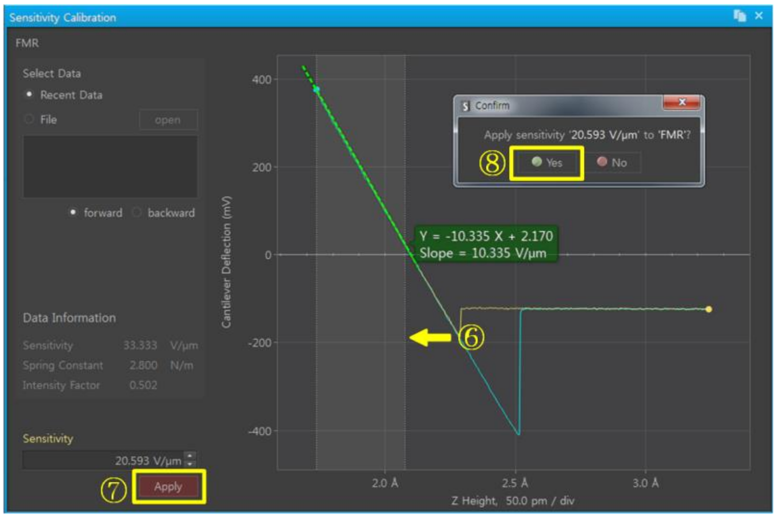


Figure 8-4-18. Sensitivity Calibration window

5) Click “Recent Data” or “File” and open the F/D curve you obtained in the F/D spectroscopy.

6) Line up the green dashed line with the linear region of the F/D curve by clicking and dragging the mouse. The software then automatically updates the slope, as displayed in the equation next to the F/D.

7) Click “Apply” button, which will lead to a pop-up window as seen in Figure 8-4-19.



Apply sensitivity '20.593 V/µm' to 'FMR'?

Y = -10.335 X + 2.170
Slope = 10.335 V/µm

Data Information

Sensitivity	33.333	V/µm
Spring Constant	2.800	N/m
Intensity Factor	0.502	

Sensitivity: 20.593 V/µm

Figure 8-4-19. Sensitivity Calibration step 6 to 8

8) Click “Yes” to apply the sensitivity to the cantilever.

4. Force Slope Correction

The A-B signal changes even if the cantilever does not bend; this is because of the coupling between the movement of the Z scanner and the A-B signal when the former moves. This coupling affects the Force value and can lead to sloped baselines in F/d curves, as seen on the left in Figure 6. The Force Slope Correction feature allows the baseline of the F/D curve to be corrected by removing the coupling, as seen on the right in Figure 8-4-20.

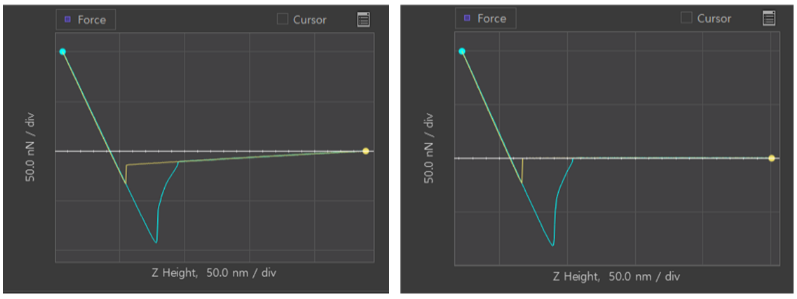
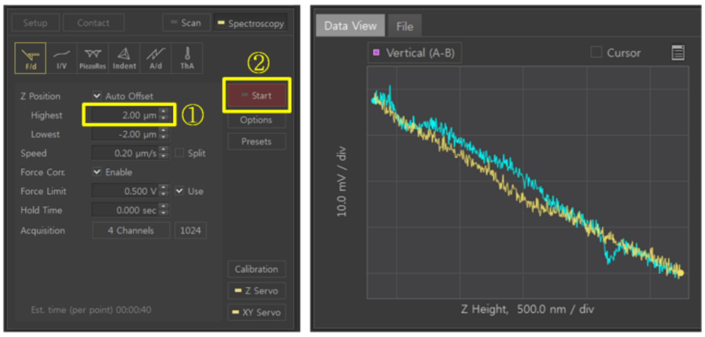


Figure 8-4-20. Before (Left) and After (Right) Force Slope Correction

Force Slope Correction is obtained from the slope of the F/D (Force vs. Z scanner) curve taken in a retracting state. To perform Force Slope Correction, follow the procedure below.

1) After completely retracting the cantilever, change the parameter for the F/d curve as follows: Highest: 2 µm

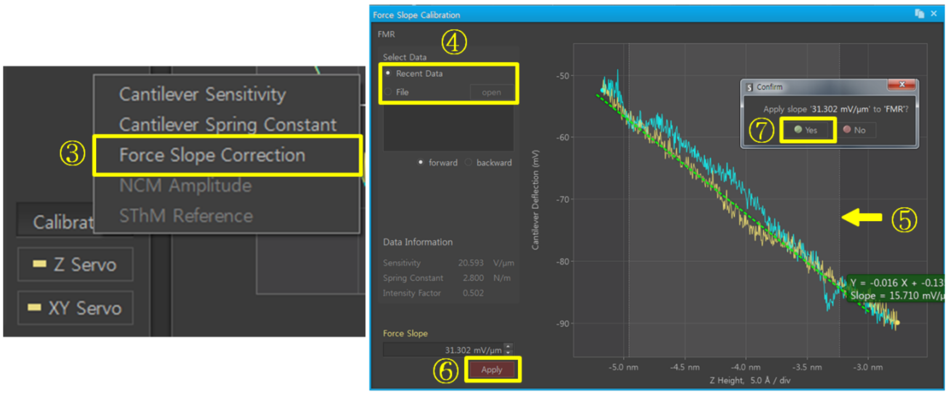
2) Click “Start” to acquire the F/D curve without an approach. When finished, a sloped line will be displayed in the “Data View” window, as in the right panel of Figure 8-4-21



Z Position ✓ Auto Offset
Highest 2.00 µm
Lowest -2.00 µm
Speed 0.20 µm/s ☐ Split
Force Corr ✓ Enable
Force Limit 0.500 V ✓ Use
Hold Time 0.000 sec
Acquisition 4 Channels 1024
Est. time (per point) 00:00:40

Figure8-4-21. F/D curve without approach

3) Click “Calibration” then “Force Slope Correction”, which will lead you to the “Force Slope Correction” window, as seen on the right panel of Figure 8-4-22.



Sensitivity 20.593 V/µm
Spring Constant 2.800 N/m
Intensity Factor 0.502
31.302 mV/µm
Apply slope '31.302 mV/µm' to 'FMR'?
Y = -0.016 X + -0.13
Slope = 15.710 mV/µ

Figure 8-4-22. Force Slope Correction step 3 to 7

4) Click “Recent Data” or Click “File” and open the F/D curve.

5) Line up the green dashed line by clicking and dragging the mouse. The software then automatically updates the slope, as displayed in the equation next to the F/D curve.

6) Click “Apply” button.

7) Click “Yes” to apply.

5. Spring Constant Calibration

- ThermalTune

Next, the spring constant of the cantilever needs to be calibrated. Please follow the procedure below:

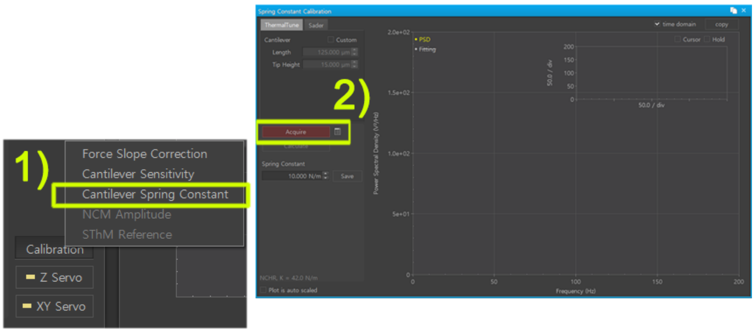


Figure 8-4-23. Spring Constant Calibration step 1 to 2

1) Click “Calibration“ then “Cantilever Spring Constant”, which will open up the “Thermal Tune” window.

2) Click “Acquire” to perform the thermal tune. Once the thermal tune is complete, double click to see the full range of data.

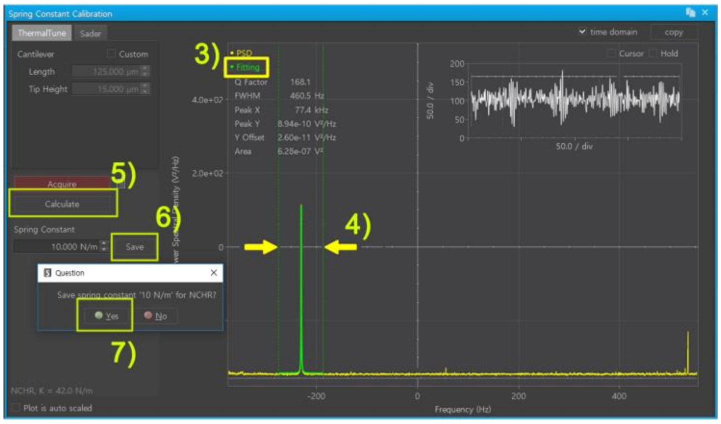


Figure 8-4-24. Spring Constant Calibration step 3 to 7

3) Click “Fitting” so the letters in the word “Fitting” turn green.

4) Find the first resonance peak and move the two boundaries such that the peak is between both of them (ensure the frequency difference between the two boundaries is larger than 20 kHz)

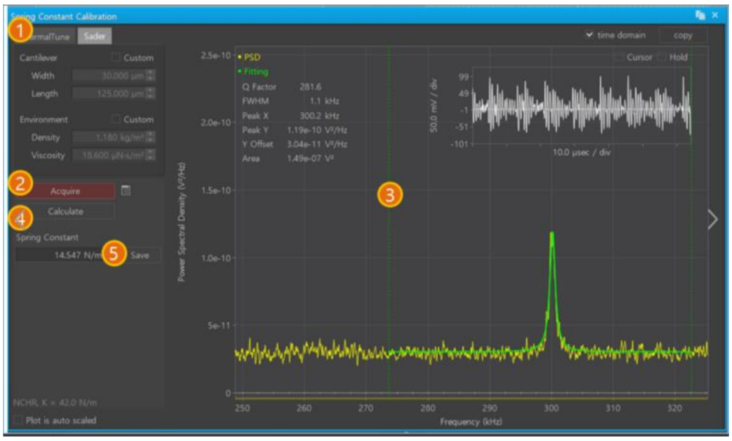
5) Click “Calculate”. The software will then calculate the spring constant and display the calculated value.

6) Click “Save”

7) Click “Yes” to apply the obtained spring constant to the cantilever.

- **Sader Method**

The Sader Method is one of the Spring Constant Calibration methods. This function is required when using the High k Cantilever (~number of N/m or more).



Width 30.000 µm
Length 125.000 µm
Density 1.180 kg/m³
Viscosity 18.600 µN·s/m²
Spring Constant 14.547 N/m
NCHR, K = 42.0 N/m

Q Factor	281.6
FWHM	1.1 kHz
Peak X	300.2 kHz
Peak Y	1.19e-10 V²/Hz
Y Offset	3.04e-11 V²/Hz
Area	1.49e-07 V²

1) Click “Calibration“ then “Cantilever Spring Constant”, which will open up the “Sader” window.

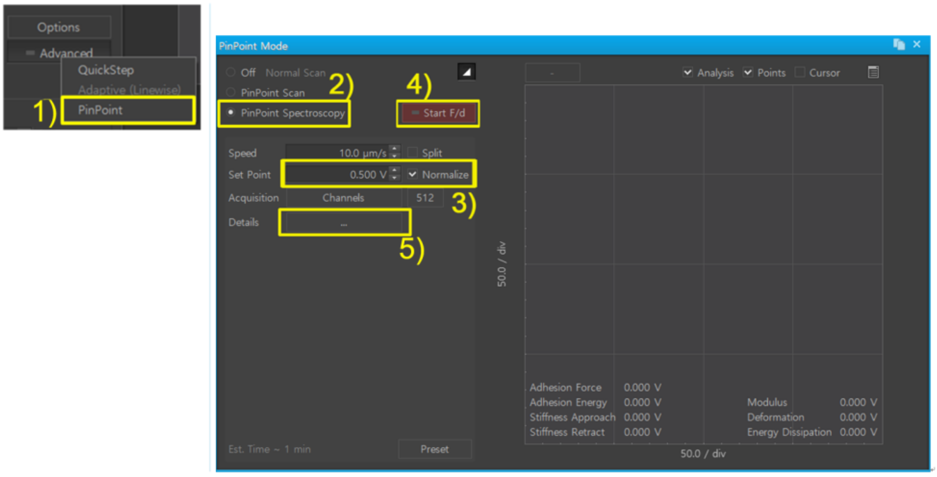
2) Click “Acquire” to perform the Sader Method.

3) Set the Cursor.

4) Click “Calculate”

5) Click “Save”

6. PinPoint Nanomechanical Mode Setup



Speed 10.0 µm/s ☐ Split
Set Point 0.500 V ☑ Normalize
Acquisition Channels 512
Details ...
Est. Time ~ 1 min

Adhesion Force	0.000 V		
Adhesion Energy	0.000 V	Modulus	0.000 V
Stiffness Approach	0.000 V	Deformation	0.000 V
Stiffness Retract	0.000 V	Energy Dissipation	0.000 V

Figure 8-4-25. Pinpoint Mode window

1) Back in Scan mode, after the completion of the approach, click “Advanced“ then ”Pinpoint” and the Scan control window for the PinPointTM mode will pop up, as seen in Figure 8-4-25.

2) Click “Spectroscopy”.

3) Check “Normalize” and put 0.5 V as the Set point.

4) Click “Start F/d” to acquire an F/d curve. The F/d curve will then appear on the right of window.

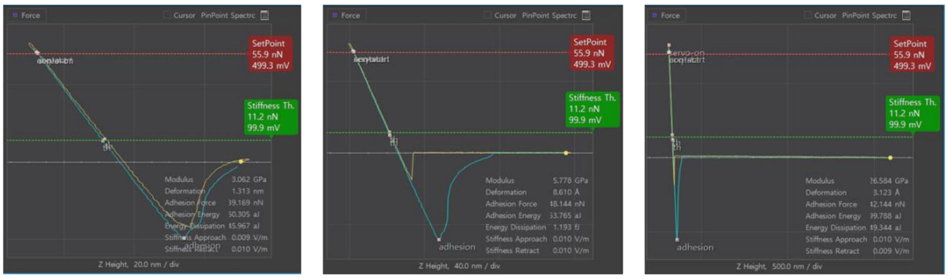
5) Modify the parameters:

Control Height
Speed
Set point

Detailed explanation about key parameters in PinPointTM mode operation and some examples are included below

Control Height

The control height must be set so a PinPoint (free cantilever) baseline can be established. The control height does not affect the stiffness calculation. This is a special value related to the travel range of the Z scanner in the Z axis direction during the acquisition of F/d curves. It provides extra clearance space when the cantilever tip moves to the next pixel position during PinPoint^{TM} mode. If this Control Height value is small, an F/d curve that is not completely eliminated by the tip-sample interaction is measured, as seen on the left of Figure 12. If the value is too large, the number of data points in the contact region is small, as seen on the right of Figure 8-4-26. This may cause an error in the modulus measurements. In most cases, a control height of 0.1-0.3 μm is appropriate, but in sticky samples, more than 0.3 μm may need to be used.



Modulus	3.062 GPa
Deformation	1.313 nm
Adhesion Force	39.169 nN
Adhesion Energy	30.305 aJ
Energy Dissipation	15.967 aJ
Stiffness Approach	0.009 V/m
Stiffness Retract	0.010 V/m

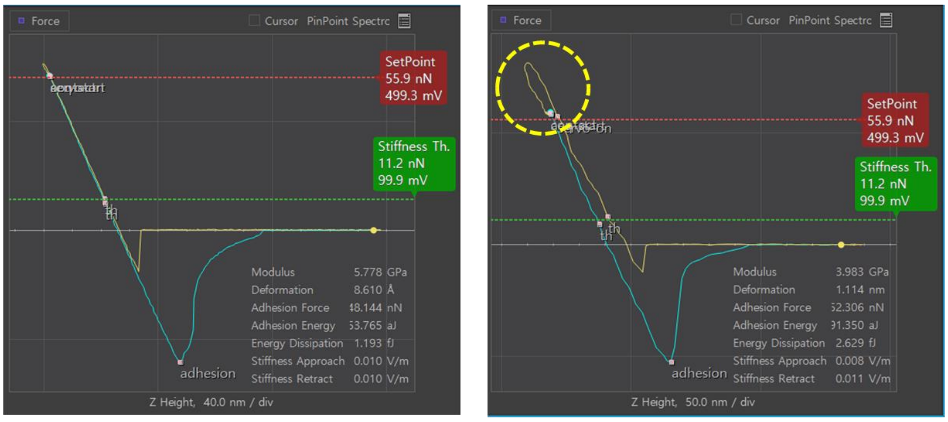
Modulus	5.778 GPa
Deformation	8.610 Å
Adhesion Force	48.144 nN
Adhesion Energy	53.765 aJ
Energy Dissipation	1.193 fJ
Stiffness Approach	0.010 V/m
Stiffness Retract	0.010 V/m

Modulus	26.584 GPa
Deformation	3.123 Å
Adhesion Force	42.144 nN
Adhesion Energy	39.788 aJ
Energy Dissipation	19.344 aJ
Stiffness Approach	0.010 V/m
Stiffness Retract	0.009 V/m

Figure8-4-26. Examples of F/d curve with small (Left), appropriate (Mid), and large (Right) Control Height values

Speed

This parameter sets the travel speed of the Z scanner during the approach-and-retract process in F/D spectroscopy. If you check “Split”, you can set the speeds of approaches and retractions separately. Too fast of a speed will lead to insufficient sample deformation as there is not enough time for the substrate to respond to the push of the cantilever, and an overshoot beyond the set point, as seen on the yellow dotted circle of **Figure 8-4-27**. On the other hand, the total imaging time will be very long if speed is set too slow. In general, 10-20 μm/s can be used for most samples.



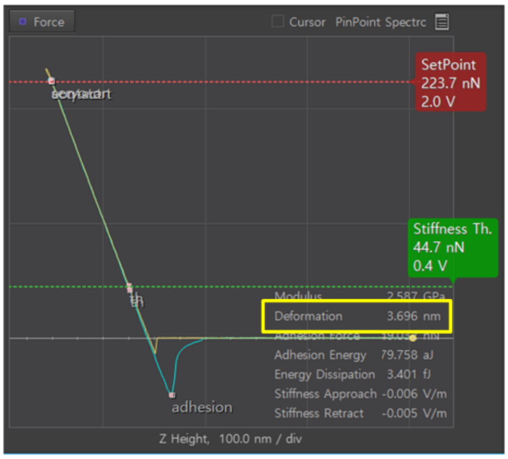
Modulus 5.778 GPa
Deformation 8.610 Å
Adhesion Force 48.144 nN
Adhesion Energy 53.765 aJ
Energy Dissipation 1.193 fJ
Stiffness Approach 0.010 V/m
Stiffness Retract 0.010 V/m

Modulus 3.983 GPa
Deformation 1.114 nm
Adhesion Force 52.306 nN
Adhesion Energy 91.350 aJ
Energy Dissipation 2.629 fJ
Stiffness Approach 0.008 V/m
Stiffness Retract 0.011 V/m

Figure8-4-27. Examples of F/d curve with appropriate (Left) and fast (Right) Speed

Set Point

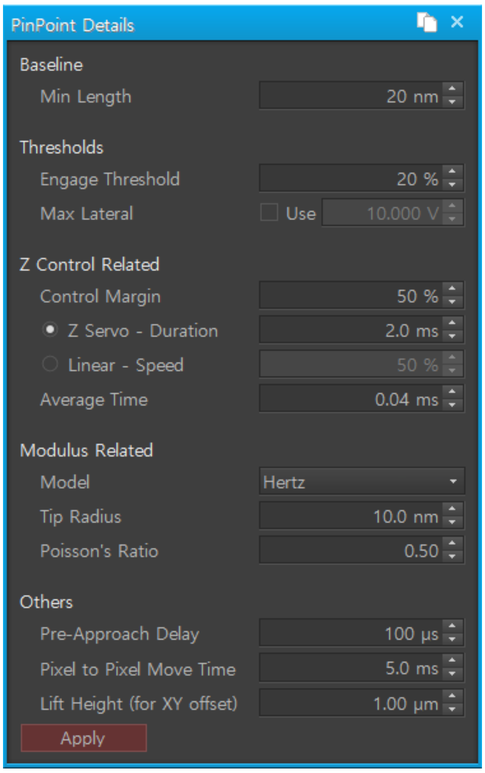
This is the maximum loading force on the sample during F/D spectroscopy. A set point that is too high can either damage the sample or wear down the tip. In general, it is desirable to use a set point value that is as small as possible. Meanwhile, a set point high enough to generate sufficient sample deformation, at least 3 nm, is needed to achieve accurate modulus measurements If your application does not involve modulus measurements, a high set point is not needed. It is recommended to start with 0.5 V as the normalized value.



Modulus 2.587 GPa
Deformation 3.696 nm
Adhesion Force [illegible] nN
Adhesion Energy 79.758 aJ
Energy Dissipation 3.401 fJ
Stiffness Approach -0.006 V/m
Stiffness Retract -0.005 V/m

Figure8-4-28. Example of sufficient sample deformation with appropriate set point

6) Advanced parameters can be set by clicking on “Details”



PinPoint Details

Baseline

Min Length 20 nm

Thresholds

Engage Threshold 20 %

Max Lateral ☐ Use 10.000 V

Z Control Related

Control Margin 50 %

● Z Servo - Duration 2.0 ms

○ Linear - Speed 50 %

Average Time 0.04 ms

Modulus Related

Model Hertz

Tip Radius 10.0 nm

Poisson's Ratio 0.50

Others

Pre-Approach Delay 100 μs

Pixel to Pixel Move Time 5.0 ms

Lift Height (for XY offset) 1.00 μm

Figure8-4-29. PinPoint^{TM} Details Parameters

Baseline	
Min Length	Prior to measuring Pinpoint Mode, there is a process to raise the Z Scanner to the top until Tip - Sample Interaction is not found. This enhancement ensures that no errors are detected in the judgment, which is recognized as Baseline during Min Length if the Force change value is below a certain value. If Tip - Sample Interaction is strong and Baseline is not working properly, increase Above Value. If you want to reduce the overall measurement time, you can reduce the above value to the extent that Baseline is coming.
Thresholds	
Engage Threshold	Position on the F/d curve used to determine the stiffness. The stiffness is calculated as the slope between the force limit (set point) of the F/d curve and the stiffness threshold. Figure 8-4-13 shows an F/d curve and the stiffness threshold.
Max Lateral	This function monitors LFM channel when 'Pinpoint' is active.

	Input range is 0.001V to 10.000V.
Z Control Related	
Control Margin	Sets a value to limit Z servo feedback. Z servo feedback turns on when the error signal is greater than the margin value.
Z Servo - Duration	Z Servo is a method of reaching the Set Point, which, after a given amount of time, moves on to the next step.
Linear - Speed	This function allows you to adjust the speed of the Z scanner by lowering the Z scanner until you reach the Set Point linearly.
Average Time	When the measurement is taken after reaching the Set Point, the average time is Takes the average of the measured values.
Modulus Related	
Model	Method of Modulus
Tip Radius	Radius of curvature for the tip.
Poissons's Ratio	Poisson's ratio for the tip.
Others	
Pre-approach Delay	Delay after moving to the next pixel before approach.
Pixel to Pixel Move Time	Total time to move from one pixel to the next.
Lift Height (for XY offset)	Z lift height when the XY scan offset changes in PinPoint mode.

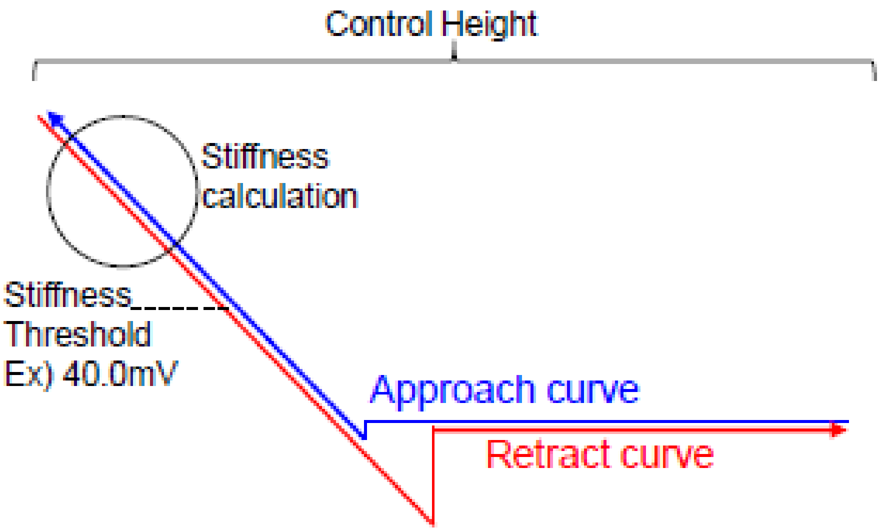


Figure 8-4-30. Stiffness calculation in F/d curve

Stiffness Forward	Stiffness calculated using the approach curve
Stiffness Backward	Stiffness calculated using the retract curve
Modulus	Young’s modulus calculation using the Hertzian method
Adhesion	Minimum A-B value from the base line in the retract curve
PinPoint Baseline	F/d curve free cantilever value. Used as a monitor for proper adhesion calculation. If you have a stable value without variation, the Z scanner travel range for F/d is proper.

7) If parameters settings are complete, click “Scan” and check “Enable”:

8) Click “Apply” and close the PinPoint^{TM} mode window.:

7. PinPoint Nanomechanical Mode Setup

You have to open PinPoint^{TM} mode channel to access the data acquired regarding the sample’s nanomechanical properties. This procedure is the same as in other modes

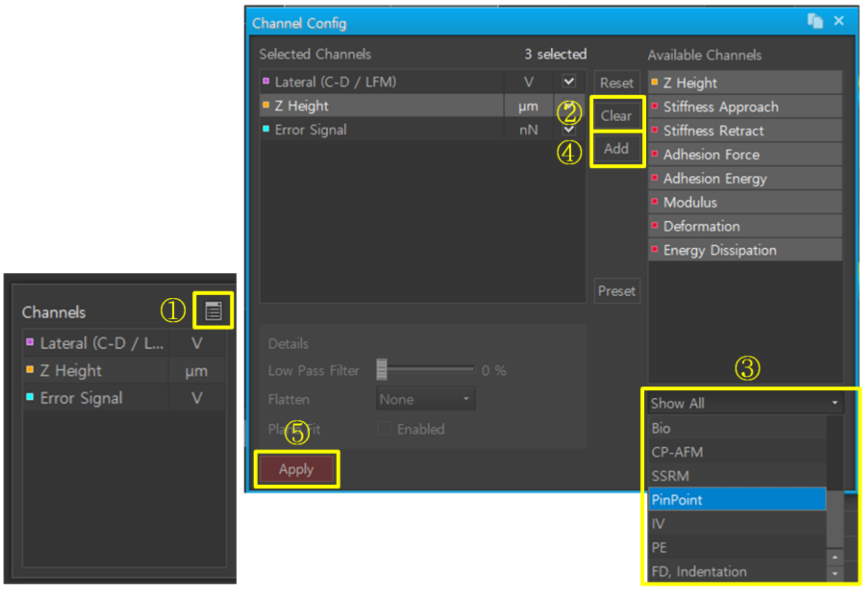


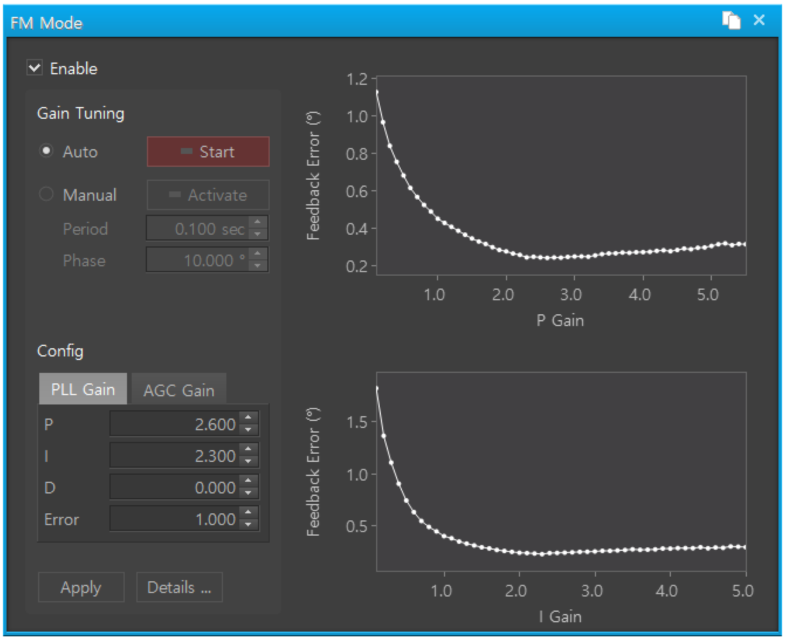
Figure8-4-31. PinPointTM Details Parameters

1. Click the “Channel Config” icon, which will open up the “Channel Config” window.
2. Click “Clear” to completely clear “Selected Channels”
3. Find and select “PinPoint^{TM}”. Then the properties that can be measured with PinPoint^{TM} appear in “Available Channels”
4. Click “Add” to copy components of “Available channels” to “Selected Channels”
5. Click “Apply”

This completes all the steps for PinPoint^{TM} mode. Press Scan to start imaging.

8-4-9. FM Mode (Only for NCM Head Mode)

FM Mode opens the FM Mode window. This is the mode of measuring AFM using the change in the resonance frequency of Cantilever. Based on this, it is a mode that measures Topography by Servo to maintain a constant resonance frequency.



FM Mode

☑ Enable

Gain Tuning

● Auto

○ Manual

Period 0.100 sec

Phase 10.000 °

Config

P 2.600

I 2.300

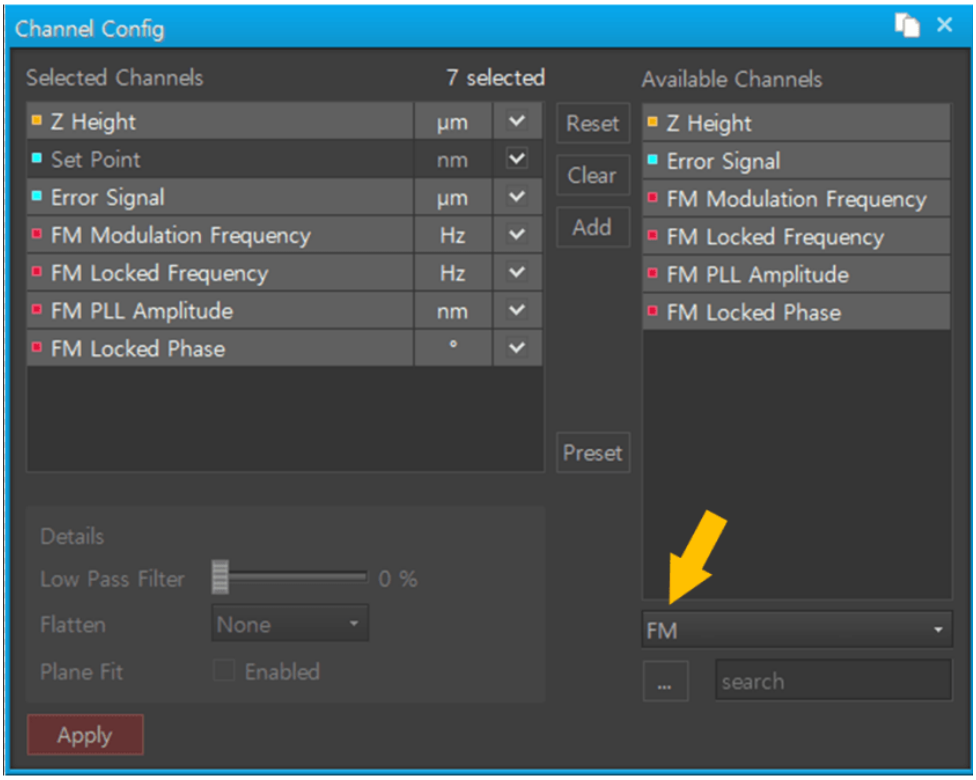
D 0.000

Error 1.000

Figure 8-4-32. FM Mode window

Gain Tuning	
Auto	Start to the Auto Gain Tuning
Manual	As a manual Gain Tuning, the Tuning function can be activated to help set the Gain value using the Tuning checkbox.
Config	
PLL Gain (Phase Locked Loop)	Adjusts the Gain value of the Phase Locked Loop.
AGC Gain (Auto Gain Control)	Adjusts the Gain value of the Auto Gain Control.
Apply	Finishing and applying FM Mode settings.
Details	Filter Bandwidth can be change and related variable values can be checked.

The channels associated with FM Mode can be selected from the Channel Config dialogue as shown below.



Selected Channels — 7 selected

Z Height	μm	✓
Set Point	nm	✓
Error Signal	μm	✓
FM Modulation Frequency	Hz	✓
FM Locked Frequency	Hz	✓
FM PLL Amplitude	nm	✓
FM Locked Phase	°	✓

Available Channels:
- Z Height
- Error Signal
- FM Modulation Frequency
- FM Locked Frequency
- FM PLL Amplitude
- FM Locked Phase

FM

Low Pass Filter 0 %

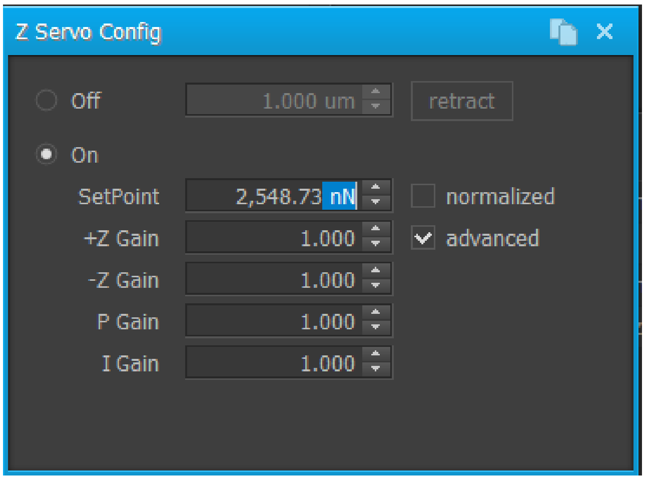
Flatten None

Plane Fit ☐ Enabled

Figure 8-4-33. Channel Setting for FM Mode

8-4-9. Z Servo

Z Servo opens the Z Servo Config window. See Section 8-4-5 for more information about the Z Servo Config window.



○ Off 1.000 um

● On

SetPoint 2,548.73 nN

+Z Gain 1.000

-Z Gain 1.000

P Gain 1.000

I Gain 1.000

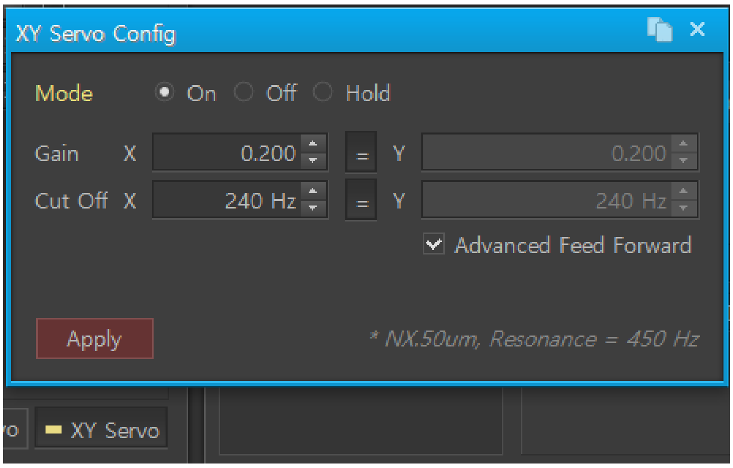
☐ normalized

☑ advanced

Figure 8-4-34. Z Servo Config window

8-4-10. XY Servo

XY Servo opens the XY Servo Config window. Figure 8-4-35 shows the XY Servo Config window.



XY Servo Config

Mode ● On ○ Off ○ Hold

Gain X 0.200 = Y 0.200

Cut Off X 240 Hz = Y 240 Hz

☑ Advanced Feed Forward

* NX.50um, Resonance = 450 Hz

Figure 8-4-35. XY Servo Configuration dialog

XY Servo is the feedback loop designated to correct the nonlinearity of the XY scanner. You can enable and disable the XY servo and set several parameters that control the operation of the XY servo configuration. However, these parameters do not need to be adjusted as the system automatically optimizes the XY servo. You can open the XY Servo Config dialog by selecting the **XY Servo** button from the Parameters Control View.

The XY servo mechanism uses an XY detector to continuously monitor and adjust the position of the XY scanner. This detector is connected to the XY feedback loop when the XY servo is turned on.

The X and Y feedback parameters control the operation of the XY feedback loop for scanner setup. There are several controls in the XY Servo Config dialog.

ON

Selecting **ON** enables the XY feedback loop. The feedback loop corrects for scanner nonlinearity in the X and Y directions by adding a correction to the voltage that is sent to the XY detector of the scanner.

OFF

Selecting **OFF** turns off the XY feedback loop. The XY feedback loop is disabled and cannot correct nonlinearity in the scanner’s XY position.

Hold

When **Servo** is disabled by selecting **Off**, the extra voltage applied to the scanner to correct error from nonlinearity suddenly vanishes, and the position of the probe changes. Selecting the **Hold** option, however, disables the servo while maintaining the position of the probe on the sample surface. **Hold** is useful when you need to take an image with the servo turned on for a large scan area, and then image a small area from within the original data with the servo turned off. For instance, when you want to image a 50nm area within a 1μm scan area that was imaged with the servo, follow the steps below.

1. Acquire the image with a 1μm scan area (XY Servo On).
2. Set the scan size to 0 for both X and Y.
3. Go to desired area by changing the Offset X, Y.
4. Select **Hold** in XY Servo Config.
5. Set the smaller scan size (50nm) for both X and Y and acquire the image.

Gain (X and Y)

The gain value of the XY feedback loop is adjustable when the servo is turned on by entering values in the **Integral Gain** field for the X and Y filters. Hence, increasing values will enhance the XY servo. However, noise will also increase, so use caution when setting this value. The available range of values is from 0.01 to 10 in arbitrary units. The default value is 0.4. Be sure that the same values are used for both the X and Y filters.

Advanced Feed Forward

Advanced Feed Forward is a feed forward function that is used to control the XY scanner. You can compare the effect of feed forward during program execution by enabling or disabling it through the user interface. However, users will need to log into the system as an Admin to change its setting value.

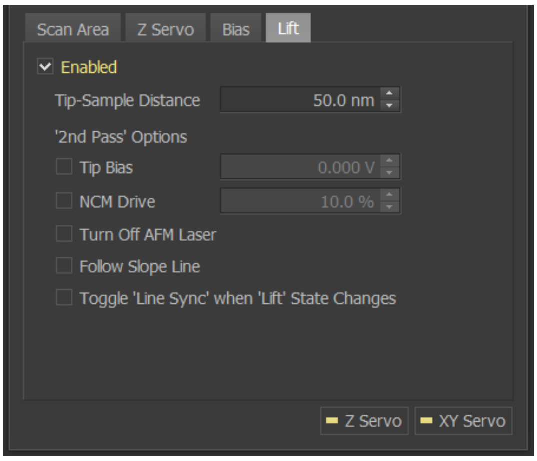
Take care not to change this setting if the system is in an Approached status.

8-4-11. Lift Scan

The following modes are compatible with Lift scanning:

MFM, EFM, EFM(DC), and C-AFM

When one of these modes is used, a **Lift** tab will appear in the Parameters View. The **Lift** option will be active when the **Enable** button is checked.



☑ Enabled

Tip-Sample Distance 50.0 nm

'2nd Pass' Options

☐ Tip Bias 0.000 V

☐ NCM Drive 10.0 %

☐ Turn Off AFM Laser

☐ Follow Slope Line

☐ Toggle 'Line Sync' when 'Lift' State Changes

Figure 8-4-36. Lift scan

Tip-Sample Distance

Tip-sample distance is the distance that the tip is lifted to perform the second scan after the first scan is complete. If the tip-sample distance is too small, the tip will not be lifted enough to be placed in the electrostatic or magnetic force dominant region. But if it is too large, tip would be placed in the region where the optional signal, such as EFM and MFM, will be small to detect. So it is important to find an optimal tip-sample distance for good optional imaging.

'2nd Pass' Options

During the second pass, a number of scanning parameters can be changed by clicking the appropriate check box.

- **Tip Bias**

You can set the bias differently applied to the tip when the system performs the second scan.

- **NCM Drive**

  When checked, NCM frequency drive percentage can be readjusted to the drive percentage in the input box for the second pass.

- **Turn off AFM Laser**

  When checked, the system will turn off the AFM SLD beam for the second pass.

- **Follow Slope Line**

  When checked, the system will compensate for sample tilt during the second pass. The Z scanner will follow the first pass topography slope during the second pass.

- **Toggle Line Sync When Lift State Changes**

  Set Line Sync as 1st scan = low level and 2nd scan = high level. When checked, the line sync signal from the BNC connection at the back of the controller outputs a square wave. The minimum voltage (low level) of the square wave represents the first pass, while the maximum voltage (high level) represents the second pass.

Chapter 9. Spectroscopy Control

Activating spectroscopy control mode changes the workspace as shown below. To get to the Spectroscopy Control View, click the **Manual** tab, then choose the **Spectroscopy** button in the Spectroscopy Parameters View. The workspace will change to the Spectroscopy Control workspace, as shown in Figure 9-1-1.

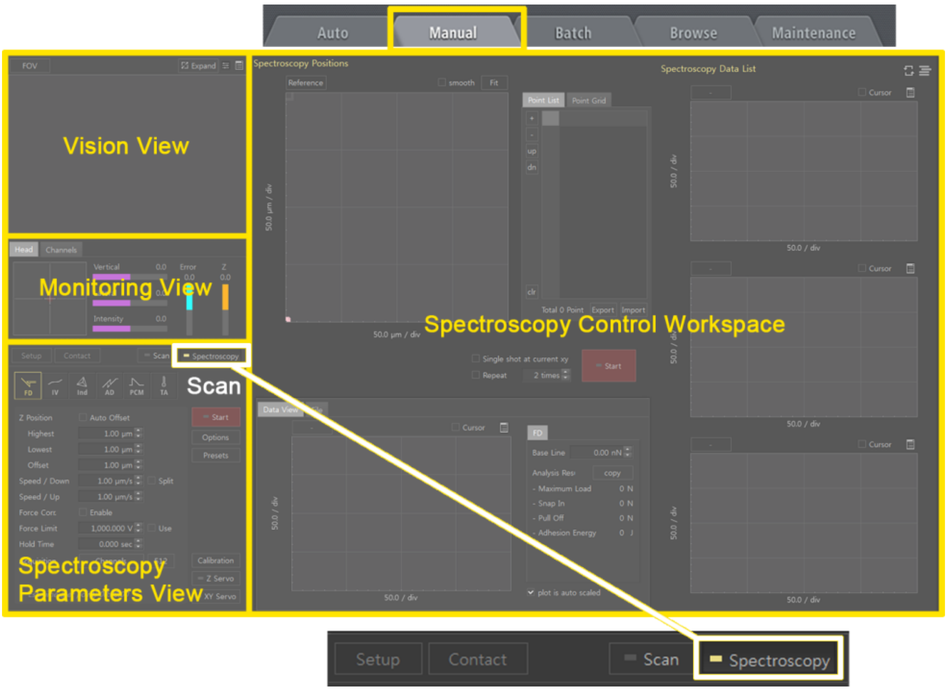


Figure 9-1-1. Spectroscopy Control workspace

Spectroscopy control mode allows users to monitor signals at one point as a paramter change is made. The following spectroscopy modes are available:

- **F/d**: Approach spectroscopy (generally referred to as force-distance spectroscopy)
- **I/V**: Voltage spectroscopy (generally referred to as current-voltage spectroscopy); activated only in current atomic force microscopy (C-AFM)
- **Piezo Res.:** Piezo response spectroscopy

- **Ind:** Nano-indentation
- **A/d**: Amplitude spectroscopy (generally referred to as amplitude-distance spectroscopy)
- **ThA.**: Temperature analysis spectroscopy (used with scanning thermal microscopy)

The **Manual** tab of the Spectroscopy Control workspace includes:

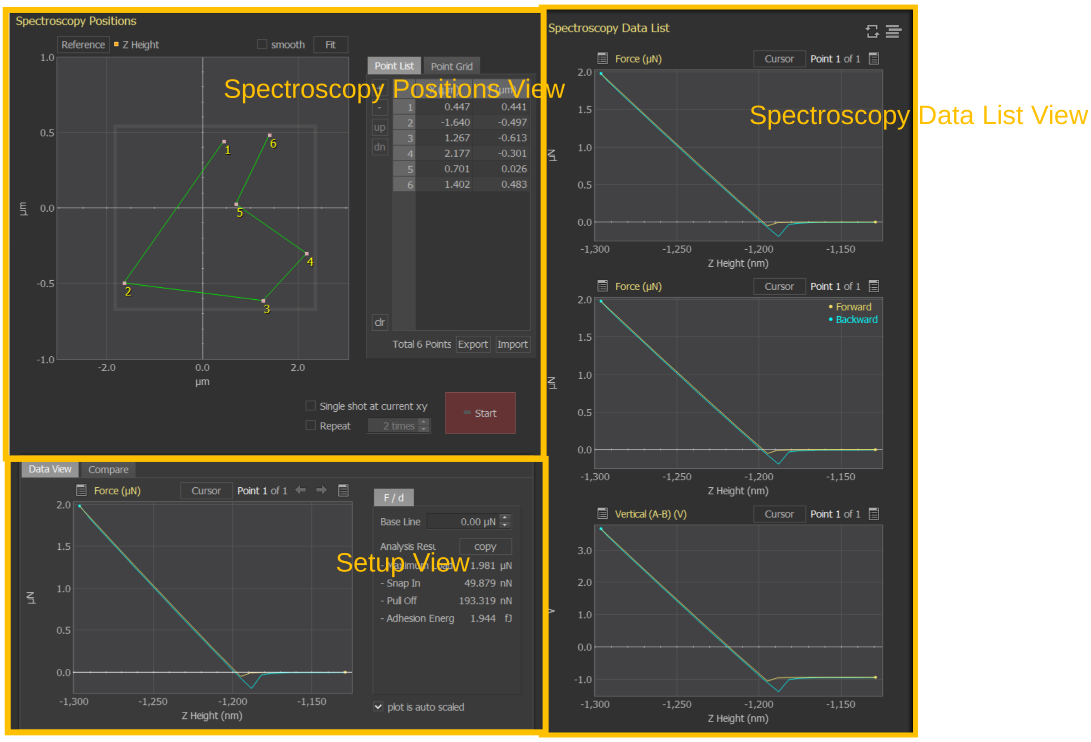
Vision View: see Section 7-1

Monitoring View: see Section 7-2

Spectroscopy Parameters View: see Section 9-1

Spectroscopy Control Workspace: see Section 9-2, 9-3

The Spectroscopy Workspace is further separated into three main areas: the Spectroscopy Positions View, the Spectroscopy Data List, and the Setup View, as shown in Figure 9-1-2.



	X (µm)	Y (µm)
1	0.447	0.441
2	-1.640	-0.497
3	1.267	-0.613
4	2.177	-0.301
5	0.701	0.026
6	1.402	0.483

Total 6 Points Export Import

☐ Single shot at current xy
☐ Repeat 2 times

Base Line 0.00 µN

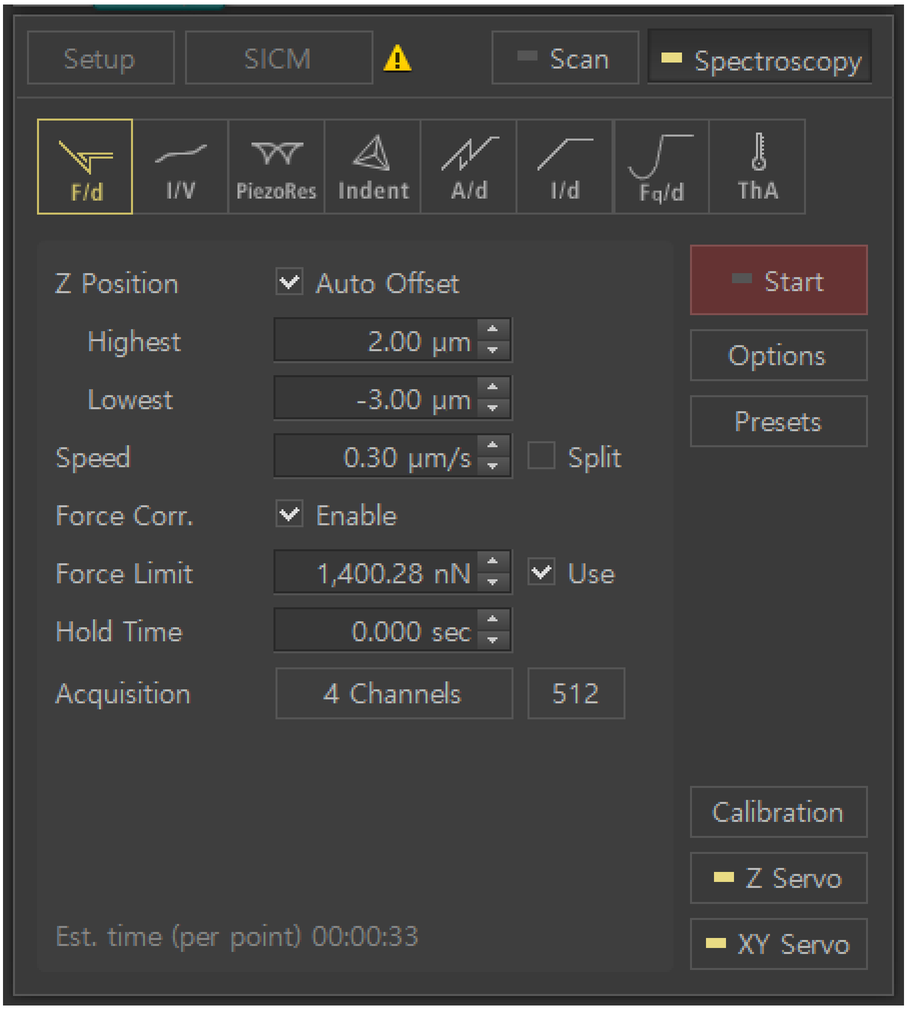
Analysis Resu
- Maximum Load 1.981 µN
- Snap In 49.879 nN
- Pull Off 193.319 nN
- Adhesion Energ 1.944 fJ

☑ plot is auto scaled

Figure 9-1-2. Spectroscopy control workspace

9-1. Spectroscopy Parameters View

The Spectroscopy Parameters View sets the parameters used to take the point measurement. The parameter interface changes depend on the type of spectroscopy measurement being taken. The various spectroscopy parameter setup interfaces are shown in Figure 9-1-3.



Z Position ☑ Auto Offset
Highest 2.00 µm
Lowest -3.00 µm
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 1,400.28 nN ☑ Use
Hold Time 0.000 sec
Acquisition 4 Channels 512
Est. time (per point) 00:00:33

Figure 9-1-3. Spectroscopy parameter View

The general procedure for spectroscopy measurement is as follows:

1. Obtain an SPM image of the sample to identify regions of interest for spectroscopy curves using Scan Control (Chapter 8) or Auto mode (Chapter 6).
2. Change to Spectroscopy Control.
3. Select points to identify for spectroscopy measurement.
4. Select one desired spectroscopy mode and parameters for one-point

spectroscopy.

5. Select the parameters related to moving between points.
6. Acquire the scan.

- **F/d**: approach spectroscopy or force-distance spectroscopy

  F/d spectroscopy mode supports the acquisition of force vs. distance curves, which are useful for the investigation of a sample's mechanical properties. The F/d curve is a plot of the force between the tip and the sample as a function of the extension of the Z scanner.

- **I/V**: voltage spectroscopy or current-voltage spectroscopy

  Used only in current atomic force microscopy (C-AFM) mode, I/V spectroscopy mode supports the acquisition of a current (I) vs. voltage (V) curve to investigate electrical properties of a sample surface. An I/V curve is a plot of the current as a function of the tip bias voltage that is applied to the sample.

- **Piezo Res.:** Piezo Response spectroscopy

  Normally, this mode is for measuring piezo samples, and like performing the I-V spectroscopy curve, the voltage bias is swept to produce the pizeo response spectroscopy data in the shape of a butterfly curve.

- **Indent**: Indentation

  Nano-indentation enables the users to perform indentation tests to measure material properties, such as nanoscale hardness and elasticity. A single indentation cycle consists of loading, holding, and unloading processes. Nano-indentation has two sub-modes: set point mode and Z scanner mode. Each sub-mode uses different parameters to control the indentation cycle. In set point mode, the force (load) between the tip and sample is varied as a linear function of time while the corresponding position of the Z scanner is measured. In Z scanner mode, the Z scanner position is varied as a linear function of time while the corresponding load applied to the tip is measured.

- **A/d:** amplitude spectroscopy

  Amplitude spectroscopy, or amplitude-distance spectroscopy, allows users to acquire NCM amplitude and NCM phase information as a function of distance from the surface. This technique can be used to study tip-sample interaction.

- **I/d:** Current spectroscopy

  Temperature analysis spectroscopy is used only with SThM for SThM probe temperature calibration.

- **Fq/d:** Frequency-Distance Spectroscopy

  Frequency Modulation Non-Contact AFM (FM-NCM) measurement using an internal PLL. The function uses the 'FM Modulation Frequency' channel value with the Z Servo Set Point. The FM Modulation Frequency - resistance curve can be a good guide for determining the appropriate set point value. The use method is very similar to I/d Spectrumcopy and the only difference is that there is a Frequency Limit instead of Current Upper / Lower Limit.

- **ThA:** Temperature analysis spectroscopy

  Temperature analysis spectroscopy is used only with SThM for SThM probe temperature calibration.

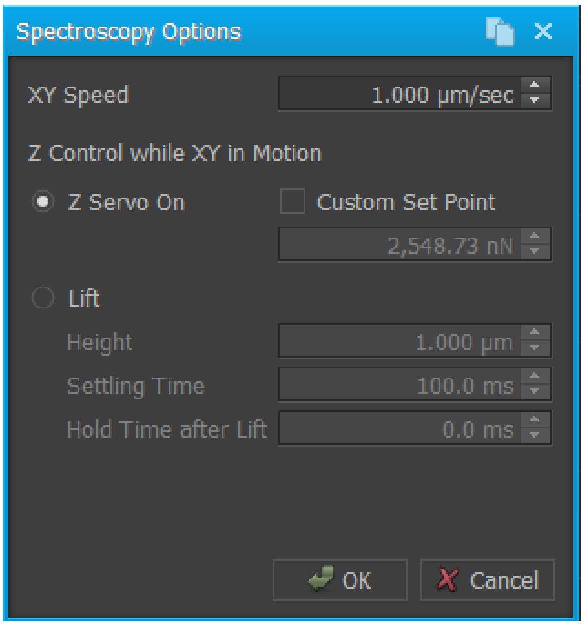
*For detailed information of these modes, refer to the User’s Manual or the Mode Manual.

9-1-1. Start

Start begins the spectroscopy data curve at the current XY position. To take spectroscopy curves of the entire point list or point grid, use the **Start** button found in the Spectrocopy Positions area (see Section 9-2).

9-1-2. Options

Clicking **Options** opens the Spectroscopy Options dialog. The Spectroscopy Options dialog allows you to control how the Z scanner behaves while the XY scanner is moving in spectroscopy modes.



XY Speed: 1.000 µm/sec

Z Control while XY in Motion

● Z Servo On ☐ Custom Set Point 2,548.73 nN

○ Lift

Height: 1.000 µm

Settling Time: 100.0 ms

Hold Time after Lift: 0.0 ms

Figure 9-1-4. Spectroscopy Options dialog

- **XY Speed**

  This field determines how fast the XY scanner moves to relocate the sample relative to the tip. When in **Z Servo On** mode, a high XY speed may be too fast for the Z servo to prevent the tip from being damaged.

- **Z Control while XY in Motion**

  When moving between two measurement points, the cantilever may crash into variations in the sample surface, which may damage both the sample and cantilever. You can select between two different methods to keep the cantilever from crashing into the surface: **Z Servo On** and **Z Servo Off** with **Lift** options.

- **Z Servo On**

  When **Use Z Servo** is checked, the Z servo may be kept on during movement so that the Z scanner follows surface variations and keeps the cantilever from crashing. **Z Servo On** utilizes this concept.

- **Use Custom Set Point**

  When in **Z Servo On** mode, the Z servo maintains a certain set point. This option determines whether this is specified separately in the **Set Point** field or is the same as the current imaging set point. When this option is checked, the **Set Point** field is activated.

- **Set Point**

  Applicable when **Use Custom Set Point** is checked, the **Set Point** field allows you to specify the set point to maintain while moving between measurement points. By default, this value will be the same as the imaging value, but you can select a different one.

- **Lift**

  When the **Lift** radio button is selected, the Z servo is off and lift options such as **Set Point**, **Lift Height**, and **Settling Time** are activated. When the Z servo is set to be off during the motion between points, the Z scanner raises by a set distance. When the cantilever reaches the new location, a new approach is performed, and measurements resume.

- **Height**

  When in **Lift** mode, the Z scanner is raised by the value shown in this field while the cantilever moves between points. A higher value will be safer, as the cantilever is less likely to crash into sample variations, but will result in a longer reapproach time. A low value reduces reapproach time, but may be insufficient to prevent collision.

- **Settling Time**

  After the tip is relocated, the Z servo must be turned on. **Settling Time** allows the user to define how much time is given for the Z servo to activate.

- **Hold Time after Lift**

  Hold Time allows the user to define. How much time is given for the cantilever tip to hold. Before it moves to next the point.

9-1-3. Presets

Presets opens the Presets window to save spectroscopy parameters so that they can be recalled at a later time.

9-1-4. Calibration

The **Calibration** button displays a pop-up menu of calibration features. The menu is displayed in Figure 9-1-5. The **NCM Amplitude Calibration** option is only active when a non-contact-based measurement mode is selected (NCM, tapping, EFM, or MFM).

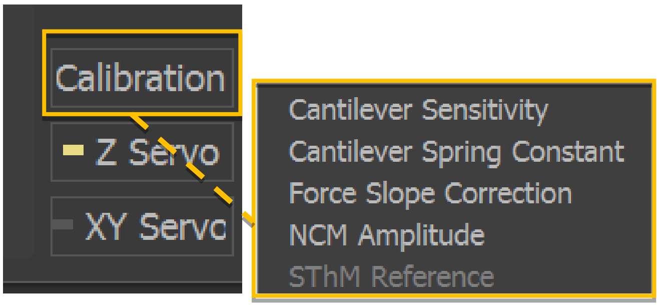
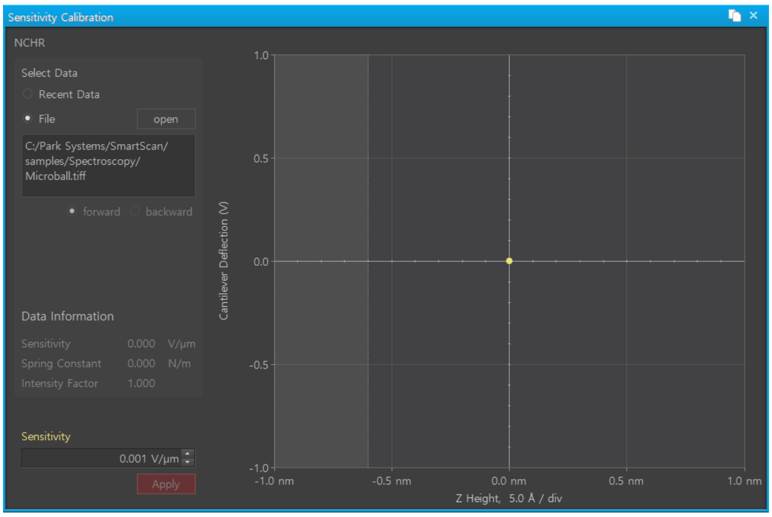


Figure 9-1-5. Spectroscopy calibration menu

Cantilever Sensitivity

This option opens the Sensitivity Calibration window. The Cantilever Sensivity Calibration window is shown in Figure 9-1-6. To calculate the sensitivity of an F/d curve:

1. Choose the data. Click **recent data** to use the data recently taken. Click **file** to save an F/d curve taken previously.
2. Choose where the sensitivity will be calculated with the forward (approach curve) or backward data (retract curve).
3. Adjust the dotted lines of the calculation window by clicking and dragging on the edges of vertical rectange. As the area is adjusted, the green fitting curve will display the calculated sensitivity. For best results, the green line should follow the linear portion of the F/d curve.
4. The **Sensitvity to be applied** display box will update the calulated sensitivity.
5. Click **Apply** to update the sensitivity of the cantilever file.



C:/Park Systems/SmartScan/samples/Spectroscopy/Microball.tiff

Sensitivity 0.000 V/μm
Spring Constant 0.000 N/m
Intensity Factor 1.000

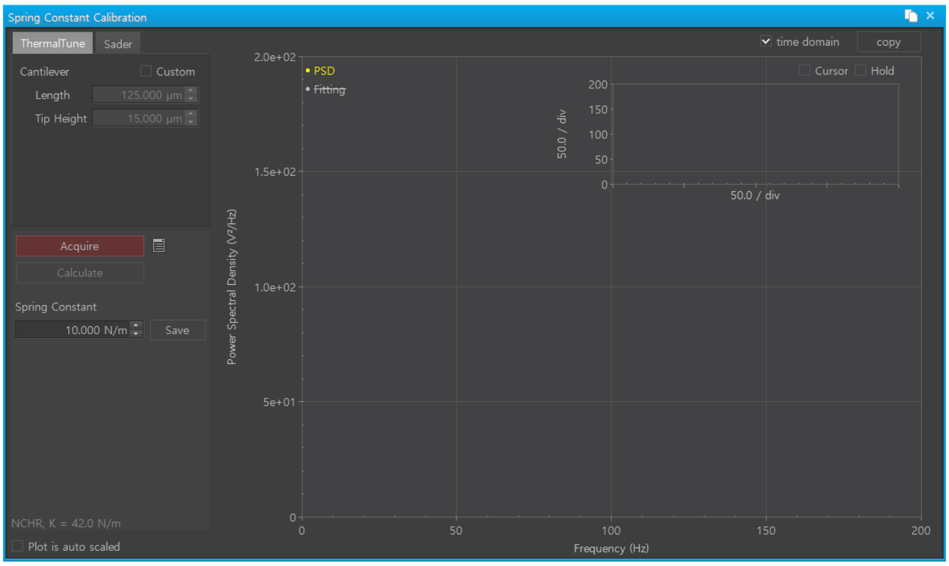
Sensitivity 0.001 V/μm

Figure 9-1-6. Cantilever Sensitivity Calibration window

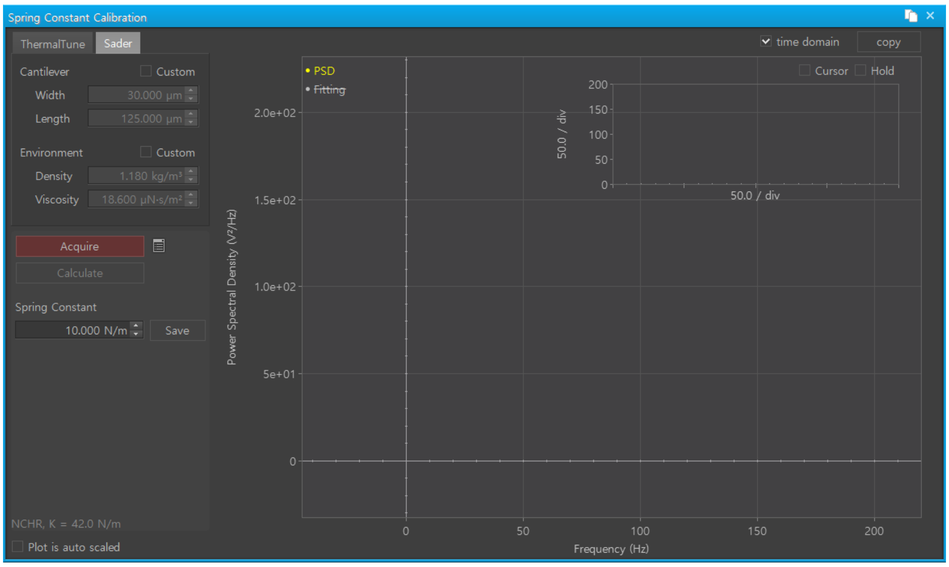
Cantilever Spring Constant

This option opens the Cantilever Spring Constant Calibration window. The Cantilever Spring Constant Calibration window is shown in Figure 9-1-7. To calculate the spring constant of a cantilever:

1. Change the cantilever file to the desired calibration file. This will load cantilever constants used to calculate the spring constant. For information on changing the cantilever file, refer to Section 7-3.
2. Install and align the laser on the cantilever.
3. Click **Acquire** to generate the power spectrum density of the thermal tune data. Clicking the **time domain** check box in the upper right corner will display the time domain of the spectrum in the upper right corner.
4. Click **Calculate** to calculate the spring constant, which will be shown in the box below.
5. Click **Save** to save the new spring constant to the cantilever file. The exact value saved to the cantilever file can be adjusted by changing the value in the Spring Constant field.



Length 125.000 µm
Tip Height 15.000 µm
Spring Constant 10.000 N/m
NCHR, K = 42.0 N/m
☐ Plot is auto scaled



Width 30.000 µm
Length 125.000 µm
Density 1.180 kg/m³
Viscosity 18.600 µN-s/m²
Spring Constant 10.000 N/m
NCHR, K = 42.0 N/m
☐ Plot is auto scaled

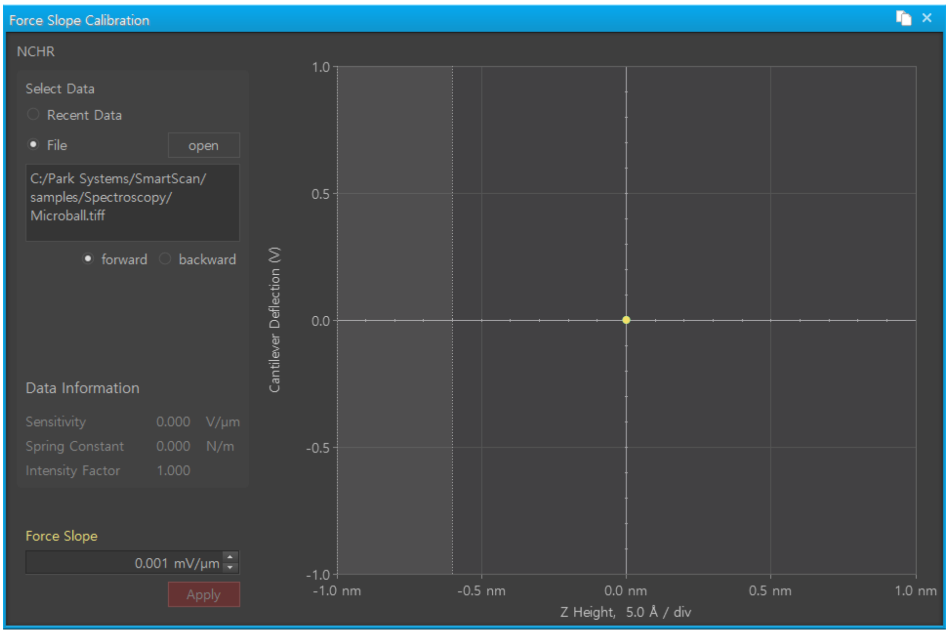
Figure 9-1-7. Cantilever Spring Constant Calibration window

Force Slope Correction

This option opens the Force Slope Correction window. The Force Slope Correction window is shown in Figure 9-1-8. The Force Slope Correction feature corrects the baseline of the F/d curve. When the F/d baseline is sloped, the curve can be corrected using the slope correction. Clicking **Apply** will correct the slope of the data by the value shown in the **Deflection Slope Correction** field.

1. Measure the force/distance curve without approach.

2. Calculate the slope by dragging the sides of the plot bar. The slope is automatically calculated when dragging the bar.
3. Enter the slope calibration in the text box, and then click **Apply**.
4. The value is uploaded to the database (V/μm) and saved in the DSP. The correction is applied when the **Enable** check box is chosen in F/d Measurement Parameters.



C:/Park Systems/SmartScan/samples/Spectroscopy/Microball.tiff

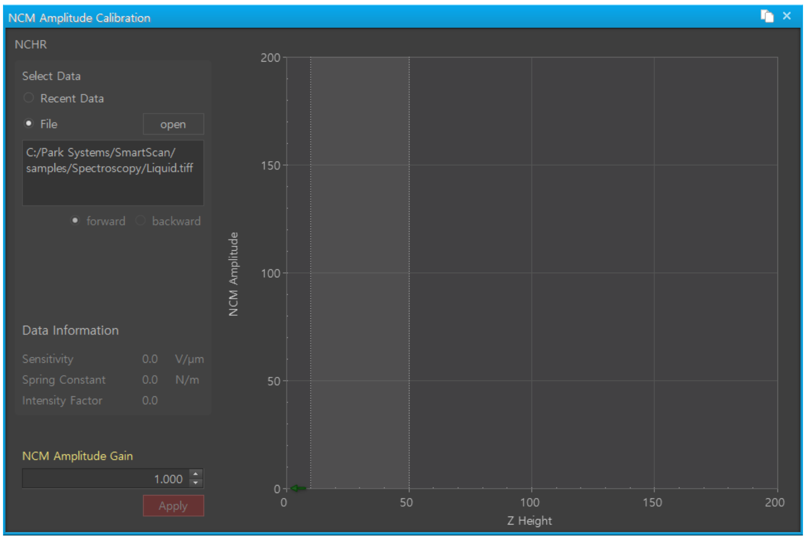
Sensitivity	0.000	V/μm
Spring Constant	0.000	N/m
Intensity Factor	1.000	

Force Slope: 0.001 mV/μm

Figure 9-1-8. Force Slope Calibration window

NCM Amplitude

This option opens the NCM Amplitude Calibration window. To activate the **NCM Amplitude** menu selection, SmartScan must be set to a non-contact-based scanning mode and **A/d Spectroscopy** must be selected. The NCM Amplitude Calibration window is shown in Figure 9-1-9.



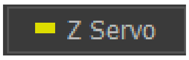
○ Recent Data
● File
C:/Park Systems/SmartScan/samples/Spectroscopy/Liquid.tiff
● forward ○ backward

Sensitivity	0.0	V/μm
Spring Constant	0.0	N/m
Intensity Factor	0.0	

NCM Amplitude Gain: 1.000

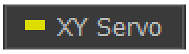
Figure 9-1-9. NCM Amplitude Calibration window

9-1-5. Z Servo



Clicking this button opens the Z Servo Configuration dialog. For more information, see Section 8-4-10.

9-1-6. XY Servo



Clicking this button opens XY Servo Configuration dialog. For more information, see Section 8-4-11.

9-2. Spectroscopy Positions View

You can select the points from the Spectroscopy Positions View to indicate where you want to obtain spectroscopy data within the scan area.

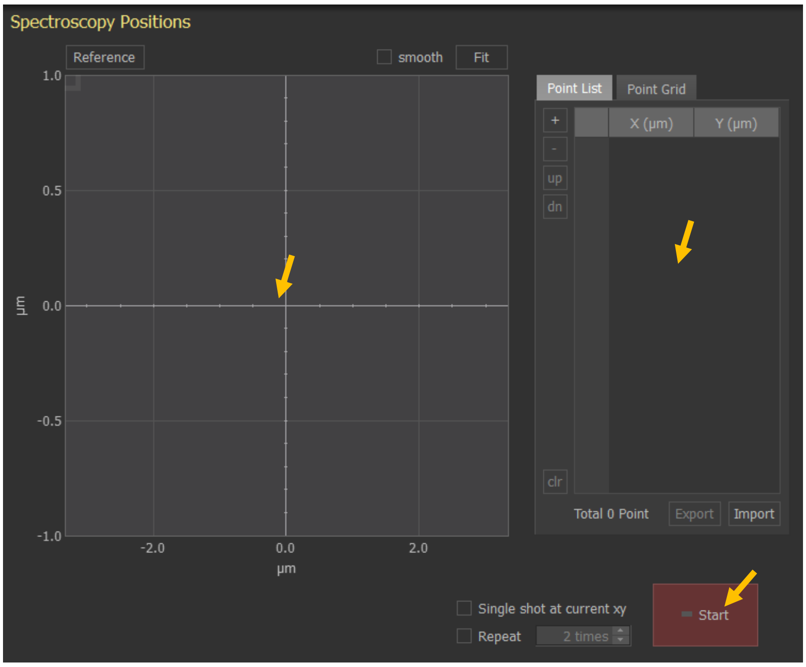


Figure 9-2-1. Spectroscopy Positions

9-2-1. Reference and Point List

The Reference window displays the last image acquired. This image can be used as a reference to determine the desired points for measurement.

Adding a point

Measurement points can be added by left-clicking on the refrence at the desired location. This will create a single numbered point on the reference. Subsequent clicks will add points to the reference. XY coordinates of the added points will be displayed on the Point List. Additional points can also be added by clicking on the **+** button next to the Point List. New points can be inserted between two existing measuring points by clicking on the line between the two points in the reference.

Moving a point

Measurement points can be moved by clicking and dragging the numbered point on the reference or by changing the coordinate values in the Point List.

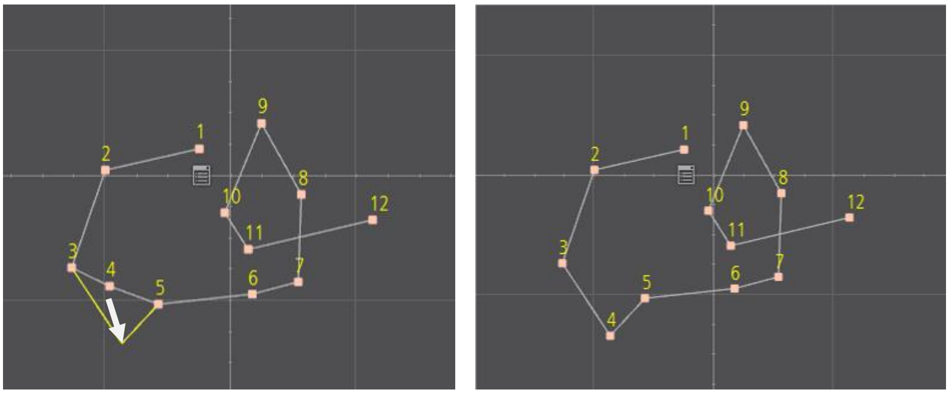


Figure 9-2-2. Moving a spectroscopy point. Left: original position and movement direction; right: final position after move.

Deleting a point

Measurement points can be deleted by highlighting the point on the Point List and clicking the **–** button.

Changing Measurement Order

The spectroscopy will be measured in ascending order starting from 1. To change the order, click the point on the Point List to hightlight the point and use the **up** or **dn** button to move the point up or down on the Point List.

Moving All Spectroscopy Points

To move the entire Point List as a whole, hover above the border surrounding the points. Once the cursor changes to the **Move** tool, click on the border and drag the spectroscopy points box to the new location.

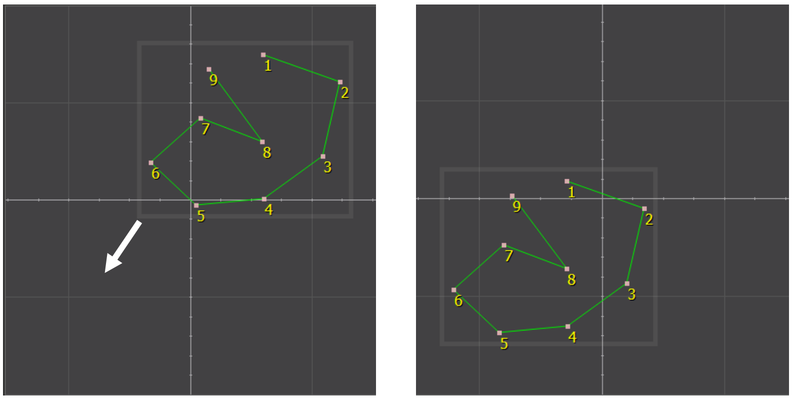
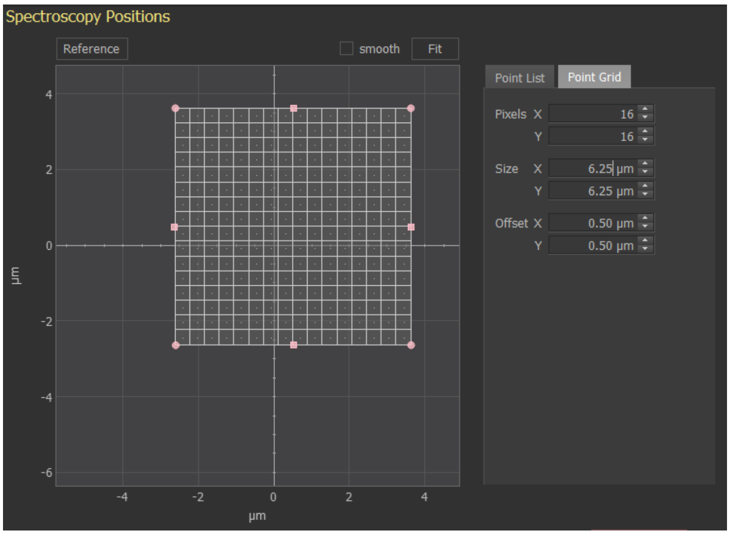


Figure 9-2-3. Moving all spectroscopy points. Left: original position and movement direction; right: final position after move.

9-2-2. Point Grid

After selecting Point Grid Spectroscopy Positions View, a white grid with pink dots will appear in Reference area. The white box indicates the grid size. Depending on the selected grid pixels, the box is divided. The measurement points will be automatically selected on all the center points of each divided small box. When you click **Start**, the spectroscopy measurements will be acquired, starting from the left bottom corner, using the parameters in parameters control panel. For example, when the grid size is 4x4, 16 measurements are acquired following the order below.

Grid points, size, and offset can be changed under the **Point Grid** tab. Size and offset can be changed visually in the Reference View. The size of the grid box can be changed by clicking and dragging any of the pink dots on the grid box. The offset can be adjusted by clicking and dragging the entire grid box once the hand cursor is visible.



Pixels X 16
Y 16
Size X 6.25 µm
Y 6.25 µm
Offset X 0.50 µm
Y 0.50 µm

Figure 9-2-4. Point grid setup and grid box

9-2-3. Single Shot at Current xy

When the **Single shot** box is checked, a single spectroscopy curve will be performed at the current tip (XY) position when **Start** button is clicked. Point List and Point Grid information is ignored.

9-2-4. Repeat

This option repeats the spectroscopy curves the number of times indicated. Values between 2 and 100 can be entered.

9-2-5. Start

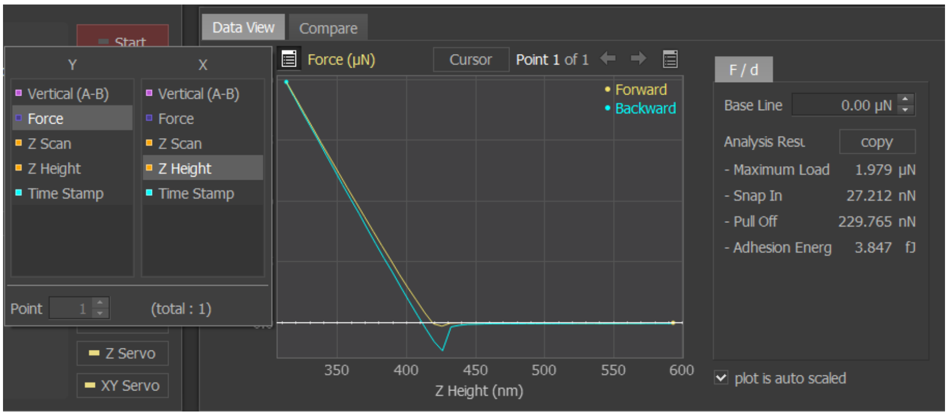
Spectroscopy measurements will be acquired in numerical order using the parameters in the parameters control panel. This procedure produces a) a single spectroscopy curve (Single shot), b) a collection of curves (Point List), or c) a 2-D grid of curves (Point Grid).

9-3. Data View

The **Data View** displays the acquired spectroscopy data. Figure 9-3-1 shows the Data View. For the F/d spectroscopy curve, analysis results are listed to the right of the plot.

9-3-1. Axis Menu

Choose the **Compare** tab to compare data from different point curves.



Point 1 (total : 1)

Point 1 of 1

Base Line 0.00 µN

Analysis Resu

- Maximum Load 1.979 µN
- Snap In 27.212 nN
- Pull Off 229.765 nN
- Adhesion Energ 3.847 fJ

Figure 9-3-1. Data View Axis menu

9-3-2. Cursor

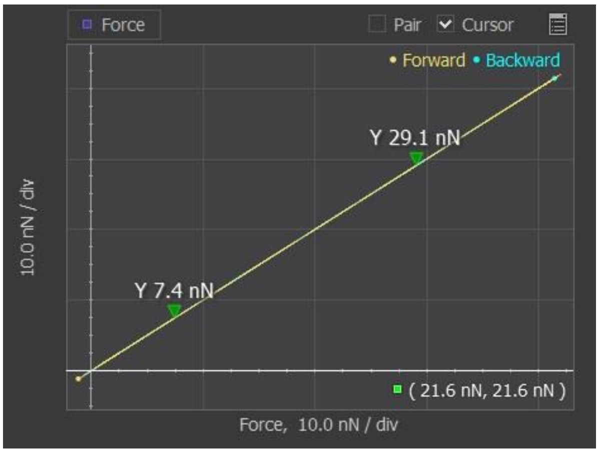
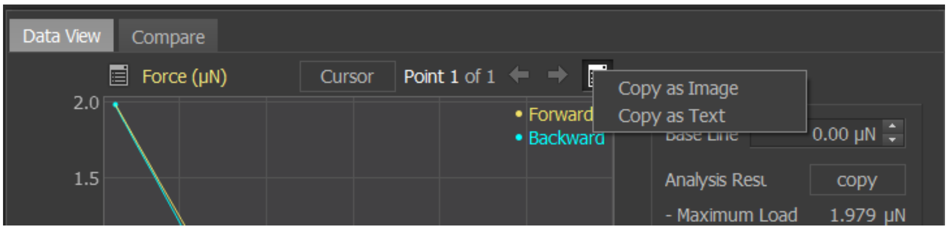


Figure 9-3-2. Single cursor example

9-3-3. Copy Menu



Point 1 of 1

0.00 µN

Analysis Resu

- Maximum Load 1.979 µN

Figure 9-3-3. Copy menu pop-up box

9-4. Spectroscopy Data List View

As shown in Figure below, the Spectroscopy Data List View is an oscilloscope window that can be used to display selected input and output signals immediately after spectroscopy measurement. Following spectroscopy measurement, the signals will be updated immediately. To check the results already obtained during the measurement, click the desired point.

The Spectroscopy Data List View can display up to three graphs on the same screen.

9-4-1. Rescale

This control rescales all plots simultaneously so that curve data fits on the oscilloscope screen. Double-clicking on each plot automatically rescales the display. The scale can also be controlled manually using the mouse wheel. The vertical axis on the screen may be rescaled accordingly.

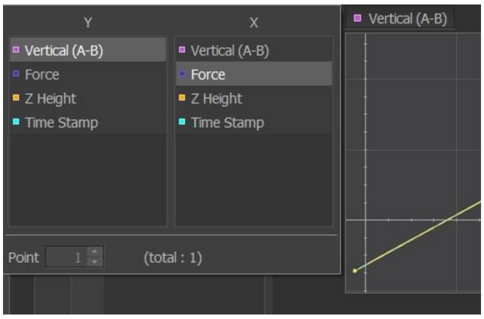
9-4-2. Relocate

Relocate each plot by clicking and dragging it after clicking this icon.

9-4-3. Axis Menu

This control is used to set the X and Y axis of spectroscopy data. The **Axis** menu is located on the left side of the plot. Clicking this button opens a drop-down menu to choose the signals displayed for X and Y. The drop-down menu for the Spectroscopy Data List is shown in Figure 9-4-1.

Highlight the desired signals to be displayed in X and Y. If multiple points are taken during a measurement cycle, specific points can be displayed by changing the point number in the **Point** field at the bottom of the menu.



Point 1 (total : 1)

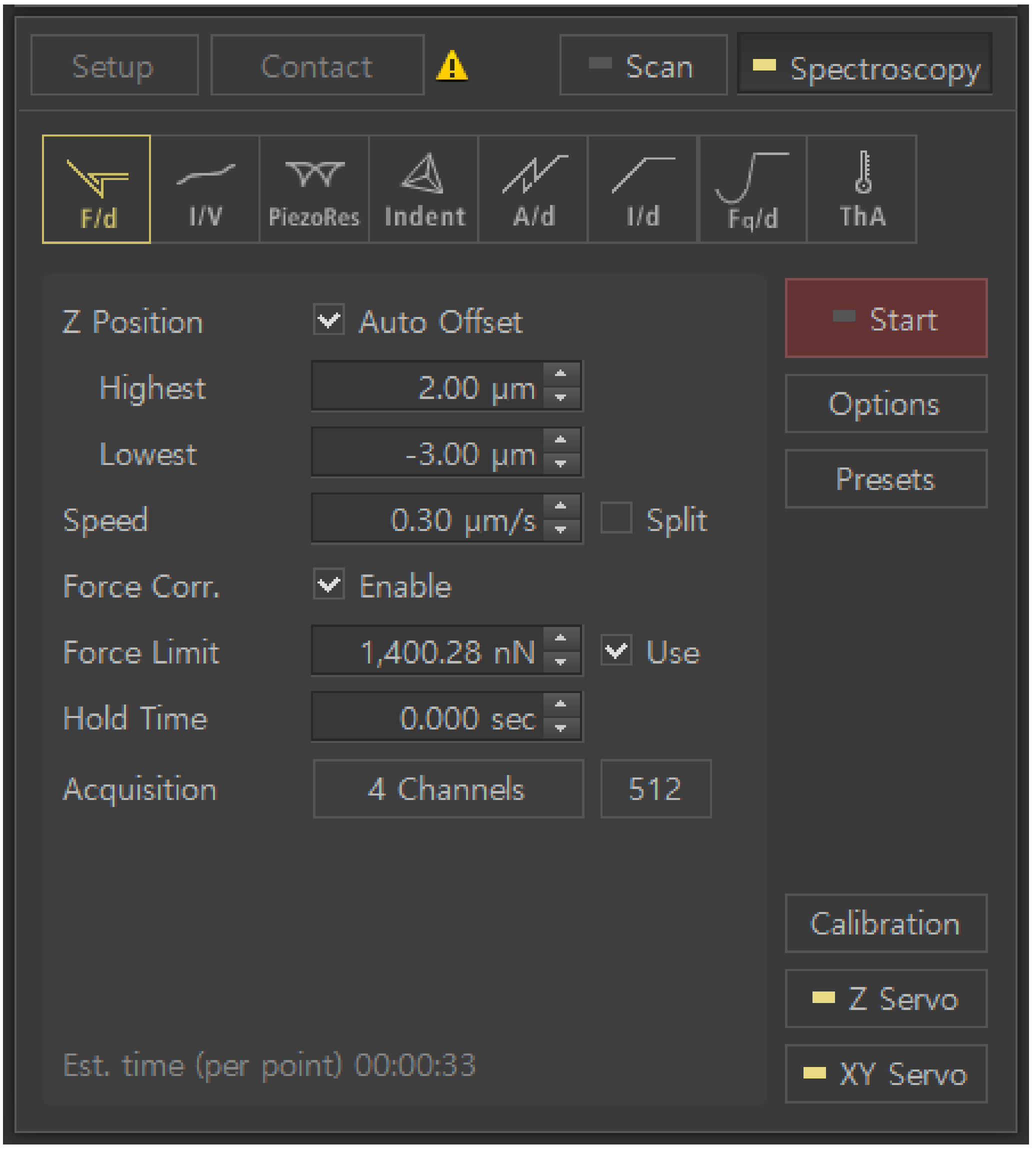
Figure 9-4-1. Spectroscopy data axis

9-4-4. Copy Menu (Right)

Clicking this opens the **Copy** menu. The **Copy** menu is located on the right side of the Spectroscopy plot. The copy choices are **Copy to Image** or **Copy to Text**.

9-5. F/d Spectroscopy

Force distance spectroscopy measures the force (deflection of the the cantilever) as the tip is brought toward and away from the surface. The F/d parameters in the Spectoscopy Parameter View can be found in Table 9-1.



Z Position ☑ Auto Offset
Highest 2.00 µm
Lowest -3.00 µm
Speed 0.30 µm/s ☐ Split
Force Corr. ☑ Enable
Force Limit 1,400.28 nN ☑ Use
Hold Time 0.000 sec
Acquisition 4 Channels 512
Est. time (per point) 00:00:33

Figure 9-5-1. F/d spectroscopy parameters

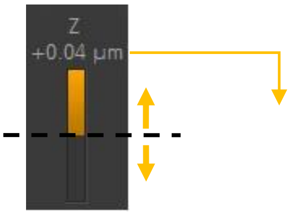
Table 9-1. Controls in F/d spectroscopy mode

Controls	Function
Z/Highest	Z scanner retracts (away from the sample) to the max value distance from the offset position. Input range is [(-1/2~1/2) x Z scanner's maximum movement range] when **Z Offset** turns on and [(-1~+1) x Z scanner maximum movement range] when **Z Offset** turns off.
Z/Lowest	Z scanner extends (towards the sample) until it reaches the min value distance from the offset position. Input range is [(-1/2~1/2) x scanner's maximum movement range] when **Z Offset** turns on and [(-1~+1) x scanner maximum movement range] when **Z Offset** turns off.
Z/Offset	When **Auto Offset** is unchecked, the **Offset** box is shown. This is the starting value of the Z scanner for an F/d curve (see Auto Offset, below).
Auto Offset	When **Auto Offset** is checked, the offset position is determined by the set point value in the Scan Control window.
Speed	Speed of Z scanner extension and retraction
Split	When the **Split** box is checked, the speed of the retraction (up) and extension (down) of the scanner can be controlled independently.
Down Speed	Speed of Z scanner extension
Up Speed	Speed of Z scanner retraction
Force Corr	The force correction applied to the F/d curve
Force Limit	When the force applied to the cantilever exceeds the force limit, the Z scanner does not extend any farther. To protect the tip, lower the force limit.
Use	When **Use** is checked, the allowable maximum force (force limit **Force Corr**) is determined by the value in the text box to the left.
Hold Time	Amount of time that the voltage is held at the start voltage value per cycle.

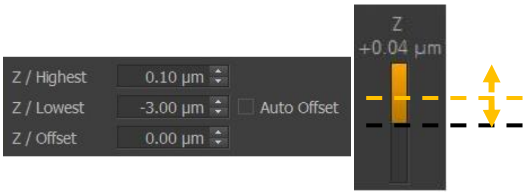
Channels	Opens the Channel Config dialog. The number of channels acquired during the F/d curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.

When setting the F/d input range, the **Min** value must be smaller than **Max** value. If not, the system will ask you to swap the values.

- **Auto Offset**
  - **Auto Offset On**: Z scanner moves from the highest to the lowest position using the current Z scanner position (by the Z servo) as the reference position. For example, in the figure below, the current Z scanner position to maintain the SetPoint value is 0.04µm. When setting the Travel range to +1um~-1um, this value will be used as the 0 value, or starting point, and the Z scanner will travel from +1.04µm to -0.96µm.

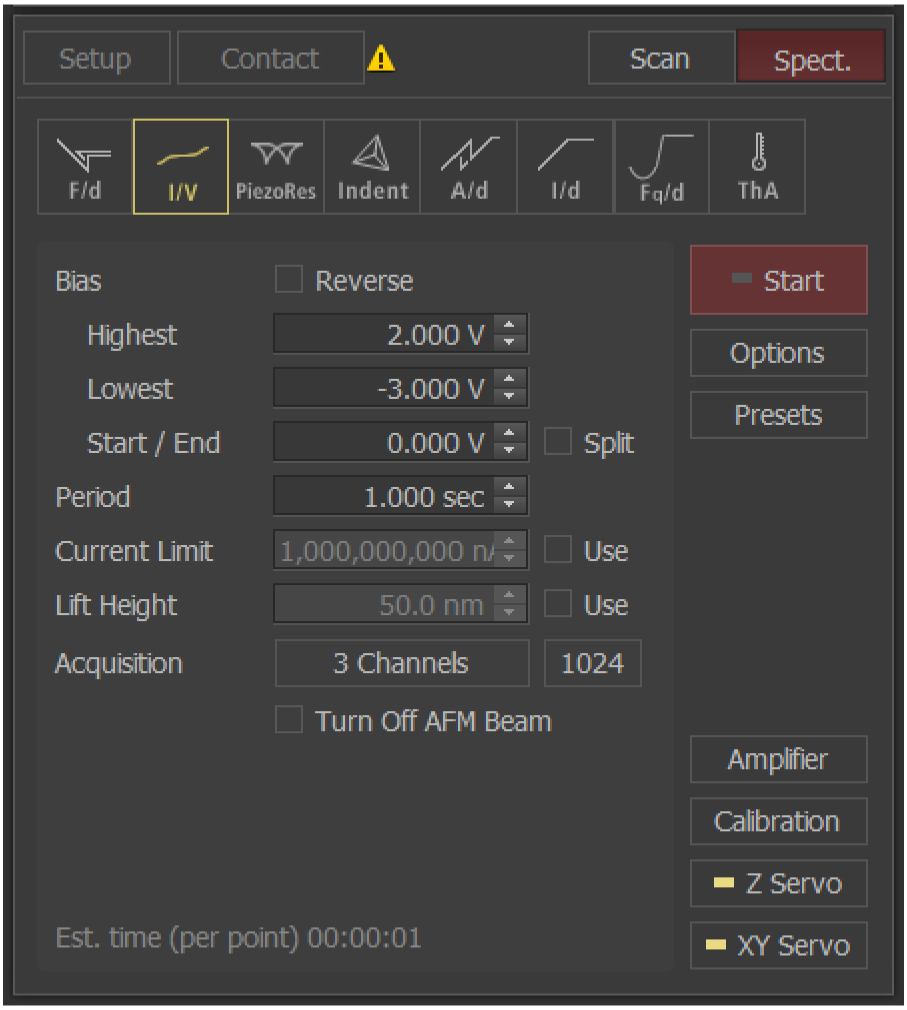


  - **Auto Offset Off:** Z scanner moves from the highest to the lowest position using the value in the **Offset** field as the reference position or starting position. For example, in the figure below, the offset value is 1µm. This value will be used as the 0 value, or starting point, and the Z scanner will travel from 2µm to 0µm.


Z / Highest 0.10 µm
Z / Lowest -3.00 µm ☐ Auto Offset
Z / Offset 0.00 µm

9-6. I/V Spectroscopy

Table 9-2, shown below, lists each control in the Spectroscopy control window with a brief description of its function.



Bias ☐ Reverse

Highest 2.000 V

Lowest -3.000 V

Start / End 0.000 V ☐ Split

Period 1.000 sec

Current Limit 1,000,000,000 n ☐ Use

Lift Height 50.0 nm ☐ Use

Acquisition 3 Channels 1024

☐ Turn Off AFM Beam

Est. time (per point) 00:00:01

Figure 9-6-1. I/V Spectroscopy parameters

Table 9-2. Controls in I/V spectroscopy mode

Controls	Function
Reverse	When **Reverse** is selected, the sample bias is applied in this order: Start-> Highest-> Lowest->End.
Highest	Highest sample bias value in acquiring an I/V curve
Lowest	Lowest sample bias value in acquiring an I/V curve
Start	Start sample bias in an I/V curve
End	End sample bias in an I/V curve
Period	Time elapsed while changing the sample bias to acquire an I/V curve
Hold Time	Amount of time that the voltage is held at the start voltage value per cycle.
Current Limit	Maximum current limit. If the current reaches this limit, the sample bias will no longer be applied.
Use	When **Use** is checked, the allowable maximum current (current limit) is determined by the value in the text box to the left.
Lift Height	The function of Bias Sweep at a certain height on the sample in I/V Spectroscopy mode.
Channels	Opens the Channel Config dialog. The number of channels acquired during the I/V curve measurement is displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Turn Off AFM Beam	The laser beam is turned off in I/V spectroscopy if this option is checked. It may be useful if the laser beam affects the sample.

9-7. Piezo Res Spectroscopy

Table 9-3, shown below, lists each control in the Piezo Res Spectroscopy control window with a brief description of its function.

- **Linear**

Same as the existing Piezo Response Spectroscopy.

Sweep Start → Highest → Lowest → End to Linear.

As shown in the figure left above, change Sample Bias to 0V → +6V → -6V → 0V over time.

- **Pulse**

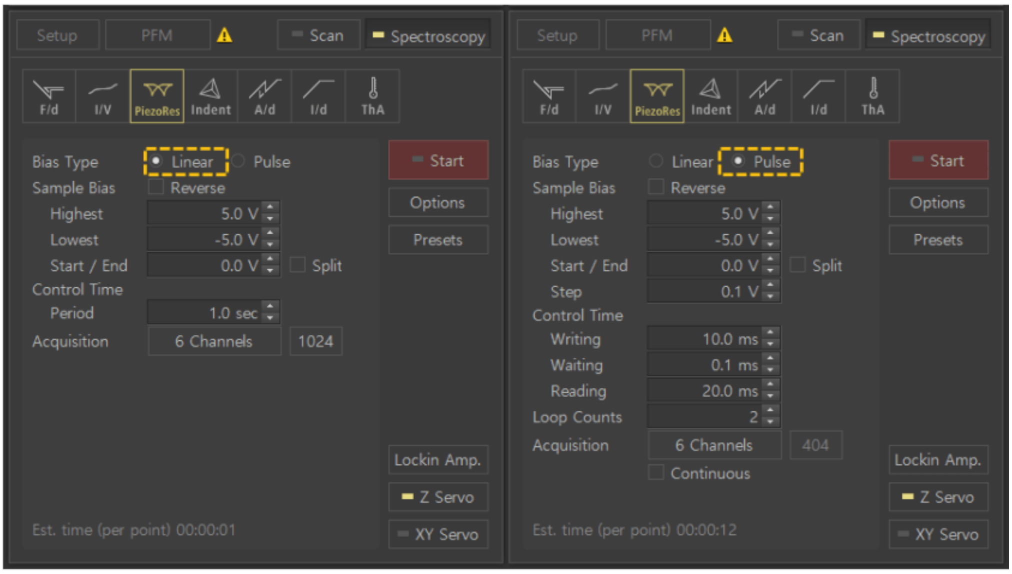
This mode is used to apply Sample Bias in the form of Pulse.

Repeat Start → Highest → Lowest → End by Step to keep it.

As shown in the figure to the right above, Sample Bias is 0V → 0.5V → 0V → 1V → 1.5V → ... → Change the form of -0.5V → 0V pulse.

One pulse is implemented in three different times (Writing, Waiting, Reading) as shown below.

Apply voltage as much as Writing time → Change voltage to 0V (ground) and wait for Waiting time → Data Acquisition during Reading time.



Bias Type ● Linear ○ Pulse
Sample Bias ☐ Reverse
Highest 5.0 V
Lowest -5.0 V
Start / End 0.0 V ☐ Split
Control Time
Period 1.0 sec
Acquisition 6 Channels 1024
Est. time (per point) 00:00:01

Bias Type ○ Linear ● Pulse
Sample Bias ☐ Reverse
Highest 5.0 V
Lowest -5.0 V
Start / End 0.0 V ☐ Split
Step 0.1 V
Control Time
Writing 10.0 ms
Waiting 0.1 ms
Reading 20.0 ms
Loop Counts 2
Acquisition 6 Channels 404
☐ Continuous
Est. time (per point) 00:00:12

Figure 9-7-1. Piezo Res Spectroscopy parameters

Table 9-3. Controls in Piezo Res spectroscopy mode

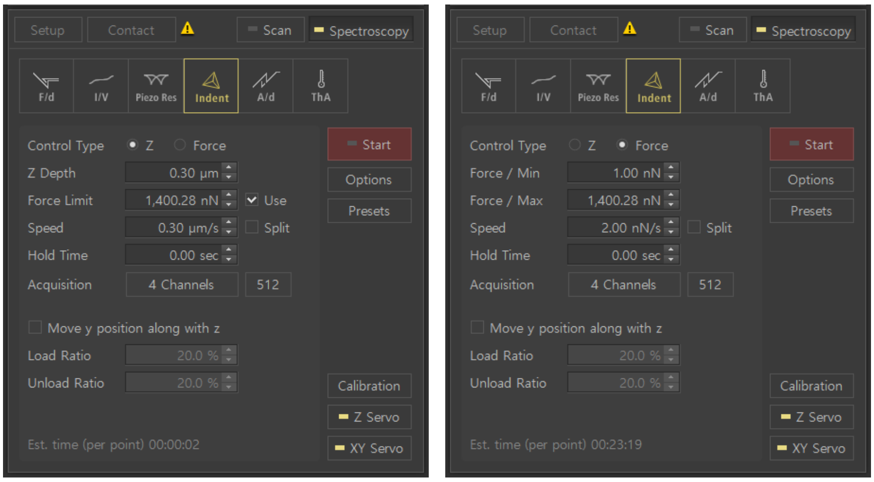
Controls	Function
Reverse	When **Reverse** is selected, the sample bias is applied in this order: Start->Highest->Lowest->End.
Highest	Highest sample bias value in acquiring an PE curve
Lowest	Lowest sample bias value in acquiring an PE curve
Start	Start sample bias in an PE curve
End	End sample bias in an PE curve
Step (for Pulse)	Width of changing voltage.
Writing	Time to apply voltage.
Waiting	Wait time after changing voltage to 0 volts.
Reading	Time to Acquisition Data.
Loop Counts	Repetition Count of Sample Bias Sweep.
Continuous	Option to cause Data Acquisition to continue without Discrete. (Sample Bias graphs in Pulse form can be checked.)
Period	Time elapsed while changing the sample bias to acquire an PE curve
Hold Time	Amount of time that the voltage is held at the start voltage value per cycle.
Current Limit	Maximum current limit. If the current reaches this limit, the sample bias will no longer be applied.
Use	When **Use** is checked, the allowable maximum current (current limit) is determined by the value in the text box to the left.
Channels	Opens the Channel Config dialog. The number of channels acquired during the PE curve measurement is displayed on the channel acquisition

	button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Turn Off AFM Beam	The laser beam is turned off in Piezo Res spectroscopy if this option is checked. It may be useful if the laser beam affects the sample.

9-8. Indent

Nano-Indentation has two sub-modes: Z scanner mode and force mode. Each sub-mode uses different parameters to control the indentation cycle. In force mode, the force (load) between the tip and sample is varied as a linear function of time while the corresponding position of the Z scanner is measured. In Z scanner mode, the Z scanner position is varied as a linear function of time while the corresponding load applied to the tip is measured.

Select set point mode by clicking the **Force** radio button. Click the Z radio button to select Z scanner mode.



Control Type ● Z ○ Force
Z Depth 0.30 µm
Force Limit 1,400.28 nN ☑ Use
Speed 0.30 µm/s ☐ Split
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:00:02

Control Type ○ Z ● Force
Force / Min 1.00 nN
Force / Max 1,400.28 nN
Speed 2.00 nN/s ☐ Split
Hold Time 0.00 sec
Acquisition 4 Channels 512
☐ Move y position along with z
Load Ratio 20.0 %
Unload Ratio 20.0 %
Est. time (per point) 00:23:19

Figure 9-8-1. Indent control window

Parameters related to controlling the measurement process for nano-indentation can be changed from the **Indent** tab.

Table 9-4. Controls in nano-indentation mode

Controls	Function
Z or Force	When the **Z** radio button is checked, nano-indentation is performed in Z scanner mode. When the **Force** radio button is checked, nano-indentation is performed in set point mode.
<u>Z Scanner Mode</u>	
Z Depth	The Z scanner extends (toward the sample) until it reaches the load depth value distance. The distance is calculated from the offset position. It is activated in Z scanner mode.
Force Limit	Once at the force limit, the Z scanner does not extend any further. To protect the tip, lower the force limit.
Use	When **Use** is checked, the force is applied to the cantilever until it reaches the force limit.
<u>Force Mode</u>	
Force Min	Minimum force value applied to the tip in set point mode
Force Max	Maximum force applied to the tip in set point mode
Speed	Speed of Z scanner extension/retraction
Split	When **Split** is checked, speed of scanner retraction (up) and extension (down) can be controlled independently.
Speed/Load	Speed of Z scanner extension
Speed/Unload	Speed of Z scanner retraction
Hold time	Amount of the time the indenter is held at the load depth position before it is lifted
Channels	Opens Channel Config dialog. The number of channels acquired during the indentation curve measurement is

	displayed on the channel acquisition button.
Pixels	Opens the **Pixel** drop-down menu, where you can select the number of pixels in each approach or retract curve. The selected pixel number is displayed on the pixel acquisition button.
Move Y position along with Z	When this option is checked, Y scanner movement compensation will be used to adjust the Y movement relative to the Z movement in the indentation process.
Load/Unload Ratio	Ratio between movement of Z scanner and Y scanner. This is activated when the **Move Y position along with z** box is checked. Positive values for the **Load/Unload Ratio** refer to the case where the movements of the Z scanner and Y scanner are the same. Movement of the Z scanner is always in the negative direction (extension) for **Load** and positive direction for **Unload**. Y scanner movement in a positive direction is referred to as “bottom to top,” while Z scanner movement in a positive direction is referred to as the “retraction in Z.” The allowable input range is -100.0~ +100.0%.

9-8-1. Moving the Y Scanner During Indentation

Normally, the cantilever will not be able to approach the sample top-down with zero degree cantilever tilt because an AFM cantilever has certain degree of tilt. Furthermore, it is possible for the tip to slip laterally as the indenter tip pushes down the sample. (Refer to Figure 9-8-2).

To prevent this problem, the Y scanner can be moved or adjusted to compensate for Z scanner extension. This feature is activated when the **Y Travel Ratio** button is selected.

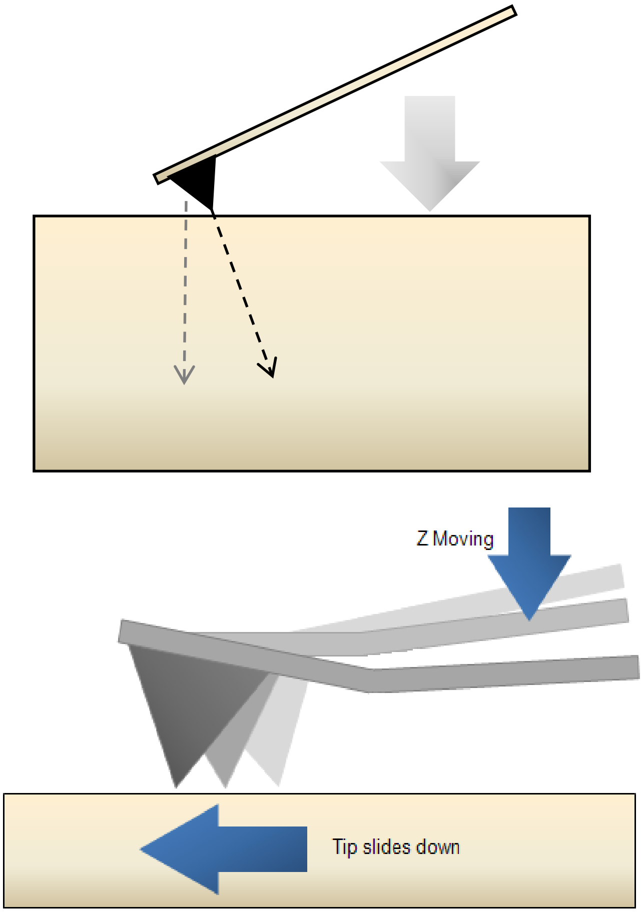
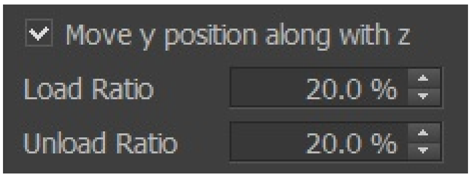


Figure 9-8-2. Scanner movement during indentation

Related options can be activated as shown in figure below.



Load Ratio 20.0 %

Unload Ratio 20.0 %

Figure 9-8-3. Load/Unload ratio control

In Figure 9-8-3, the values displayed in the Load Ratio and Unload Ratio specify the ratio between the movement of the Z scanner and the Y scanner. Inserting positive values will cause the Y scanner and Z scanner to adjust in the same direction. Inserting negative values will cause the Y scanner and Z scanner to adjust in opposite directions.

In Figure 9-8-4, when the Y scanner adjusts in the +Y direction, it adjusts in the positive direction, and vice versa. If the Z scanner shrinks, it will adjust in the positive direction, and vice versa.

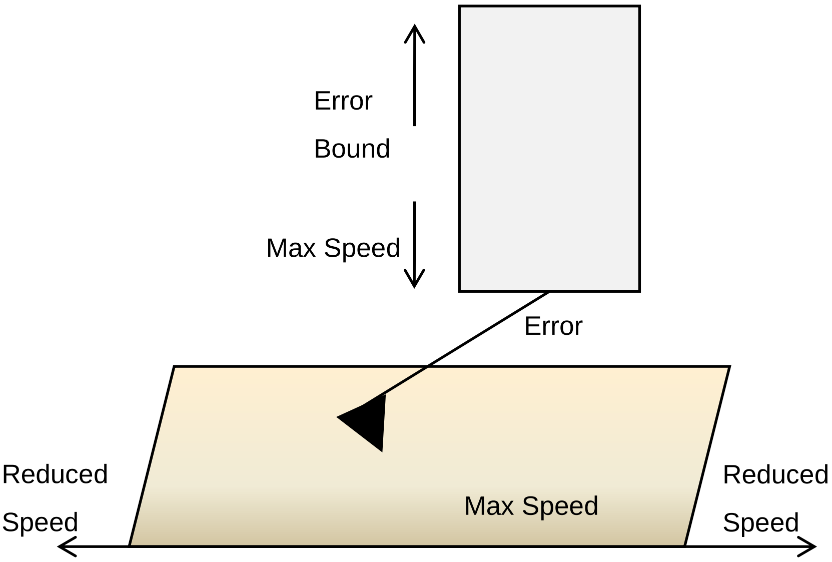
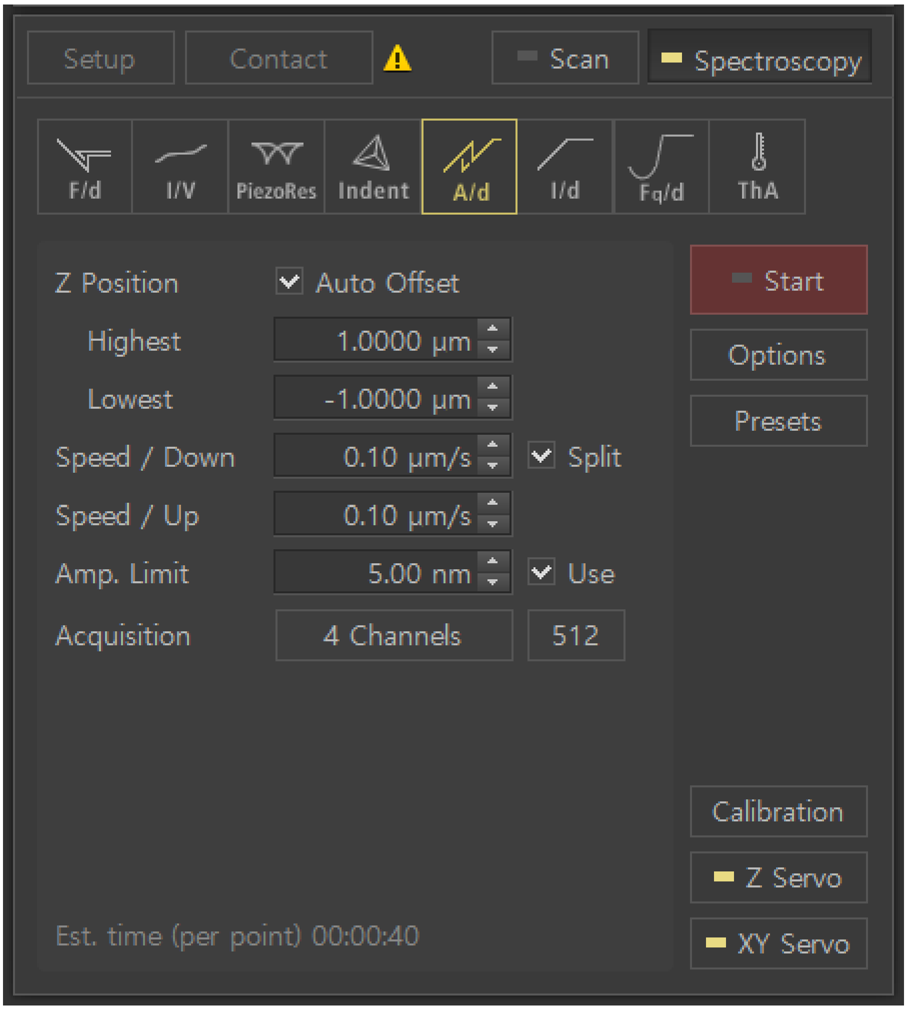


Figure 9-8-4. Scanner direction

For example, when entering a loading value of 100%, as the Z scanner adjusts in the –Z direction with a certain distance, the Y scanner will adjust in the –Y direction with the same distance. When entering a loading value of -100%, as the Z scanner adjusts in the –Z direction with a certain distance, the Y scanner will adjust in the +Y direction with the same distance. For example, to improve angle of the tip (13°), it is recommended to enter a **Loading/Unloading** value of -Tan(13°) x 100 ~ -23%.

9-9. A/d Spectroscopy

In A/d(amplitude distance spectroscopy) spectroscopy, the cantilever is oscillated at a constant frequency and amplitude. As the scanner is extended and the cantilever approaches the surface, the amplitude begins to decrease. This change in amplitude can be measured as a function of distance to the surface using A/d spectroscopy. Controls for A/d spectroscopy can be set so that the cantilever moves a specified distance or stops at a set amiplitude (amplitude limit).



Z Position ☑ Auto Offset
Highest 1.0000 µm
Lowest -1.0000 µm
Speed / Down 0.10 µm/s ☑ Split
Speed / Up 0.10 µm/s
Amp. Limit 5.00 nm ☑ Use
Acquisition 4 Channels 512
Est. time (per point) 00:00:40

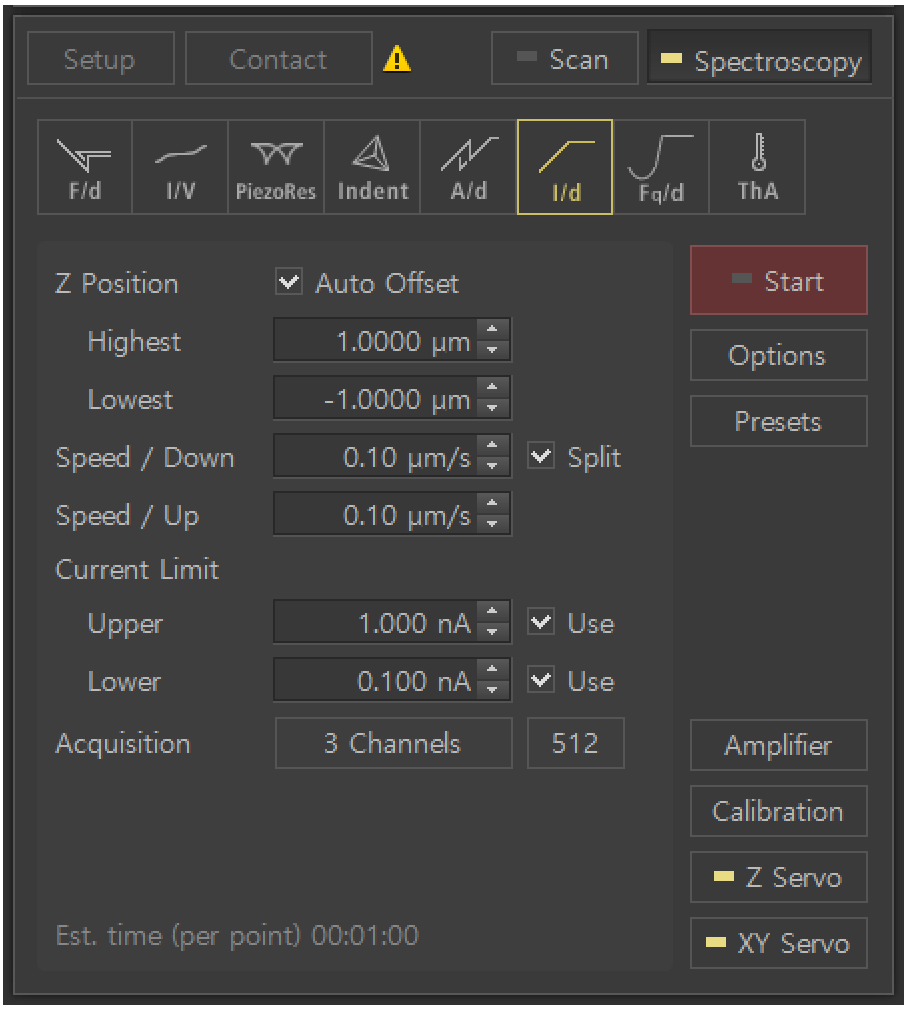
Figure 9-9-1. A/d spectroscopy control window

Table 9-5. Controls in A/d spectroscopy mode

Controls	Function
Z/Highest	The Z scanner retracts (away from the sample); the highest value that the Z scanner will be lifted away from the surface
Z/Lowest Z	The Z scanner extends (toward the sample); the lowest value that the scan will extend toward the surface
Auto Offset	Uses the relative Z position
Speed	Speed of Z scanner extension/retraction
Split	When the **Split** box is checked, the speed of the retraction (up) and extension (down) of the scanner can be controlled independently.
Down Speed	Speed of Z scanner extension
Up Speed	Speed of Z scanner retraction
Amp Limit	Amplitude at which the cantilever will stop
Use	When **Use** is checked, the system will use the amplitude limit

9-10. I/d Spectroscopy

Current Spectroscopy is a feature for measuring data on other channels as well as Force and NCM Amplitude channels for changing the position of the Z scanner. If the Auto Offset checkbox is checked, use the current location as the starting point for Z. When the check mark is removed, a box appears for entering Manual Offset. If you check the Split Checkbox, you can set a different Forward / Backward Sweep speed and, if not, maintain the same speed during the Sweep process.



Z Position ☑ Auto Offset

Highest 1.0000 µm

Lowest -1.0000 µm

Speed / Down 0.10 µm/s ☑ Split

Speed / Up 0.10 µm/s

Current Limit

Upper 1.000 nA ☑ Use

Lower 0.100 nA ☑ Use

Acquisition 3 Channels 512

Est. time (per point) 00:01:00

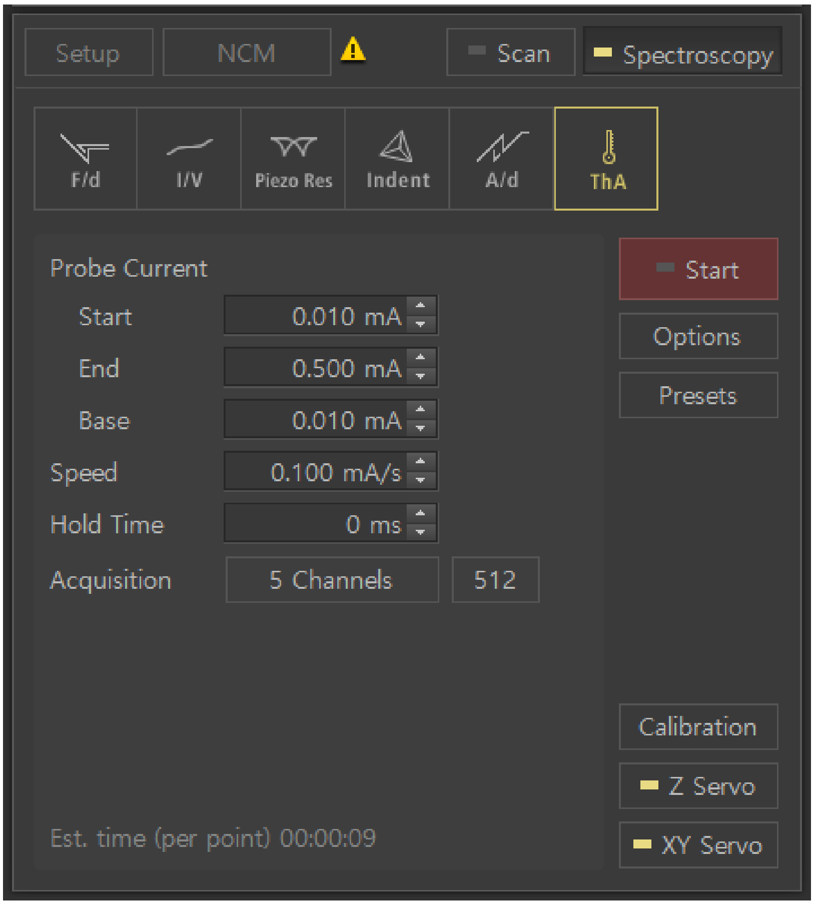
Figure 9-10-1. I/d spectroscopy control window

Table 9-6. Controls in ThA spectroscopy mode

Controls	Function
Z/Highest	The Z scanner retracts (away from the sample); the highest value that the Z scanner will be lifted away from the surface
Z/Lowest Z	The Z scanner extends (toward the sample); the lowest value that the scan will extend toward the surface
Auto Offset	Uses the relative Z position
Split	When the **Split** box is checked, the speed of the retraction (up) and extension (down) of the scanner can be controlled independently.
Down Speed	Speed of Z scanner extension
Up Speed	Speed of Z scanner retraction
Current Limit Upper	Maximum limit of current.
Current Limit Lower	Minimum limit of current.

9-11. ThA Spectroscopy

ThA (Thermal analysis) spectroscopy mode is used to control current through the nanothermal probe in SmartScan. It is a method to calibrate 'probe current vs. temp.' using a polymer sample that knows melting point. When current is transmitted to the nanothermal probe, melting of the known calibration sample can occur heating the probe tip, and change the probe’s deflection. The sample temperature measured by the probe can be calibrated in this way. ThA spectroscopy mode requires SThM hardware options. Figure 9-11-1 shows the ThA spectroscopy mode interface.



Probe Current
Start 0.010 mA
End 0.500 mA
Base 0.010 mA
Speed 0.100 mA/s
Hold Time 0 ms
Acquisition 5 Channels 512
Est. time (per point) 00:00:09

Figure 9-11-1. ThA spectroscopy control window

Table 9-7. Controls in ThA spectroscopy mode

Controls	Function
Start	Starting current of the temperature ramp (Min 0.01mA – Max 2.5mA)
End	Ending current of the temperature ramp (Min 0.01mA – Max 2.5mA)
Base	Base probe current before and after acquiring data
Speed	Speed of probe’s current sweep
Hold time	Amount of time that the current is held at the Start Probe Current
Channel Config	The Channel Config window allows choosing data channels to monitor and record while scanning (see Section 6-2-4. Channels).
Data Count	Number of points for acquiring data. The number of points can be changed by clicking the indicator button and choosing the points desired.
Controls	**Function**
Calibration	Opens the Calibration pop-up menu. In this mode, you can adjust the SThM parameters by selecting SThM reference (see Figure. 9-10-1 SThM Reference Calibration)
SThM Reference	
Offset:Temperature	Temperature inside the acoustic enclosure
Offset: SThM Error	SThM error (V) value when the probe current is 0mA
Ref: Temperature	Standard sample’s melting temperature for calibration
Ref: SThM Error	SThM error (V) value when the standard sample starts to melt
Ref: Current	Probe current (mA) value when the standard sample starts to melt

Chapter 10. Program Mode

Program Mode is useful when repeating same scanning over the predefined XY Stage coordinate. User can define some ratio to make adjacent scan image could be overlapped, which maybe useful for custom post-processing of data set.

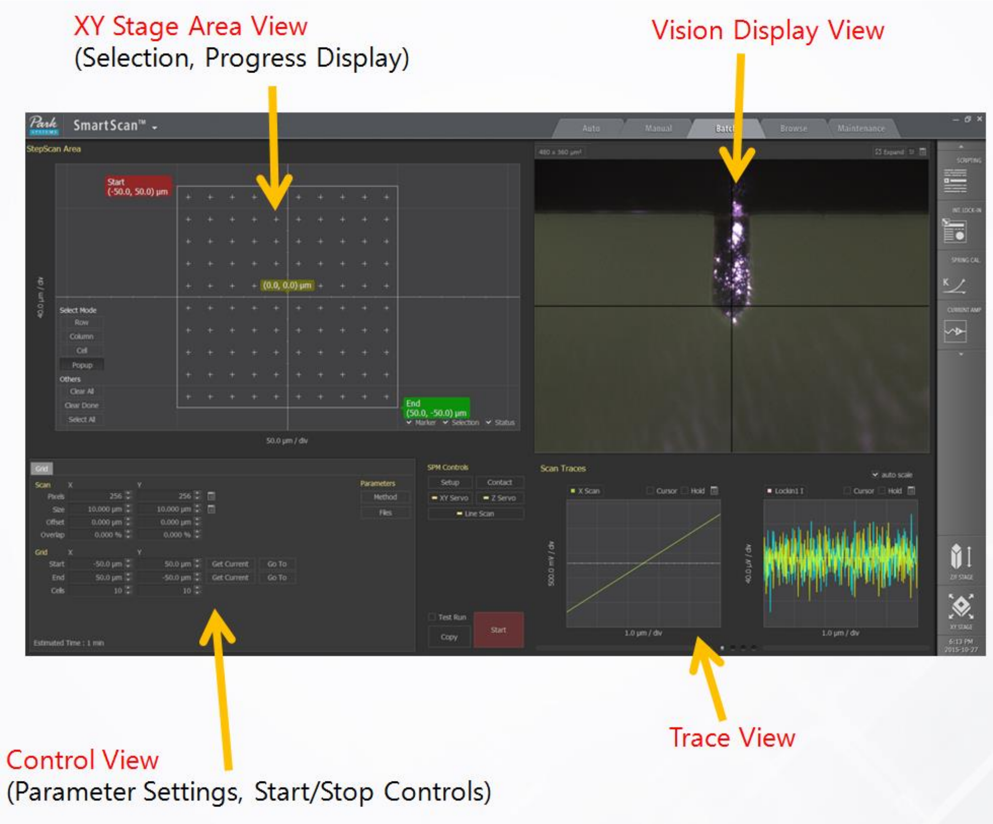


Figure 10-1-1. Program Mode workspace

10-1. XY Stage Area View

The Directories and Files View is composed of three general areas: a) File Systems, b) Current Directory, and c) Thumbnails.

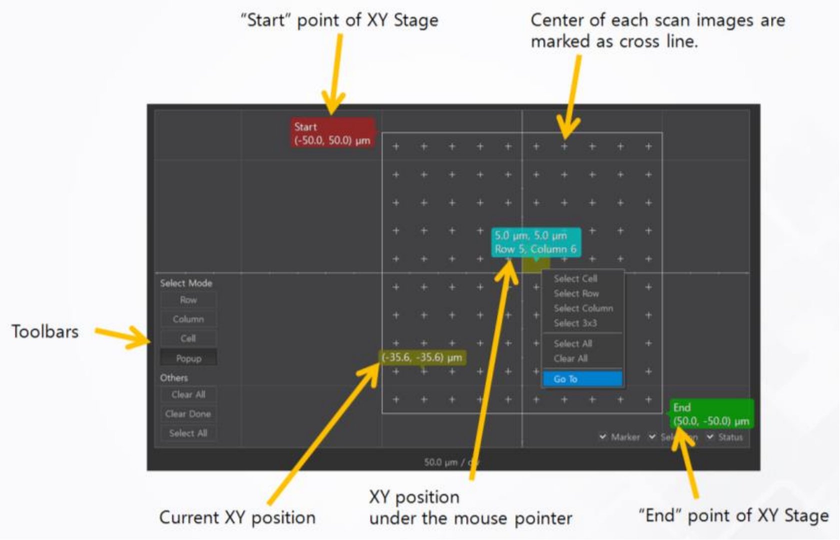


Figure 10-1-2. XY Stage View workspace

10-1-1. Select Mode

Column

Only the Selected cell will be scanned.

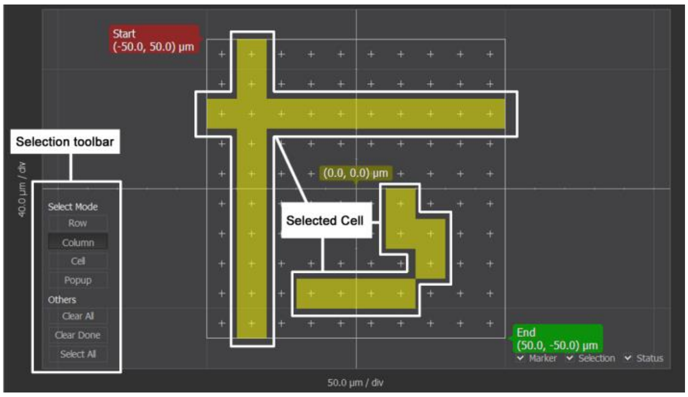


Figure 10-1-3. Column mode

Selection will be checked by clicking mouse button and selection behavior

(Row, Column, Cell) could be chosen from Selection toolbar.

Cell

Only the Selected cell will be scanned.

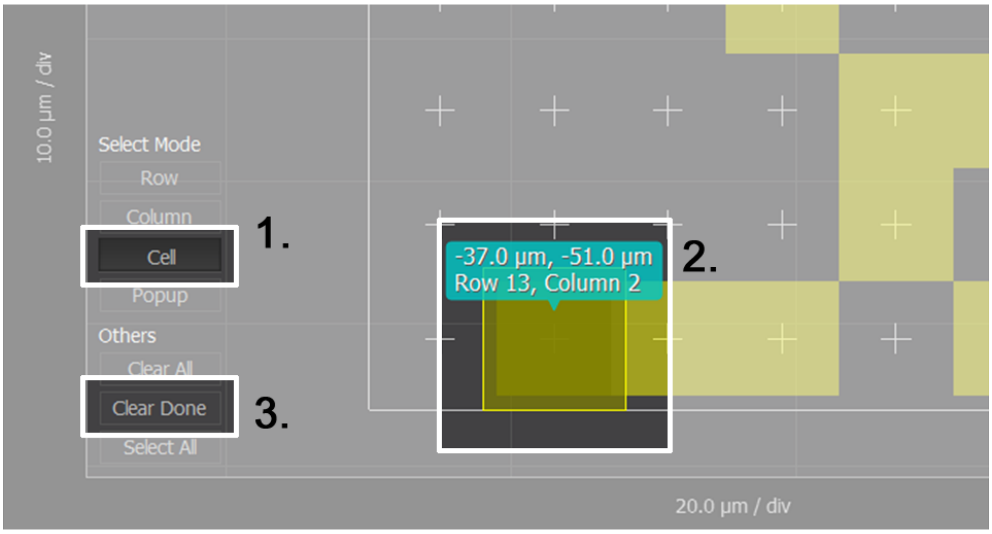


Figure 10-1-4. Cell mode

Overlapped area is rendered as semi-transparent way. If scanning is finished, cell will be turned as 'Green'. By clicking [Clear Done] button, user can remove all finished cells from selection. This could be useful when user is trying to resume unfinished cells after interrupting Program operation.

Popup

If [Popup] mode is selected, user is given more options when clicked specific cell.

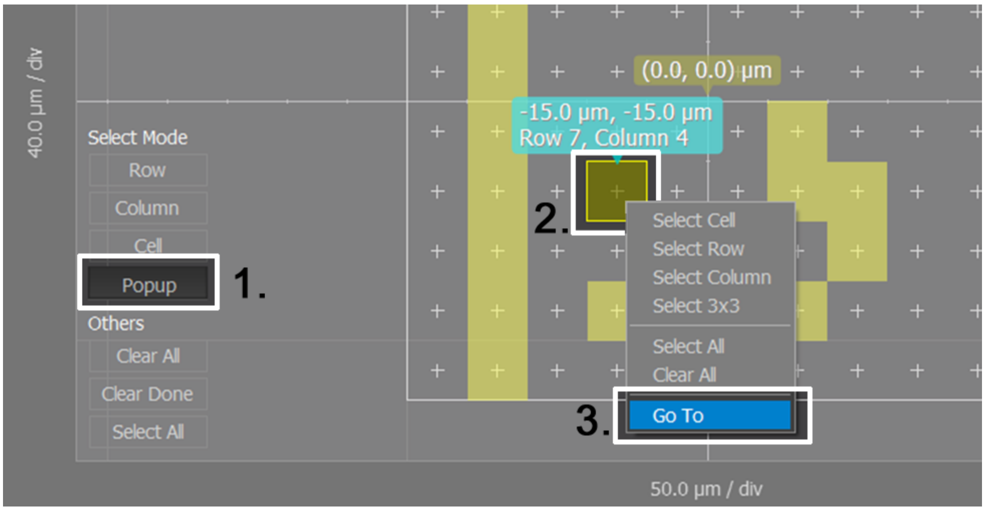
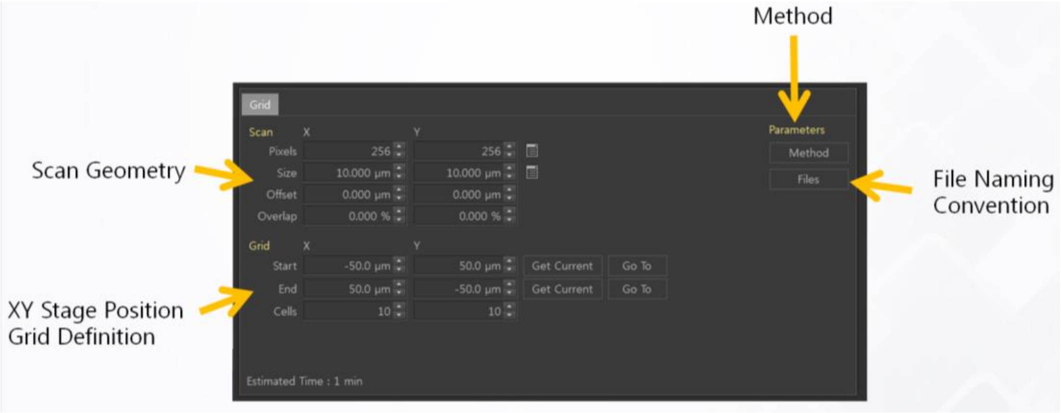


Figure 10-1-5. Popup mode

10-2. Control View

Control view user can define scan geometry with overlap ratio, XY Stage postion and grid definition, method, file naming convention.



Scan	X	Y
Pixels	256	256
Size	10.000 µm	10.000 µm
Offset	0.000 µm	0.000 µm
Overlap	0.000 %	0.000 %

Grid	X	Y
Start	-50.0 µm	50.0 µm
End	50.0 µm	-50.0 µm
Cells	10	10

Estimated Time : 1 min

Figure 10-2-1. Control View workspace

Overlap ratio

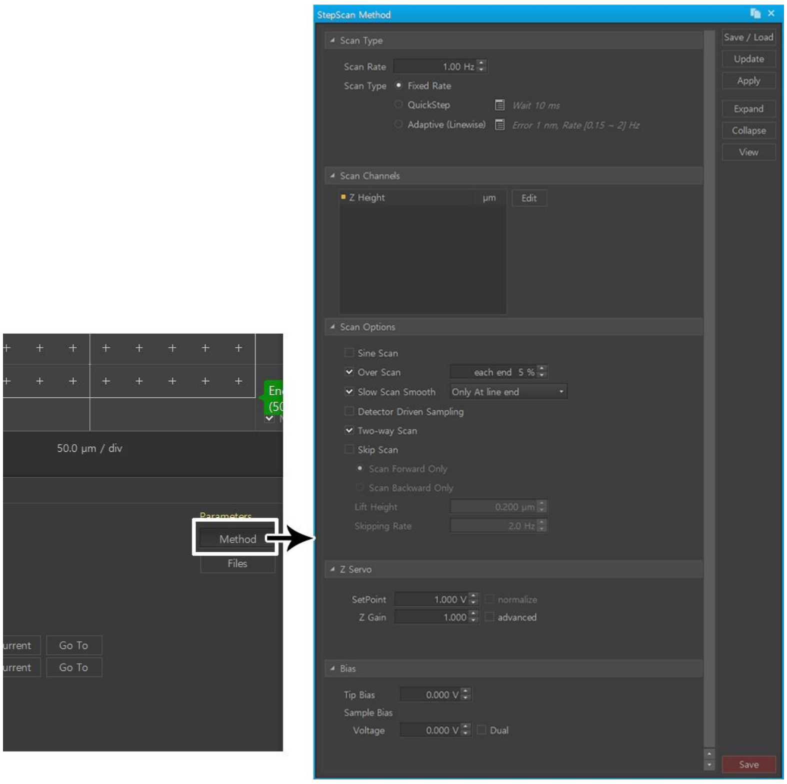
Overlap ratio defines how much adjacent scan images will be overlapped each other. Used to stitching images after all scanning are finished.

Method

Method defines parameter set for each scanning.

Contains

- Scan Type (Fixed Rate / Stepwise / AdaptiveScan)
- Scan Channels
- Scan Options
- Z Servo Configurations
- Tip, Sample Bias



Scan Type
Scan Rate 1.00 Hz
Scan Type ● Fixed Rate ○ QuickStep ○ Adaptive (Linewise)
Wait 10 ms
Error 1 nm, Rate [0.15 ~ 2] Hz

Scan Channels
Z Height µm Edit

Scan Options
☐ Sine Scan
☑ Over Scan each end 5 %
☑ Slow Scan Smooth Only At line end
☐ Detector Driven Sampling
☑ Two-way Scan
☐ Skip Scan
● Scan Forward Only
○ Scan Backward Only
Lift Height 0.200 µm
Skipping Rate 2.0 Hz

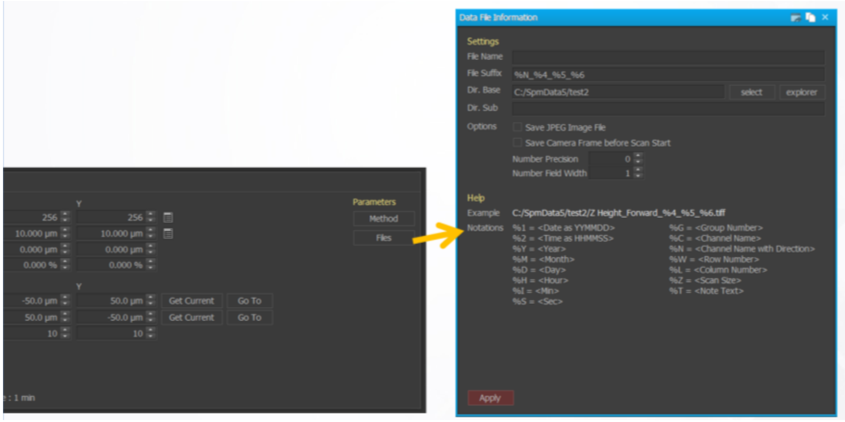
Z Servo
SetPoint 1.000 V ☐ normalize
Z Gain 1.000 ☐ advanced

Bias
Tip Bias 0.000 V
Sample Bias
Voltage 0.000 V ☐ Dual

Figure 10-2-2. Method window workspace

File naming convention

Various file naming convention are supported to organize data file and folders.Sub-directory name also could be designed rather than a fixed name. Number precision and field width could be adjusted also. Row, column numbers could be uused to distinguish grid postions. Camera image can be saved when before each scanning process is started.



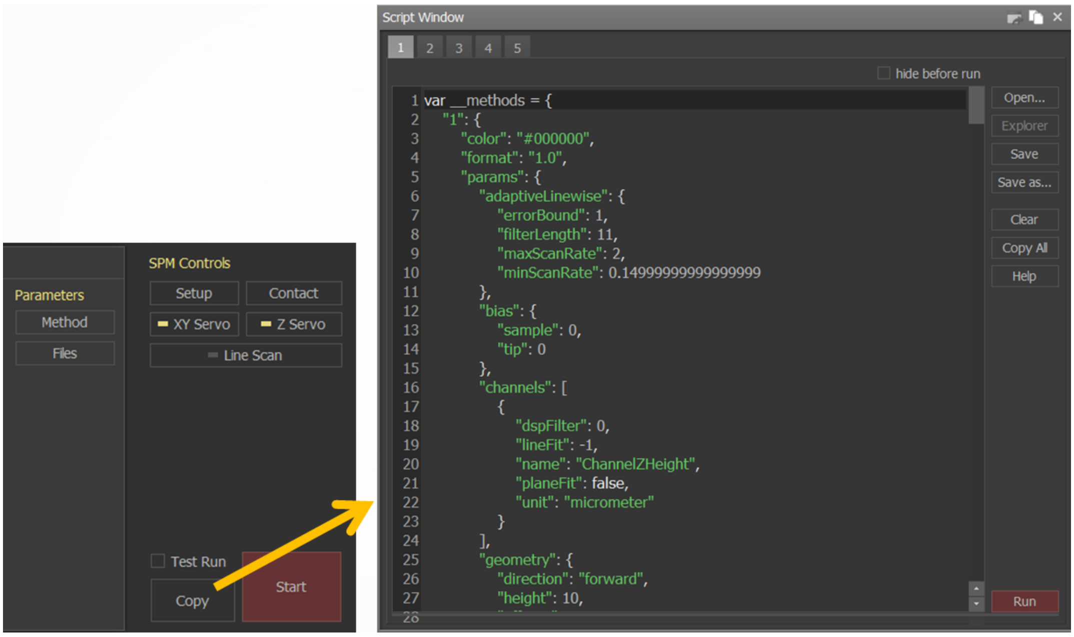
Settings
File Name
File Suffix %N_%4_%5_%6
Dir. Base C:/SpmData5/test2
Dir. Sub
Options ☐ Save JPEG Image File
☐ Save Camera Frame before Scan Start
Number Precision 0
Number Field Width 1

Help
Example C:/SpmData5/test2/Z Height_Forward_%4_%5_%6.tiff
Notations
%1 = <Date as YYMMDD>
%2 = <Time as HHMMSS>
%Y = <Year>
%M = <Month>
%D = <Day>
%H = <Hour>
%I = <Min>
%S = <Sec>
%G = <Group Number>
%C = <Channel Name>
%N = <Channel Name with Direction>
%W = <Row Number>
%L = <Column Number>
%Z = <Scan Size>
%T = <Note Text>

Figure 10-2-3. Data file information window

File naming convention

User can copy all settings and routines as a separated script program. The whole operations could be repeated afterward or can be customized further as user's need.



```
var __methods = {
  "1": {
    "color": "#000000",
    "format": "1.0",
    "params": {
      "adaptiveLinewise": {
        "errorBound": 1,
        "filterLength": 11,
        "maxScanRate": 2,
        "minScanRate": 0.14999999999999999
      },
      "bias": {
        "sample": 0,
        "tip": 0
      },
      "channels": [
        {
          "dspFilter": 0,
          "lineFit": -1,
          "name": "ChannelZHeight",
          "planeFit": false,
          "unit": "micrometer"
        }
      ],
      "geometry": {
        "direction": "forward",
        "height": 10,
```

Figure 10-2-4. PowerScript window

Chapter 11. Data Browsing

You can convert to data browsing mode by selecting the **Browse** tab from the mode menubar or by clicking **SmartScan ▼ -> Browsing**. The data browsing workspace is arranged so that you can perform simple image analysis tasks after a measurement. The workspace consists of three general areas a) Directories, Image View, and Profiles. When **Browsing** is selected, the Directories and File View is shown as default. Clicking on the ➔ or anywhere on the right side of the screen will expand the Image View by adding Information and Profile data. Clicking on the lefthand ⬅ returns the view to the default configuration.

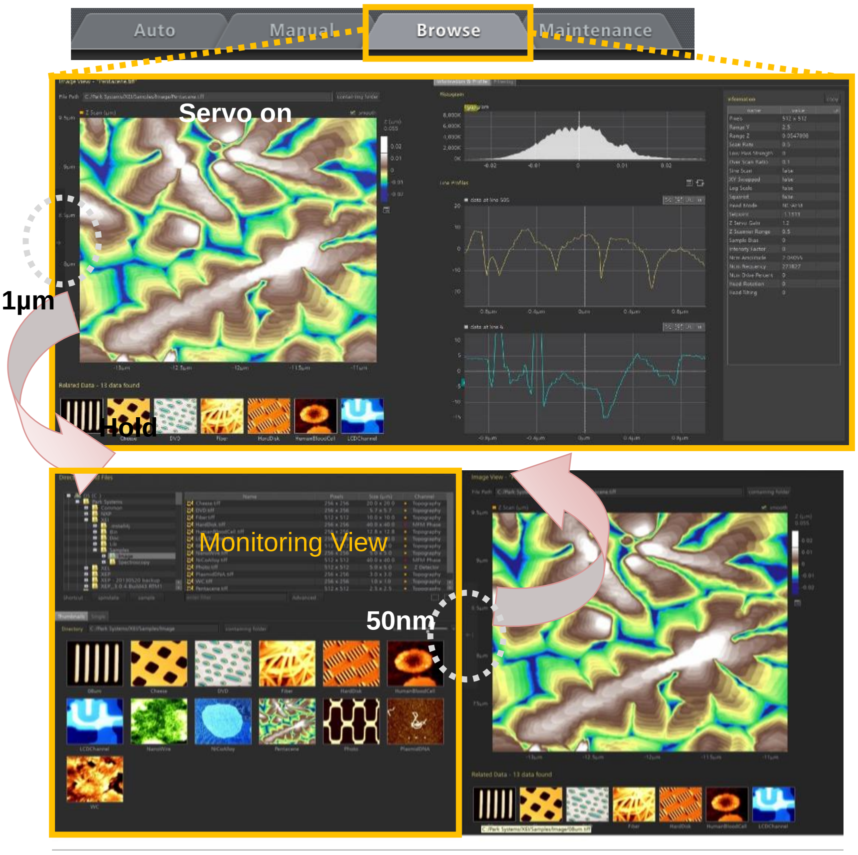
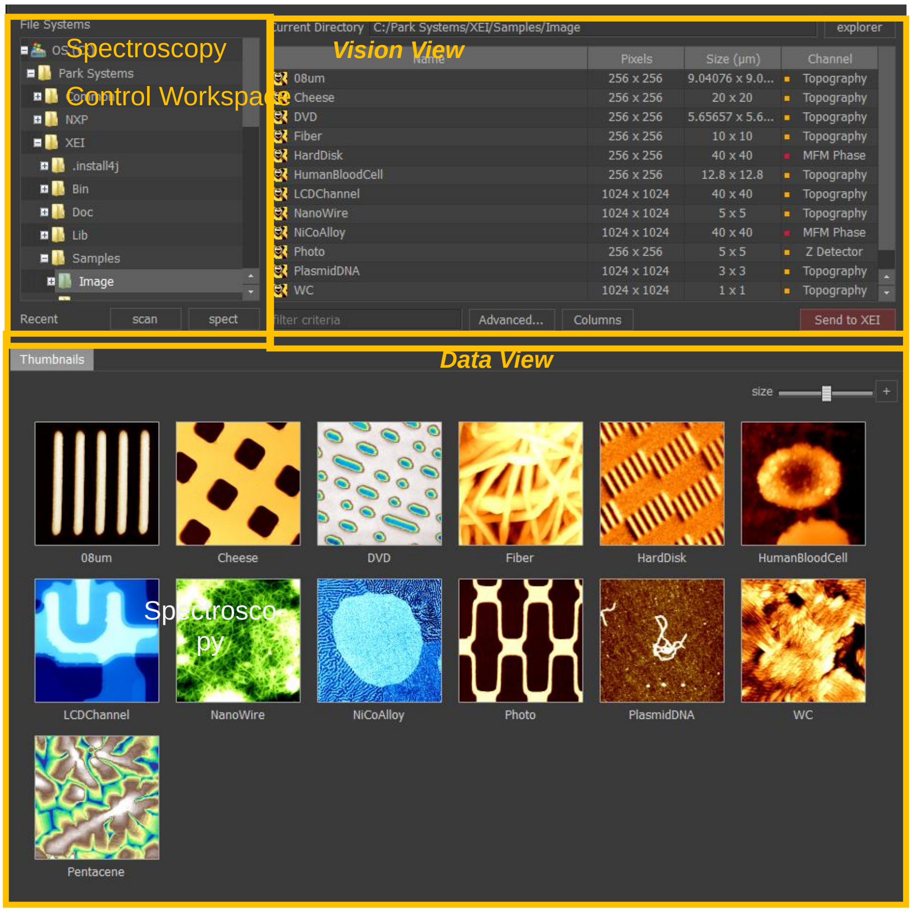


Figure 11-1-1. Data browsing and file view control



urrent Directory C:/Park Systems/XEI/Samples/Image

Name	Pixels	Size (µm)	Channel
08um	256 x 256	9.04076 x 9.0...	Topography
Cheese	256 x 256	20 x 20	Topography
DVD	256 x 256	5.65657 x 5.6...	Topography
Fiber	256 x 256	10 x 10	Topography
HardDisk	256 x 256	40 x 40	MFM Phase
HumanBloodCell	256 x 256	12.8 x 12.8	Topography
LCDChannel	1024 x 1024	40 x 40	Topography
NanoWire	1024 x 1024	5 x 5	Topography
NiCoAlloy	1024 x 1024	40 x 40	MFM Phase
Photo	256 x 256	5 x 5	Z Detector
PlasmidDNA	1024 x 1024	3 x 3	Topography
WC	1024 x 1024	1 x 1	Topography

Figure 11-1-2. File system and view

11-1. Directories and Files View

The Directories and Files View is composed of three general areas: a) File Systems, b) Current Directory, and c) Thumbnails.

11-1-1. File Systems

File Systems is located in the upper left corner of the interface and provides access to file directories. Selecting the desired directory in File Systems causes any TIFF files in that directory to be displayed in Current Directory section.

Shortcuts

Shortcut buttons below File Systems display provide access to recent data.

10-1-2. Current Directory

TIFF files in the the selected directory are listed in the Current Directory display. Filename and file properties, such as scan size, channel name, pixel, file name, file type, and file size, can be displayed in the columns to easily identify the file.

File Path

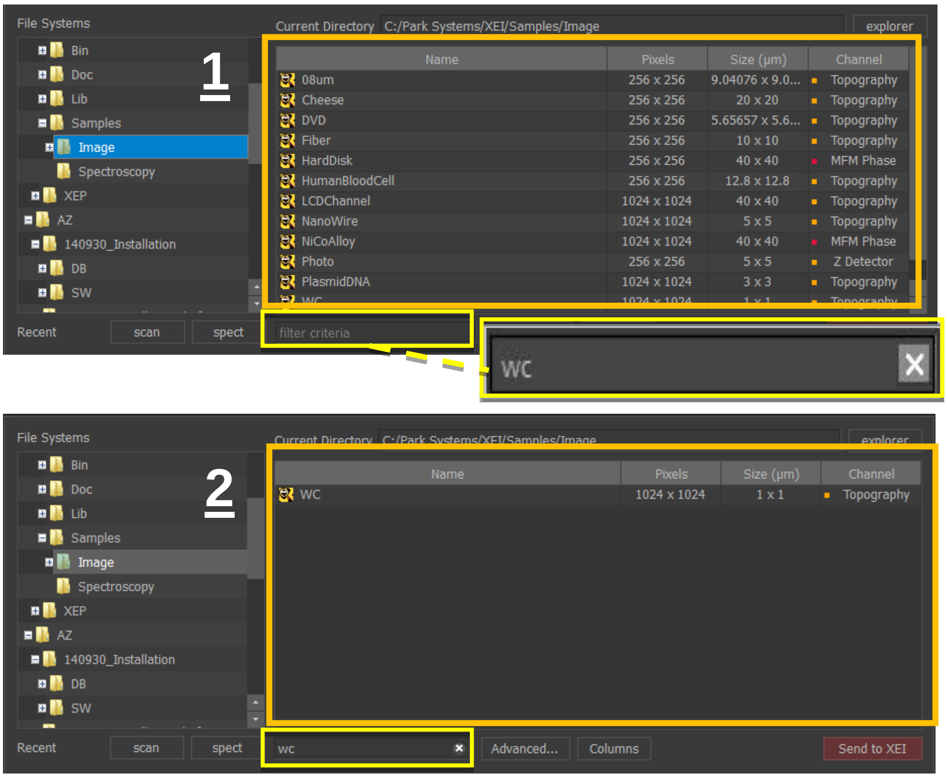
The selected directory path is displayed in the field at the top of the display.

Explorer

The Explorer button opens the current directory in Windows Explorer.

Filter Criteria

At the bottom of the Current Directory View is a filter criteria field that can be used to quickly search the current directory for the filter criteria within the filename. Enter filter criteria into the field and click **Enter** to begin the search.



Current Directory C:/Park Systems/XEI/Samples/Image

Name	Pixels	Size (µm)	Channel
08um	256 x 256	9.04076 x 9.0...	Topography
Cheese	256 x 256	20 x 20	Topography
DVD	256 x 256	5.65657 x 5.6...	Topography
Fiber	256 x 256	10 x 10	Topography
HardDisk	256 x 256	40 x 40	MFM Phase
HumanBloodCell	256 x 256	12.8 x 12.8	Topography
LCDChannel	1024 x 1024	40 x 40	Topography
NanoWire	1024 x 1024	5 x 5	Topography
NiCoAlloy	1024 x 1024	40 x 40	MFM Phase
Photo	256 x 256	5 x 5	Z Detector
PlasmidDNA	1024 x 1024	3 x 3	Topography
WC	1024 x 1024	1 x 1	Topography

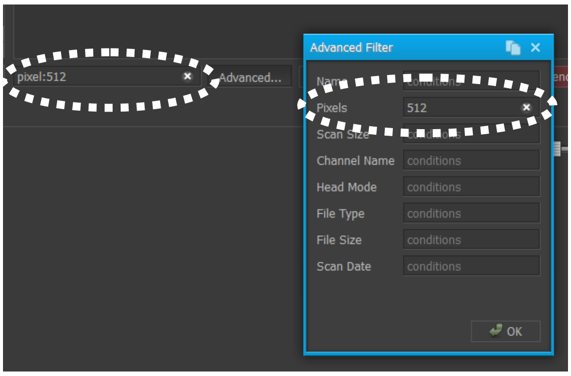
Current Directory C:/Park Systems/XEI/Samples/Image

Name	Pixels	Size (µm)	Channel
WC	1024 x 1024	1 x 1	Topography

Figure 11-1-3. Using the filter criteria field

Advanced Filter Dialog

Clicking **Advanced…** opens the Advanced Filter dialog. The advanced filter enables data filtering by file and scan parameters. Enter the parameter in the corresponding field and click **OK** to retrieve search results. When the Advanced Filter feature is active, the filter is displayed in the filter criteria field. To remove the filter, click the **x** in the field, and then click **Enter** within the filter criteria field or the Advanced Filter dialog. Figure 11-1-4 shows the Advanced Filter dialog.

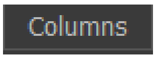


pixel:512

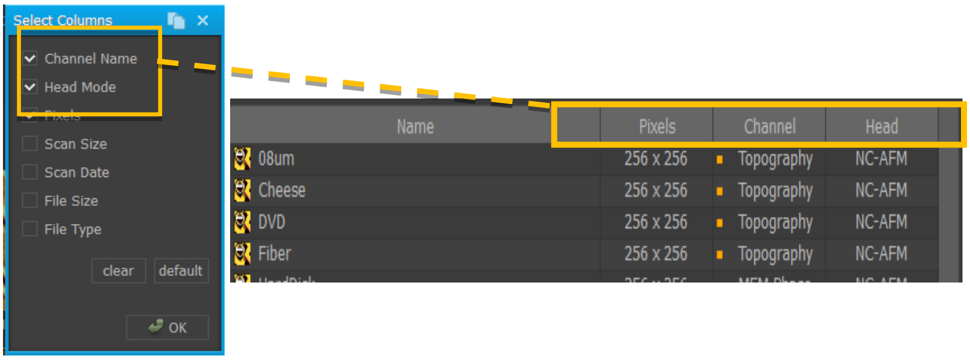
Name	conditions
Pixels	512
Scan Size	conditions
Channel Name	conditions
Head Mode	conditions
File Type	conditions
File Size	conditions
Scan Date	conditions

Figure 11-1-4. Advanced Filter dialog

Columns



Columns opens the Select Columns dialog, where you can specify file attributes to display.

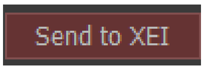


☑ Channel Name
☑ Head Mode
☑ Pixels
☐ Scan Size
☐ Scan Date
☐ File Size
☐ File Type

Name	Pixels	Channel	Head
08um	256 x 256	Topography	NC-AFM
Cheese	256 x 256	Topography	NC-AFM
DVD	256 x 256	Topography	NC-AFM
Fiber	256 x 256	Topography	NC-AFM

Figure 11-1-5. Select Columns dialog and example

Send To XEI



Clicking this button sends the highlighted file in the current directory list to XEI.

11-1-3. Thumbnails

The thumbnails of the files in the selected folder in the Current Directory panel will display in this area. Folder path information is located at the top of the display. Double-click the image you want to analyze to open the file in the Image View.

Thumbnail Size

Thumbnail size can be controlled using scaling slider located at the upper right.

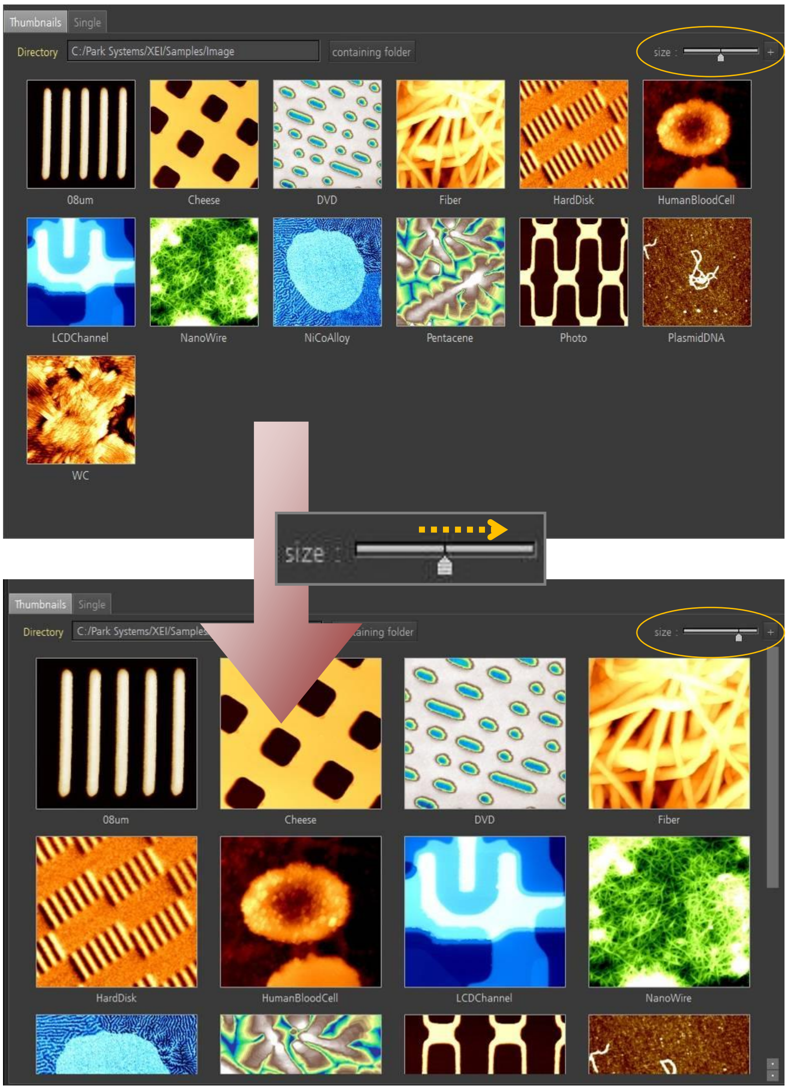


Figure 11-1-6. Resizing thumbnails

11-2. Image View

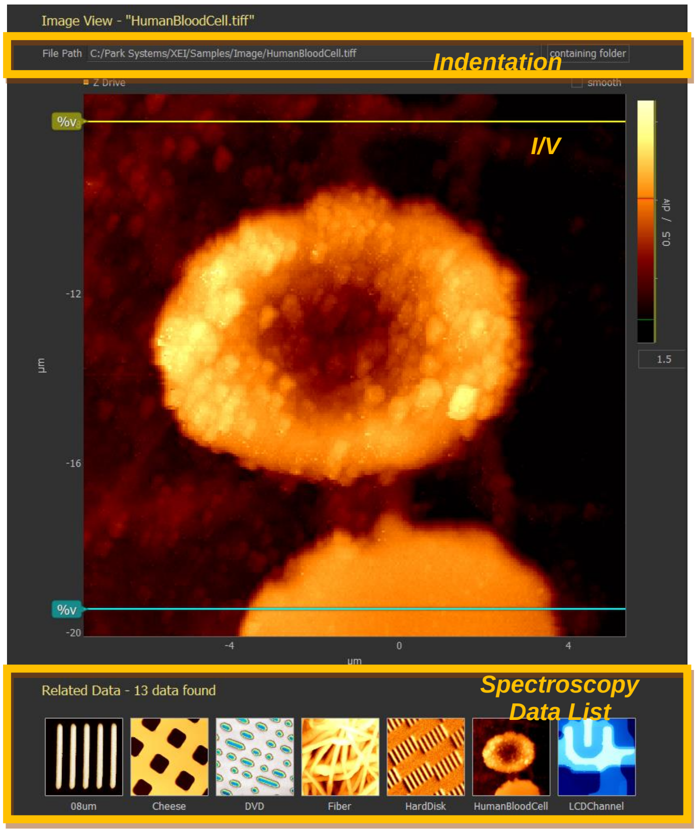


Figure 11-2-1. Image View

11-2-1. Displaying an Image in Image View

Double-click a thumbnail image to analyze it in Image View. Image View displays the filter name and the file path at the top of the screen. Clicking the **containing folder** button opens the directory in Windows Explorer. Data channels acquired in the same scan are displayed in the Related Data area at the bottom of the screen. Double-clicking a thumbnail in Related Data will upload the image to Image View.

Zooming into an Image

To magnify certain region, click and drag the mouse cursor to make a box on the desired area. Magnification of the area does not affect scan size or scan area.

Alternatively, the scan area can be magnified by placing the mouse cursor in the scan area, left-clicking on the desired area for magnification, AND

a) pressing the **+/-** key on the keyboard OR

b) using the mouse wheel to adjust the magnification

To zoom out, double-click anywhere on the scan area.

11-2-2. Pallete

At the right side of the loaded image is a palette menu used to adjust the image's appearance without changing the actual data.

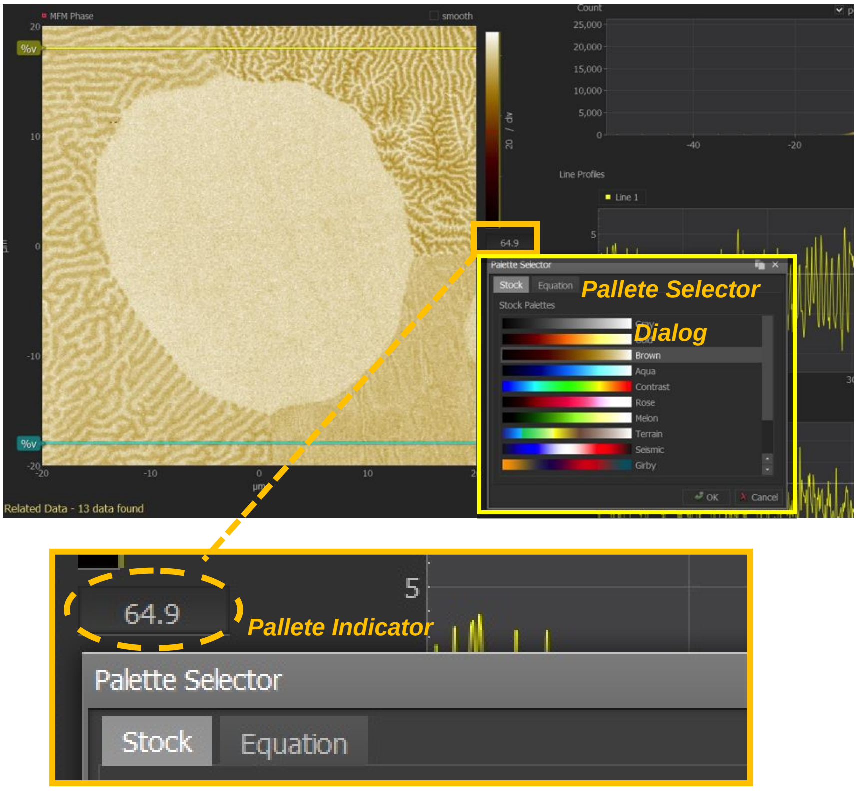


Figure 11-2-2. Changing the image palette

Palette Change

Clicking the **Palette** indicator button as shown in Figure 11-2-3 opens the Pallete Selector dialog. The Pallete Selector enables the user to change the color scaling of the image. Select the desired palette and click **OK** to set a new palette.

Palette Range

The Palette panel is used to adjust the contrast level range of an image. The Palette panel displays the range of the image data values of the measured signal, as well as the relationship between the color of the pixel in the image and corresponding data values of the measured signal. Different colors or shades in the Palette panel represent different height values of the data in the image. The default palette is based on the gold color palette scale, in which darker colors indicate lower heights and the brighter colors indicate higher height values. As shown in Figure 11-2-3, there are three adjustable cursors in the scale bar that indicate the level and range of the scale bar.

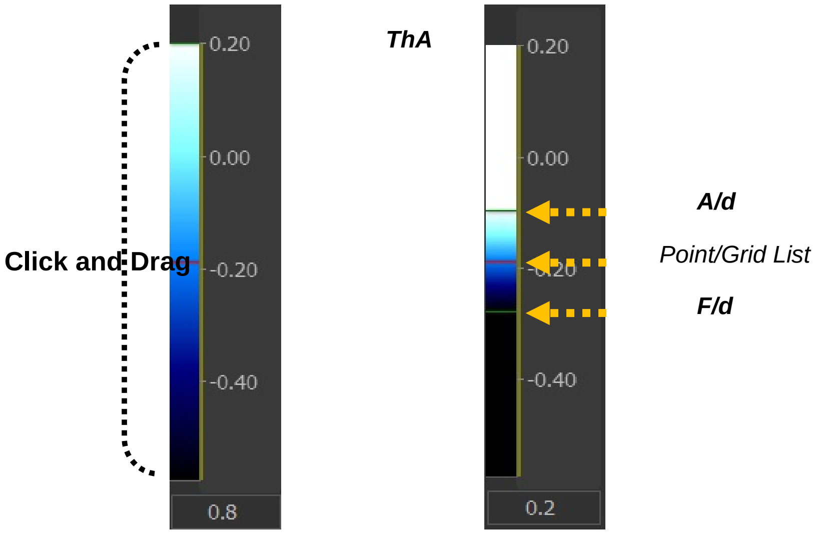


Figure 11-2-3. Palette panel

Data Range Adjustment

On the right side of the Palette panel, the vertical data scale indicates the height range of the image. By default, the maximum (minimum) value of the data range corresponds to the maximum (minimum) data of the pixel data.

Contrast Range Adjustment

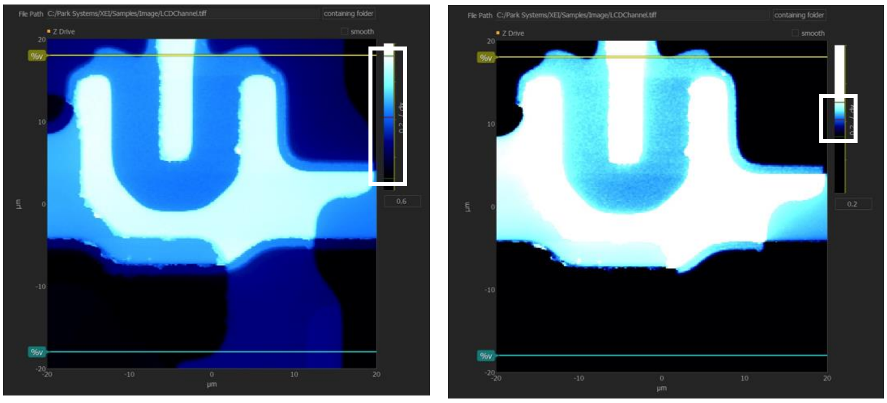
The Contrast Max and Min cursors in the palette panel are used to change the contrast range. The contrast range is set by adjusting the vertical length of the color palette by dragging these two cursors. Double-clicking on the contrast bar automatically sets the maximum (minimum) value of the data range to the maximum (minimum) value of the pixel data. Adjusting the contrast range is useful when you are interested in a specific height range in an image. You can narrow the contrast range so that it covers smaller features in an image. In this way, you can scale up a specific height range in an image to see smaller features in greater detail.

Contrast Max cursor

The **Contrast Max** cursor indicates the data value on the data scale that corresponds to the brightest color of the current color palette (generally white). Any pixels with data values that exceed the value indicated by **Contrast range max** will be displayed in brightest color of the color palette, regardless of their values.

Contrast Min cursor

The **Contrast Min** cursor indicates the data value on the data scale that corresponds to the darkest color of the current color palette. Any pixels with data values less than the value indicated by **Contrast range min** will be displayed in the darkest color of the color palette, regardless of their values.



File Path C:/Park Systems/XEI/Samples/Image/LCDChannel.tiff

File Path C:/Park Systems/XEI/Samples/Image/LCDChannel.tiff

Figure 11-2-4. Contrast range adjustment

Contrast Level Adjustment

The **Contrast level marker** is a red line on the palette panel. This marker indicates the data value on the data scale that corresponds to the middle of the current color palette. As shown in Figure 11-2-5, the contrast level can be adjusted by clicking and dragging the **Contrast level marker** on the Palette panel.

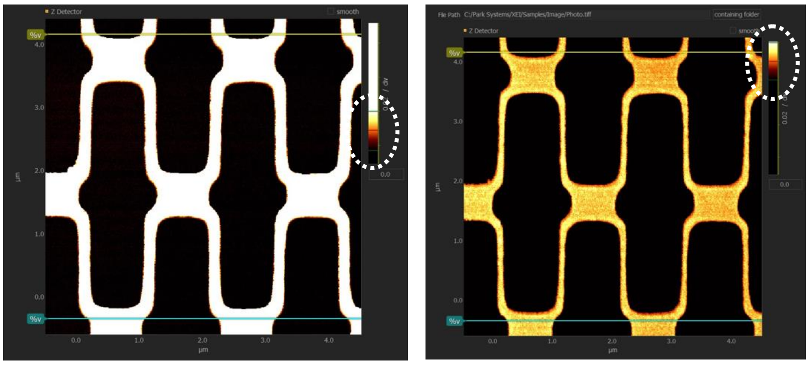


Figure 11-2-5. Contrast level adjustment

11-2-3. Line Profile Indicators and Display

Two line profile indicator lines appear on the main Image View. These lines can be moved by clicking and dragging the lines to the desired location. The profiles of the lines are displayed in the graphs on the **Information & Profile** tab. The yellow line is denoted as **Line 1** while the aqua line is denoted as **Line 2**.

The Line Profile panel displays the cross-sectional height profile of the image varies depending on the collected signal to generate its image (for example, μm, nm, mV, V, and so on).

You can easily move each line for analysis anywhere in the loaded image by repeatedly dragging and dropping the line. As the line is moved, the line profile in the Line Profiles panel will change. Figure 11-2-6 shows an example of moving the line for analyzing different image cross sections.

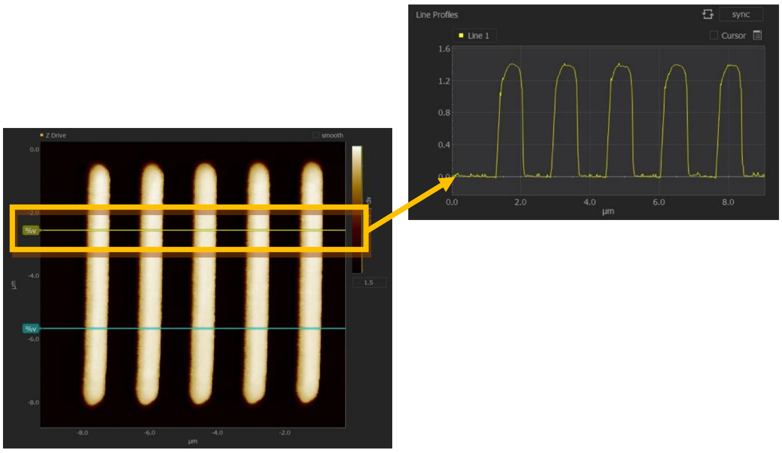


Figure 11-2-6. Line profile indicators and panel

11-3. Information & Profile

The **Information & Profile** tab on the righthand side of the Expanded Image View includes histogram, line profile, and file information.

11-3-1. Histogram

The histogram shown below is a bar graph that displays the distribution of heights along a height profile. When you load an image, a histogram is automatically displayed.

The X axis represents the height of data points in the sample surface, and its unit can be Å, nm, µm, and so on. The width of a bar depends on the overall height range of the sample and the number of data points of the line profile. The Y axis is the number of data points with the same height values, and its unit is pixels.

Checking the **peak** checkbox will place numerical indicators of the peak measurement on the Histogram display. Checking the **cumulative** checkbox will draw a cumulative curve of the running total of frequencies on the histogram plot. Figure 11-3-1 shows the histogram plot with and without the peak and cumulative features activated.

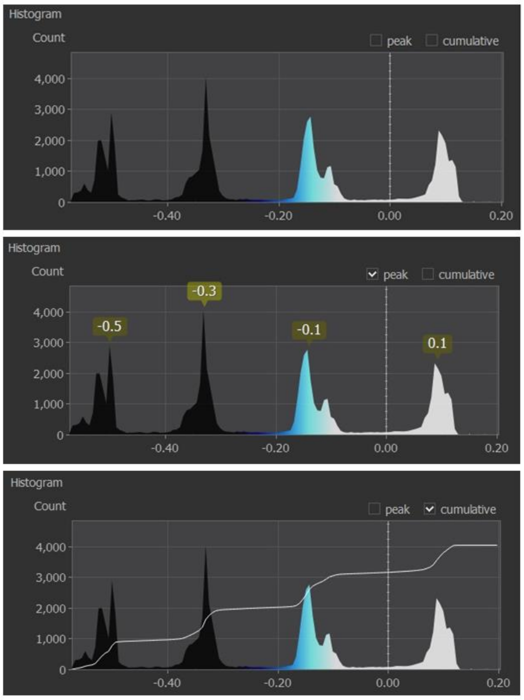
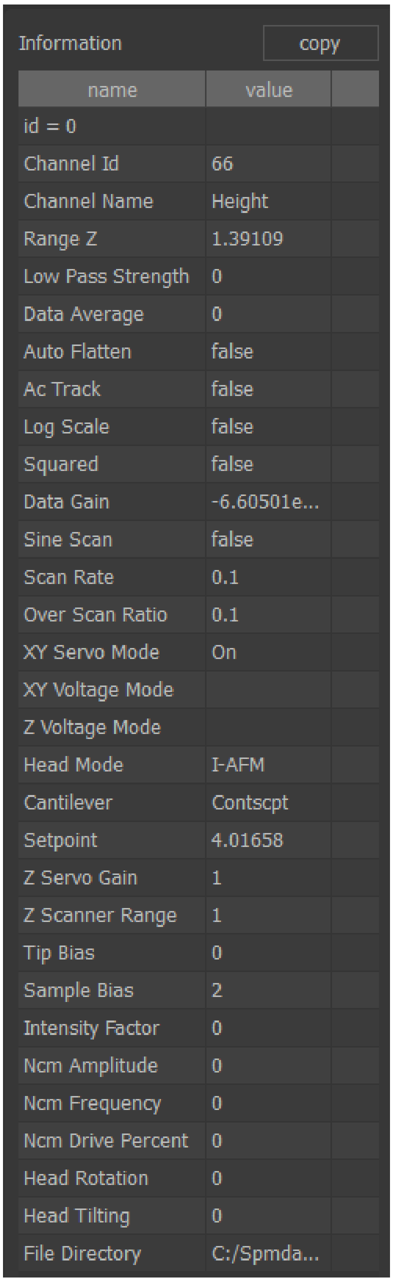


Figure 11-3-1. Histogram

11-3-2. Information

When a scan image file is generated from SmartScan, various information and scan parameters used to obtain image are saved along with the image itself. As shown in Figure 11-3-2 below, these can be viewed on the Information table. A summary of each item is provided in Table 11-2.



name	value
id = 0	
Channel Id	66
Channel Name	Height
Range Z	1.39109
Low Pass Strength	0
Data Average	0
Auto Flatten	false
Ac Track	false
Log Scale	false
Squared	false
Data Gain	-6.60501e...
Sine Scan	false
Scan Rate	0.1
Over Scan Ratio	0.1
XY Servo Mode	On
XY Voltage Mode	
Z Voltage Mode	
Head Mode	I-AFM
Cantilever	Contscpt
Setpoint	4.01658
Z Servo Gain	1
Z Scanner Range	1
Tip Bias	0
Sample Bias	2
Intensity Factor	0
Ncm Amplitude	0
Ncm Frequency	0
Ncm Drive Percent	0
Head Rotation	0
Head Tilting	0
File Directory	C:/Spmda...

Figure 11-3-2. Information table example

Table 11-2. Detailed summary of Information table items

Name/Value	Description
Id=0	none
Channel Id	Indicates the channel identification number
Channel Name	Indicates the input signal source used to acquire an image. This channel was selected in the Channel Config dialog.
Range Z	Indicates the range mode of the Z scanner (Large or Small) during imaging.
Low Pass Strength	Indicates the time interval used to generate the averaged data pixel so that high frequency noise can be eliminated. A higher value for LPF means that a longer time interval is permitted to generate each pixel.
Date Average	none
Auto Flatten	Indicates if auto flattening was applied (True or False)
AC Track	Indicates if AC was on (True or False)
Log Scale	Indicates if Log Scale was used (True or False)
Squared	Indicates if Squared was used (True or False)
Data Gain	Real data is obtained by multiplying the raw data and data gain
Sine Scan	When Sine Scan is True, the sine scan was applied to an image while scanning. This parameter is selected in the Scan Options dialog.
Scan Rate	Indicates the frequency the scanner is rastering back and forth across the sample surface. This parameter is adjusted in XEP’s Parameters Control window.
Over Scan Ratio	Indicates the percentage (expressed as a decimal value) that an overscan was applied to an image while scanning. This parameter is selected in the Scan Options dialog.

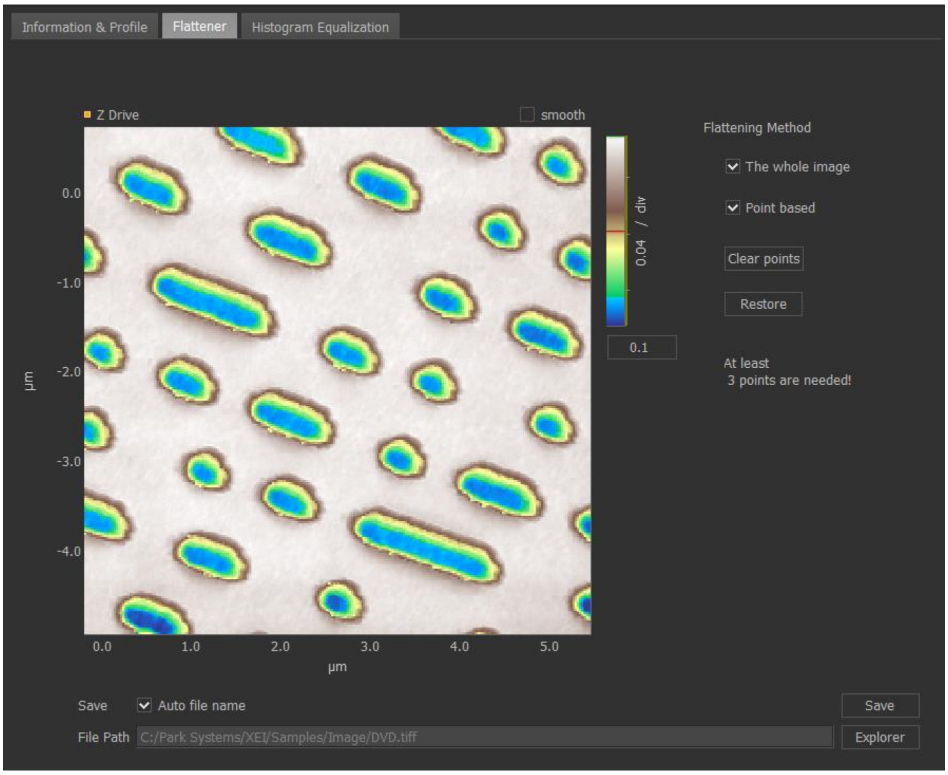
Name/Value	Description
XY Servo Mode	Indicates whether the XY scanner servo scanner was on (closed loop imaging) or off (open loop imaging). The XY servo insures linearity of the XY scan.
XY Voltage Mode	Only for XE.
Z Voltage Mode	Only for XE.
Head Mode	Indicates the head mode, such as AFM, NC AFM, MFM, LFM, EFM, FMM, and so on.
Cantilever	Idenitifies the cantilever database file selected when the image was acquired. The cantilever database file is used in the software to calculate force loads and amplitude values.
Set Point	Indicates the set point value set in the Parameters Control window or NCM Sweep dialog. Depending on the scan mode, the meaning of this value may differ for different scan modes.
Z Servo Gain	Indicates the value of Z servo gain set during the imaging process.
Z Scanner Range	For XE only. Indicates the range of the Z scanner (0 to 1 corresponding to 0 to 12μm range of the Z scanner) during imaging. This parameter is set from the Part Config dialog box in XEP.
Tip Bias	Indicates the voltage that was applied to the tip with the sample being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in XEP’s Parameters Control window.

Name/Value	Description
Sample Bias	Indicates the voltage that was applied to the sample with the tip being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in XEP's Parameters Control window.
Intensity Factor	The intensity normalization ratio, which is the ratio of the intensity divided by 3.0
NCM Amplitude	The amplitude at which the cantilever was modulated during NC-AFM mode images
NCM Frequency	The frequency at which the cantilever was modulated during NC-AFM mode images
NCM Drive Percentage	The strength of the mechanical driving oscillation of the cantilever used during the NC-AFM image acquisition, denoted as a percentage
Head Rotation	The angle of the image taken from NX-3DM
Head Tilting	none
File Directory	Path where the image file is saved

Copy

Copies the data table as text onto the clipboard.

11-4. Flattener



At least
3 points are needed!

File Path: C:/Park Systems/XEI/Samples/Image/DVD.tiff

Figure 11-3-3. The Flattener tab

11-4-1. Flattening Method

Clicking the **Flattener** tab displays the image in Image View into the tab to flatten it. Controls for adjusting the palette, data range, and zooming into the image are similar to those for the Image View. To flatten the image, follow the steps below:

1. Upload the image in Image View
2. Click the **Flattener** tab
3. Choose a flattening method
    a. **The whole image**
    b. **Points based**. If using this method, click on the image in the flattener to add a point, which should be on the same level plane. See below for more information about flattening methods.

The whole image

Choose this flattening method to remove the slope plane of the entire image before any “point base” is processed.

Point based

At least points three points must be added to define the plane. Up to five points can be added in the calculation. The flattened image is automatically updated as the points are added.

Clear points

Clicking this clears all of the points added in point-based flattening.

Restore

Click to restore the previous image.

11-4-2. Save

Click **Save** to store the flattened image. If the **Auto file name** box is checked, the OS will save using a filename with “_flattened_generation number” appended. For example, if the original file was named:

Sample5_141006_Z Detector_Backward_032.tiff

the new file(s) would be named

Sample5_141006_Z Detector_Backward_032**_flattened_001**.tiff

Sample5_141006_Z Detector_Backward_032**_flattened_002**.tiff

If **Auto file name** is unchecked, clicking **Save** will open Windows Explorer to rename and save the file. Clicking the Explorer button will open the directory listed in the file path in Windows Explorer.

11-5. Histogram Equalization

Click the **Histogram Equalization** tab to display the image in Image View into the tab view. Controls for adjusting the palette, data range, and zooming into the image are similar to those for the Image View.

Chapter 12. Maintenance

Access the maintenance mode workspace by clicking the **Maintenance** tab or by clicking **SmartScan ▼ -> Maintenance**. Figure 12-1-1 shows the maintenance mode workspace and labels for each view area (Vision View, Monitoring View, Setup View, and Sweep Result View). Each view area is described below.

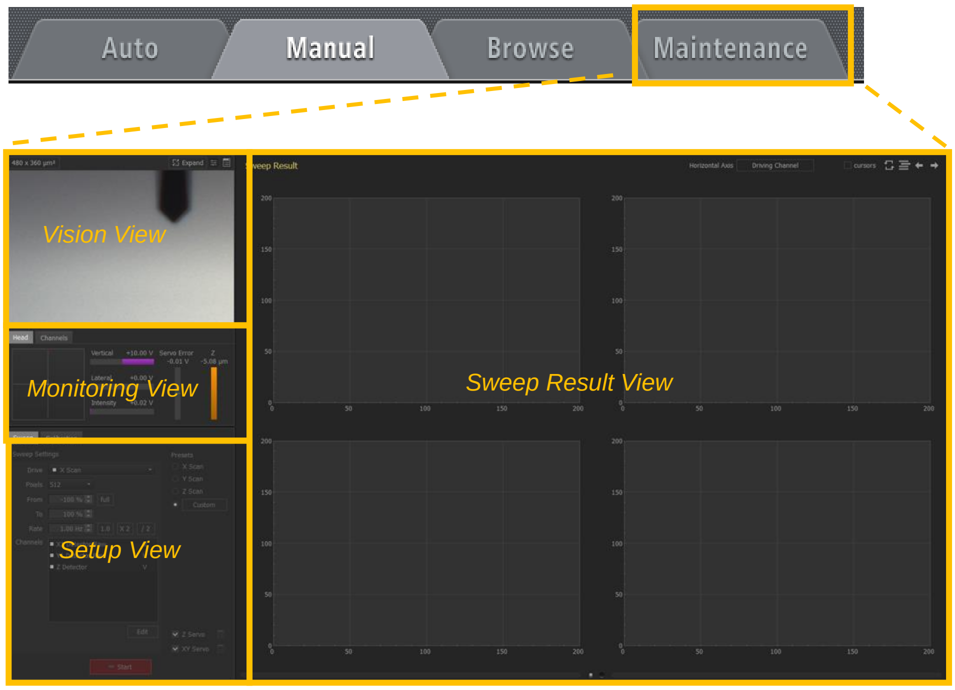


Figure 12-1-1. The maintenance mode workspace

12-1. Vision View

See Section 7-1 for a detailed description of the Vision View.

12-2. Monitoring View

See Section 7-2 for a detailed description of the Monitoring View.

12-3. Setup View

Setup View displays setup parameters for sweep tests and scanner and cantilever calibration. Setup View is separated into two tabs: the Sweep Setup View and the Calibration Setup View.

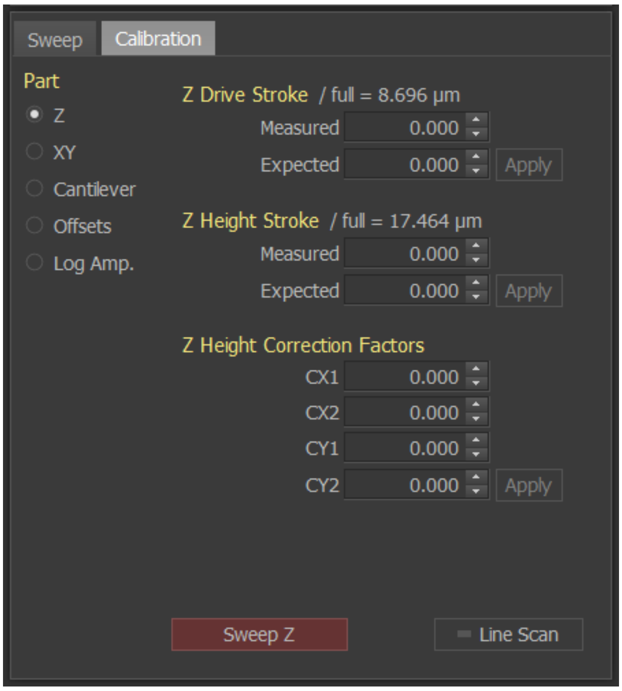
12-3-1. Sweep Setup View

Use the controls here, you can perform a sweep of the desired driving channel and view various resulting signal traces. For more detail, refer to Chapter 13, Sweep Tests.

12-3-2. Calibration Setup View

Various instrument components, including the Z scanner, XY scanner, and cantilever can be calibrated from this tab. The sub-interface for each component can be toggled by clicking the desired radio button.

Calibration/Z Scanner



Z Drive Stroke / full = 8.696 μm
Measured 0.000
Expected 0.000

Z Height Stroke / full = 17.464 μm
Measured 0.000
Expected 0.000

Z Height Correction Factors
CX1 0.000
CX2 0.000
CY1 0.000
CY2 0.000

Figure 12-3-1. Z Scanner calibration setup

Z Calibration Parameters	**Function**
Z Scan Stroke	**Z Scan Stroke** is the Z scanner movement determined by the applied voltage bias to the Z piezo/scanner. The **Measured** value is the height derived from the Z scan calibration image. The **Expected** value is the height value reported for the known sample. After entering the **Measured** and **Expected** values, click **Apply** to adjust the calibration.
Z Height Stroke	**Z Height Stroke** is the Z scanner movement determined by the linearized sensor. The **Measured** value is the height derived from the Z height calibration image. The **Expected** value is the height value reported for the known sample. After entering the **Measured** and **Expected** values, click **Apply** to adjust the calibration.
Z Height Correction Factors	These are factory calibrated nonlinear correction factors.

- **Stroke Calibration**

  The Z scanner stroke can be calculated by imaging a grating sample that has a known height. Differences between the known value and the measured value can be adjusted through calibration tables.

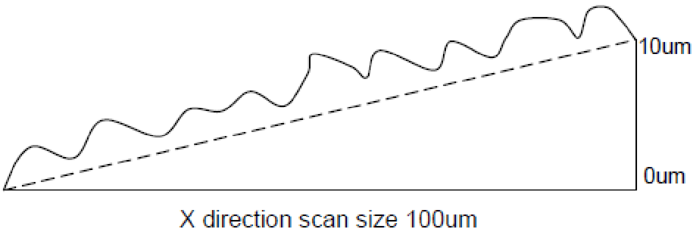
  For example, a grating sample of height 3μm×3μm is measured as 120nm. If the known height reported by the manucturer is 100nm +/-7nm, the measured value is off by 13-20nm. Calibration of the scanner stroke can correct the measurement discrepancy.

  The Z stroke is calculated two ways. The first way to determine the stroke is using the voltage applied to the Z piezo. The second way determines the stroke using a sensor. Each signal must be calibrated separately using different channels.

- **Non-Linear Correction Factors**

The Z scanner calibration provides software correction for non-linear Z scanner movement. For example, if you can see a non-linear image like the one below, you can correct it by calibrating **CX**, **CX2**, **CY**, and **CY2**.

The X direction and Y direction of this surface are expressed as $AX^2+BX+CY^2+DY$, where $AX^2=CX2$, $BX=CX$, $CY^2=CY2$ and $DY=CY$. When you obtain a 1st order slope from the Z height as below, you can enter +0.1 into CX since the equation is $Y=AX^2+BX+C$, where A=0, B=10µm/100µm=0.1, and C=0. Please note that currently the software does not caluculate the values of X, Y, X2 and Y2. You will need to calculate these values manually.



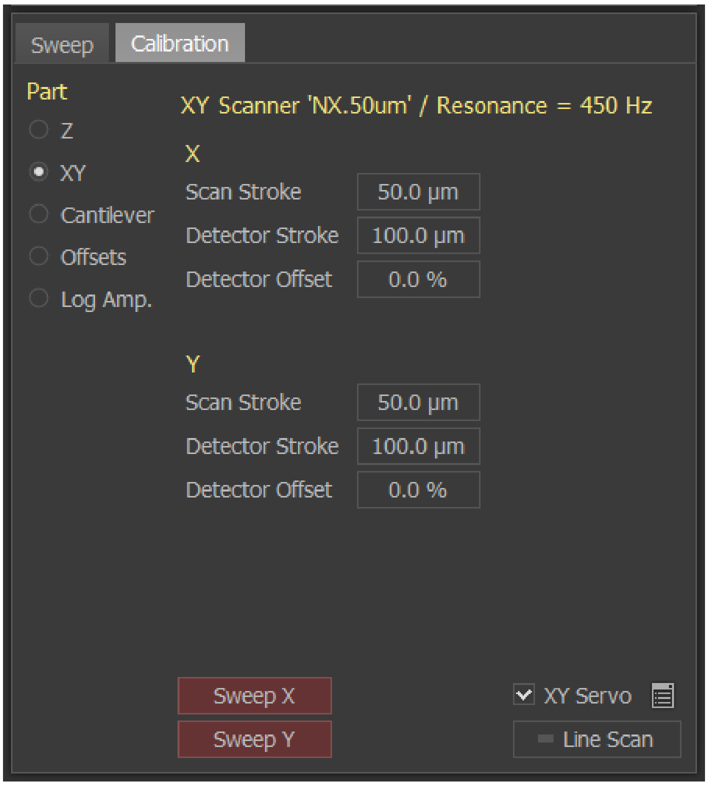
To calibrate the Z scanner, image a standard sample with a known step height and enter the measured and known (expected) heights into the calibration setup interface. A summary of the parameters for Z scanner calibration can be found in the table below. For more information about scanner calibration, please refer to the NX User’s Manual.

- **Sweep Z**

Clicking this button sweeps the Z scanner in full bias range and displays the result in the Sweep Result panel on the right. With this, you can check the full stroke of the Z drive / hight. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

Calibration/XY Scanner

Figure 12-3-2 below shows the XY scanner calibration setup. XY calibration values include **Scan Stroke**, **Detector Stroke**, and **Detector Offset**. Each can be adjusted independently for the X and Y directions. When calibrating the scanner, the X scan values are used when then XY servo is off (open loop), while the X detector values are used when the XY servo is on (closed loop). Please see the NX manual for more detailed information about XY scanner calibration.



XY Scanner 'NX.50um' / Resonance = 450 Hz

X
Scan Stroke 50.0 µm
Detector Stroke 100.0 µm
Detector Offset 0.0 %

Y
Scan Stroke 50.0 µm
Detector Stroke 100.0 µm
Detector Offset 0.0 %

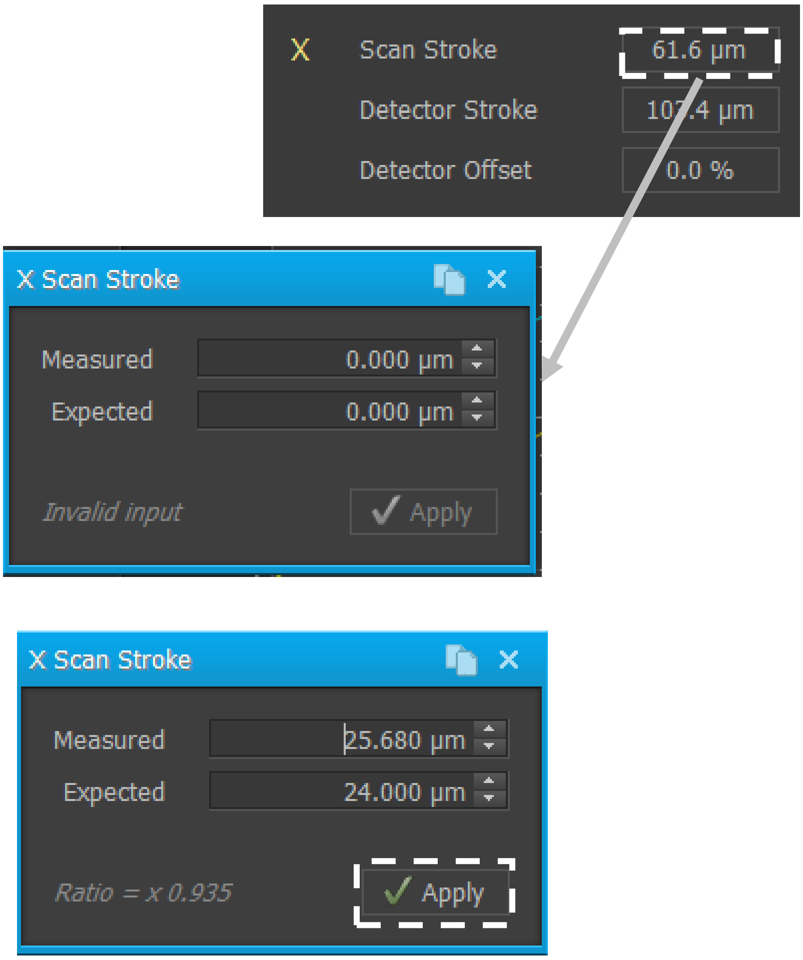
☑ XY Servo

Figure 12-3-2. XY scanner calibration setup

To change XY scanner calibration values:

1. Click the appropriate display button next to the parameters to change.
2. A dialog box will open. Enter the measured and expected values for the desired parameter.
3. Click **Apply**. The software will calibrate the scanner automatically.

Figure 12-3-3 gives an example of how to change the X **Scan Stroke** value.



X
Scan Stroke 61.6 µm
Detector Stroke 102.4 µm
Detector Offset 0.0 %

X Scan Stroke
Measured 0.000 µm
Expected 0.000 µm
Invalid input

X Scan Stroke
Measured 25.680 µm
Expected 24.000 µm
Ratio = x 0.935

Figure 12-3-3. XY scanner calibration example

- **Stroke Calibration**

  Stroke calibration changes the movement in the X or Y direction. Scan signals are used for calibration of open loop scanning (XY servo off). Detector signals are used for calibration of the detector used for closed loop scanning (XY servo on). It is verified by checking the measured scanner movement against a known structure. For example, if a known 3μm×3μm grating sample is measured, the width of three gratings is known to be 3μm×3 gratings=9μm. If the actual measured value is 9.8μm, then the X or Y scanner needs calibration. In this example, depending on the direction of measurement, you would enter 9μm and 9.8μm in the **Expected** and **Measured** fields for the X or Y row.

- **Offset Detector**

  The offfset detector is used to center scanner movement within the stroke range. For the detectors' offset calibration, you should enter the **Offset** value. This value describes how the detector shifts from the origin in the X and Y directions. You can estimate the **Offset** values by performing a sweep test of the X and Y scan and monitoring the non-zero X and Y coordinates of the origin in the the **Oscilloscope** screen. Then the X and Y detectors can be calibrated by entering the **Offset** value and then clicking **Apply**. For more information, please refer to the NX User's Manual.

Panel	Function
Measured X(Y) Scan/Detector	Input the measured XY scan/detector's stroke length.
Expected X(Y) Scan Detector	Input the known XY scan/detector's stroke length.
Offset of X(Y) Detector	Input how the detector shifts from the origin.

**XY Scan: XY movement in open loop (XY servo off)*

**XY Detector: XY movement in closed loop (XY servo on)*

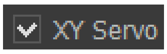
- **Sweep X**

Click this button to sweep the X scanner in full bias range and display the result in the Sweep Result panel on the right. With this, you can check the full stroke of the X scan and X detector. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

- **Sweep Y**

Click this button to sweep the Y scanner in full bias range and display the result in the Sweep Result panel on the right. With this, you can check the full stroke of the Y scan and Y detector. When the button is active, the system will continuously sweep the scanner range, and **Cancel** will appear in the button. Clicking **Cancel** will stop the sweep.

- **XY Servo Check box**



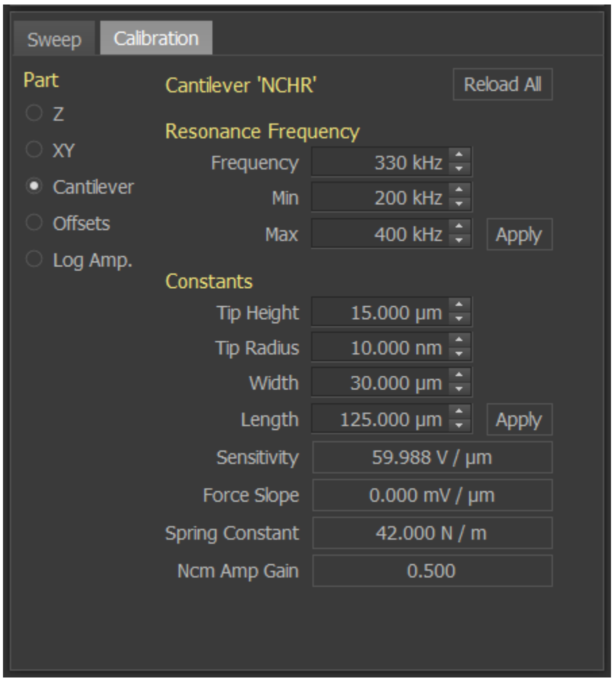
Checking this box turns on the XY servo. Unchecking this box turns off the XY servo.

- **Config**

Clicking **config** opens the XY Servo Configuration dialog. Please see Section 8-4-11 for more information about XY servo configuration.

Calibration/Cantilever

Different models of cantilevers are produced with varying force constants and resonance frequencies, resulting in differing values in various performance metrics. Because these values cannot always be obtained nondestructively, SmartScan maintains a database of known cantilever properties. This database is pre-populated with several common cantilevers. If you choose a different cantilever, you must perform a cantilever calibration and create a database entry for it. Cantilever calibration is divided four main sections: resonance frequency range, cantilever constants, A-B sensitivity, force constant, and NCM amplitude gain.



Part

○ Z

○ XY

● Cantilever

○ Offsets

○ Log Amp.

Cantilever 'NCHR'

Resonance Frequency

Frequency 330 kHz

Min 200 kHz

Max 400 kHz

Constants

Tip Height 15.000 µm

Tip Radius 10.000 nm

Width 30.000 µm

Length 125.000 µm

Sensitivity 59.988 V / µm

Force Slope 0.000 mV / µm

Spring Constant 42.000 N / m

Ncm Amp Gain 0.500

Figure 12-3-4. Cantilever calibration setup

- **Cantilever Resonant Frequency**

When performing an NCM sweep, the frequency is varied from the known minimum to the known maximum resonance range for the current cantilever type. Enter the minimum, maximum, and typical resonant frequencies for your cantilever. These values are usually provided by the cantilever manufacturer. Click **Apply** to finish calibration.

- **Cantilever Constants**

Descriptions for cantilever constants are provided by the manufacturer and defined as follows:

Tip Height	This is the height of the tip, defined as the length from the end of the tip to the center of the cantilever beam. This value is provided by the cantilever manufacturer.
Cantilever Length	This is the length of the cantilever. This value is provided by the cantilever manufacturer.

To change values, update values in the appropriate fields and click **Apply**.

- **A-B sensitivity calibration**

  As the cantilever moves across a sample surface and deflects upwards or downwards, the A-B signal on the PSPD is changed because the beam is reflected off the top of the cantilever. The A-B sensitivity value determines how much the A-B signal changes in respect to the cantilever deflection (A-B sensitivity=A-B/height).

  To input this value automatically using acquired data, click the **Data** button. A dialog box will appear. Select a file containing an F/d curve obtained in contact mode. Select the linear region and click **Apply**. The A-B Sensitivity Cantilever Calibration dialog is shown in Figure 9-1-6.

- **Force Constant**

  Input the typical force constant for the cantilever. You can find this value in the cantilever manufacturer's specifications. Update the field for the force constant and click **Apply** to save the force constant to the cantilever file listed at the top of the view area.

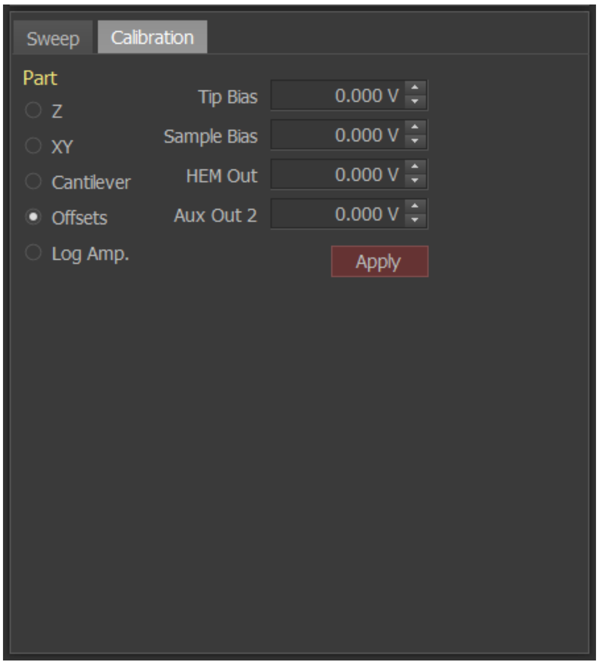
- **NCM Amp Gain**

  The A-B (AC) signal on the PSPD is amplified by a lock-in circuit. This electronics gain is called **NCM Amp Gain** (V/V). The value for **NCM Amp Gain** can be entered into the text field. Click **Apply** to save the values into the cantilever calibration.

  To determine the gain automatically, click the **Data** button, which opens the NCM Amplitude Calibration Dialog window.

Calibration/Offsets

Figure 12-3-5 below shows the Offset calibration setup.



Tip Bias 0.000 V

Sample Bias 0.000 V

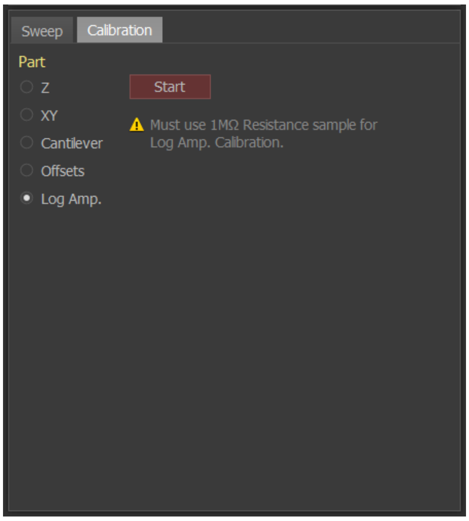
HEM Out 0.000 V

Aux Out 2 0.000 V

Figure 12-3-5. Cantilever Offsets setup

Calibration/Log Amp.

Figure 12-3-6 below shows the Log Amplifier setup.



⚠ Must use 1MΩ Resistance sample for Log Amp. Calibration.

Figure 12-3-6. Log Amplifier setup

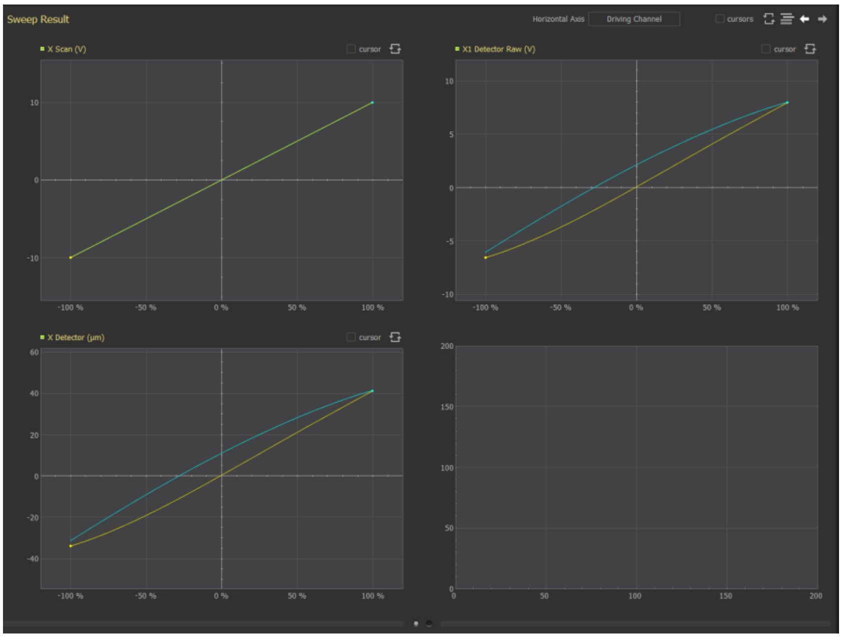
Perform calibration in the following order.

1. Place the standard resistance sample on the sample chuck and connect it to the 1 MΩ resistance.
2. Press the Start button.
3. Wait until the process is complete.
4. Use when finished.

When only the resistance sample is connected, calibration ends with a single click of the button, as shown in the procedure above, and is automatically saved in 'DB'.

12-4. Sweep Result

The Sweep Result workspace displays up to eight signal channels resulting from sweeping the driving signal. Figure 12-4-1 shows the Sweep Result workspace.



Horizontal Axis: Driving Channel

Figure 12-4-1 Sweep Result workspace

The horizontal axis of the all the graphs displayed can be set by clicking the **Horizontal Axis** button and choosing the desired parameter from the drop-down menu. The name of the channel used for the horizontal axis will be displayed in the button.

Figure 12-4-2. Horizontal Axis button with Driving Channel selected

Options buttons for the Sweep Result graphs are as follows:

☐ cursors	Displays cursors on all sweep result graphs
⇅	Auto scales the graph to display the enter curve
☰	Allows for graphs to be rearranged by clicking and dragging graphs to the desired location. Re-click the button once rearrangement is complete.
← →	Moves to the previous or next page of graphs in the sweep results.

For more information about the Sweep Result workspace and Graphs View, please see Chapter 13.

Chapter 13. Sweep Tests

You can perform the Sweep Test in preparation mode. To do so, click the **Sweep Control** tab in Parameters Control View. You can plot any available system signal as a function of another signal you select as the driving channel. The system drives the selected driving signal by a sawtooth wave function of time while the change in the input signal is plotted. Figure 13-0-1 displays the sweep test process.

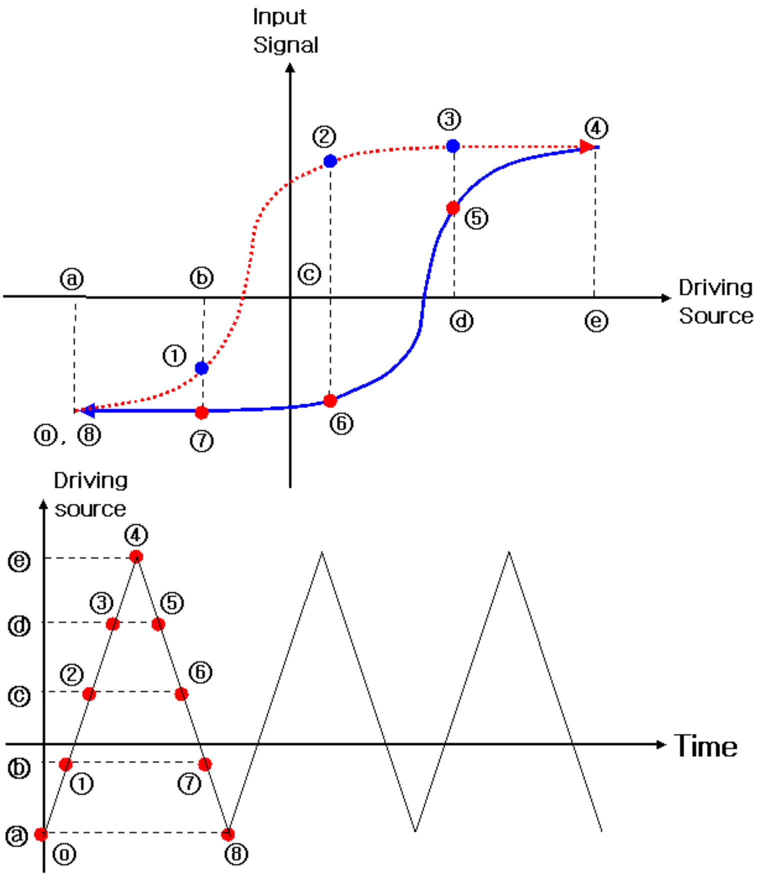


Figure 13-0-1 Sweep plotting

13-1. Sweep Result Workspace

The input signal is plotted as a function of the driving signal in the Sweep Result panel. Each signal selected as a monitoring channel will be plotted separately in a Sweep Result panel.

The horizontal X axis of the plot displays the signal you selected as the driving source. The vertical Y axis of the plot displays the signal you selected as a monitoring channel. The units per division of the Y is displayed in the upper left of the graph. The X axis at the bottom of each division value display is set according to the driving range (maximum voltage = 100%).

The yellow trace curve (called "forward") is a trace of the input signal while the driving source is increasing. In Figure 13-1-1 the yellow trace curve corresponds to a dotted curve plotted while the driving source changes from 0 to ④. The blue trace curve (called "backward") is a trace of the input signal while the driving source is decreasing from ④ to ⑧. In Figure 5-1, the blue trace curve corresponds to the solid line.

Sweep Result View will display up to four XY plots on one screen. More plots are stored in the following pages.

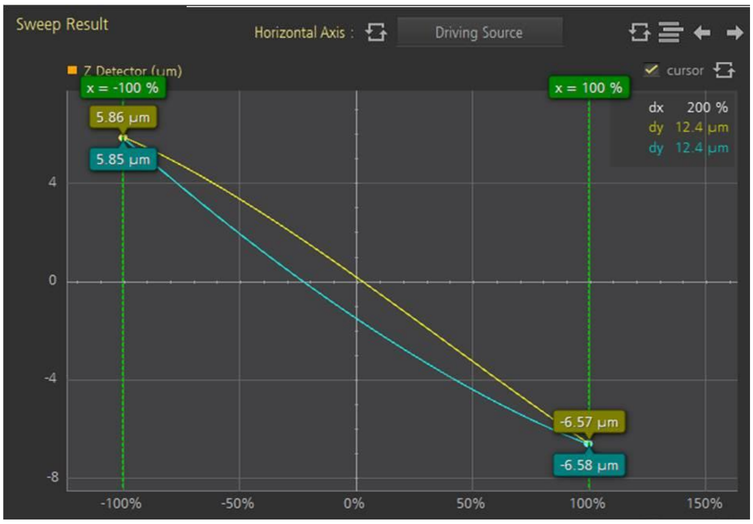


Figure 13-1-1 Sweep Result View

13-1-1. Horizontal Axis

It is possible to change the horizontal axis. Select the previously selected driving source, then select the desired signal from the pop-up channel list next to **Horizontal Axis**.

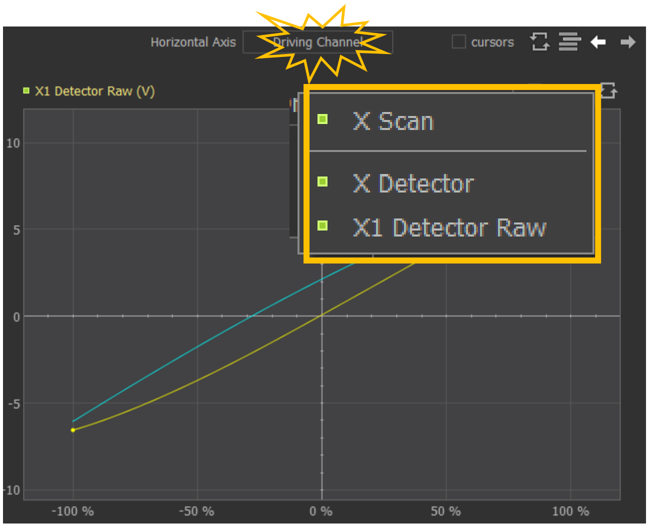


Figure 13-1-2. Changing horizontal axis

13-1-2. Rescale

Clicking this icon automatically scales all plots.

13-1-3. Relocate

Change the plot position. Clicking this icon allows selecting a plot using the mouse. Once a plot is selected, click and move it to the desired position.

13-1-4. Page Toggle

Click this icon to toggle the color scheme of Trace Sweep Results page from dark to light gray.

13-1-5. Previous / Next

Click these buttons to view the previous or next Trace Sweep Result page.

13-1-6. Cursor Check Box

☑ cursor Check this box to add the cursor pair in the graph. Click and drag to move the cursor. The X and Y position of the cursor is just a notation to trace/retrace the contact region, X between the cursor, Y interval (△ X, △ Y) is at the top of the graph is automatically indicated (see Figure 13-1-3. Cursors).

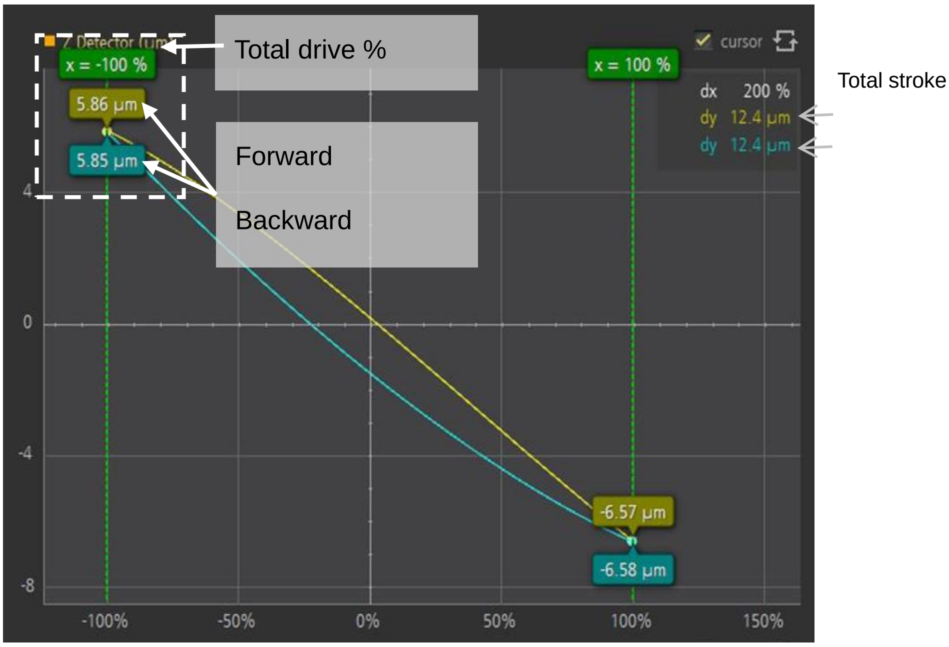
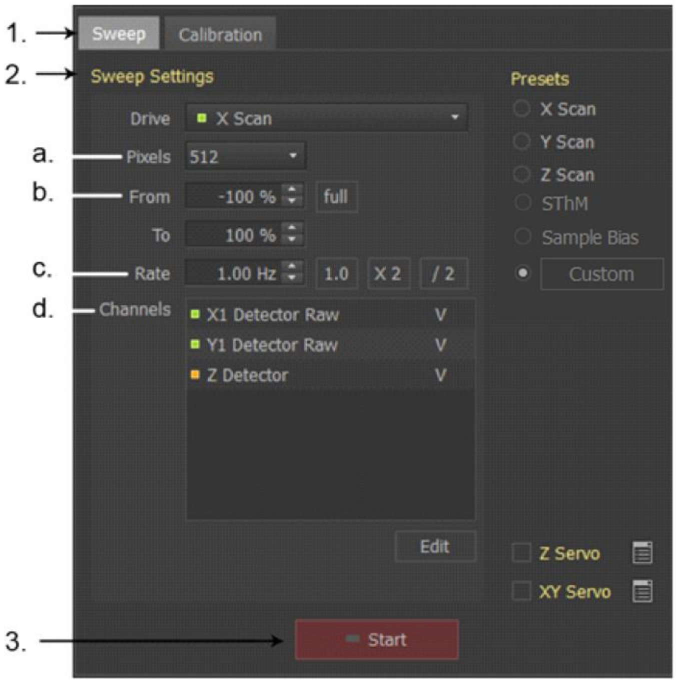


Figure 13-1-3. Cursors

Clicking ⟳ on the right of the **cursor** check box positions the cursor pairs at the minimum and maximum values in the X axis on the displayed signal. This is useful for checking the signal's full stroke at once.

13-2. Sweep Control Tab

In the **Sweep Control** tab of Parameters Control View, you can sweep the desired driving channel to view traces of selected signals versus the selected driving signal.



Drive: X Scan
Pixels: 512
From: -100 %
To: 100 %
Rate: 1.00 Hz
Channels:
- X1 Detector Raw V
- Y1 Detector Raw V
- Z Detector V

Figure 13-2-1. Sweep control tab

13-2-1. To Perform a Sweep Test

1. Click the drive signal to sweep.
2. Adjust sweep parameters:
    a. **Pixels**
    b. **To** and **From** range
    c. **Rate**
    d. **Channels** to be collected
3. Click **Start**.
4. Click **Cancel** to stop.

Drive

Clicking the selected driving source drop-down menu will display a list of signals that can be selected as a driving source. The signal selected as the driving source will be driven by a sawtooth wave function of time.

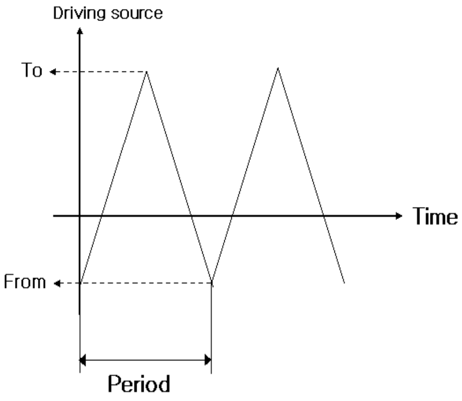


Figure 13-2-2. Driving source and definition of From/To and Period

The following drive signals are available:

- X Scan: the driving voltage of the XY scanner in the X axis
- Y Scan: the driving voltage of the XY scanner in the Y axis
- Z Scan: the driving voltage of the Z scanner
- Tip Bias: the voltage applied to the tip
- Sample Bias: the applying voltage of the sample
- AuxOut1: the output voltage of the Aux Out1 connector on the rear side of the NX controller
- SThM Probe Current: the applying voltage to the SThM probe (active only in SThM mode)

Pixels

From the **Pixel** drop-down menu, you can choose the number of the data points to acquire (64, 128, 256, 512, 1024, 2048, or 4096) for each curve.

From and To Range

You can set the limits of the driving source in the **From** and **To** fields. The maximum available range is from -100% to +100%. This range is selected by default. A value of -100% in the **From** field represents the minimum output voltage. A value of +100% represents the maximum output voltage. For example, if the available voltage range of the driving source is from -10 to 10, and **From** and **To** are set to -50% and 50%, respectively, the voltage range will be from -5V to 5V.

Clicking the **Full** button sets the range to the maximum range. It is recommended to use the maximum allowed range, but you can adjust the range by entering new values in the **From** and **To** fields.

Rate

Rate allows you to specify the sweep rate (sweep velocity of the sawtooth signal) of the driving signal. The sweep rate means the frequency of the back (driving range is changed from maximum to minimum) and forth (driving range is changed from minimum to maximum) of the driving signal. A 1Hz sweep rate indicates that one back and forth sweep of data is collected per second. Therefore the higher the rate value, the faster the sweep velocity.

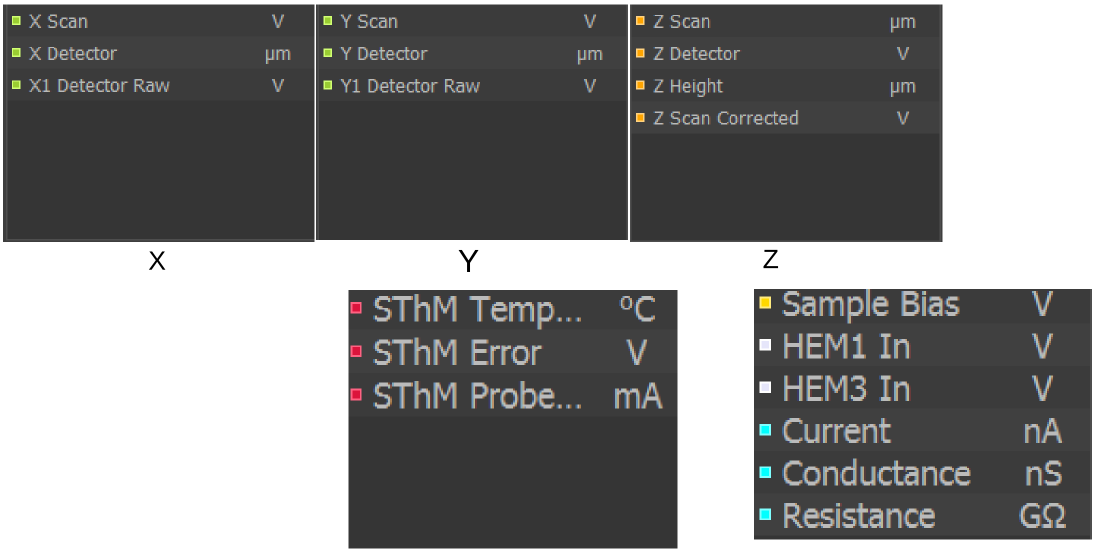
- **1.0**: Clicking this button directly changes the sweep rate to **1Hz** without requiring you to enter the value manually.
- **X2**: Clicking this button sets twice the current sweep rate value.
- **/2**: Clicking this button sets half the current sweep rate value.

Channels

The Channels List displays the selected signals that are monitored and acquired during the sweep. Channels can be added by choosing the channel presets for common sweep functions (X Scan, Y Scan, Z Scan, and Custom) OR by clicking the **Edit** button to display the Channels Config dialog for changing the signals.

- **Presets**

  Presets for X Scan, Y Scan, Z Scan, SThM, and Sample Bias are shown in Figure 13-2-3.



X Scan	V
X Detector	µm
X1 Detector Raw	V

X

Y Scan	V
Y Detector	µm
Y1 Detector Raw	V

Y

Z Scan	µm
Z Detector	V
Z Height	µm
Z Scan Corrected	V

Z

SThM Temp...	°C
SThM Error	V
SThM Probe...	mA

SThM

Sample Bias	V
HEM1 In	V
HEM3 In	V
Current	nA
Conductance	nS
Resistance	GΩ

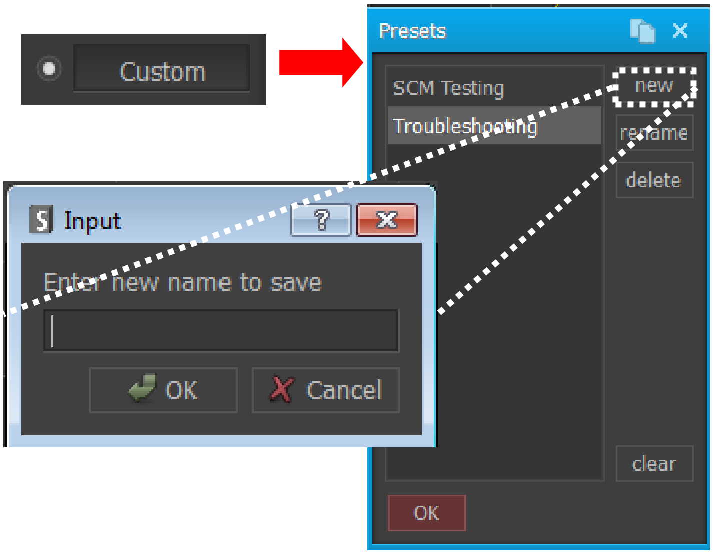
Sample Bias

Figure 13-2-3. Preset channels for sweep tests

- **Adding a Custom Preset**

  To add a custom set of channels to the Channels display, click the **Custom** radio button to open the Preset dialog. Click to highlight **Preset** from the Custom Preset list and click **OK**.

  To create new group of presets, add the desired channels to the channel display using the **Edit** button. Click the **new** button to save the a new preset with the desired name.



Enter new name to save

Figure 13-2-4. Creating a custom preset

- **Renaming a Presets Group**

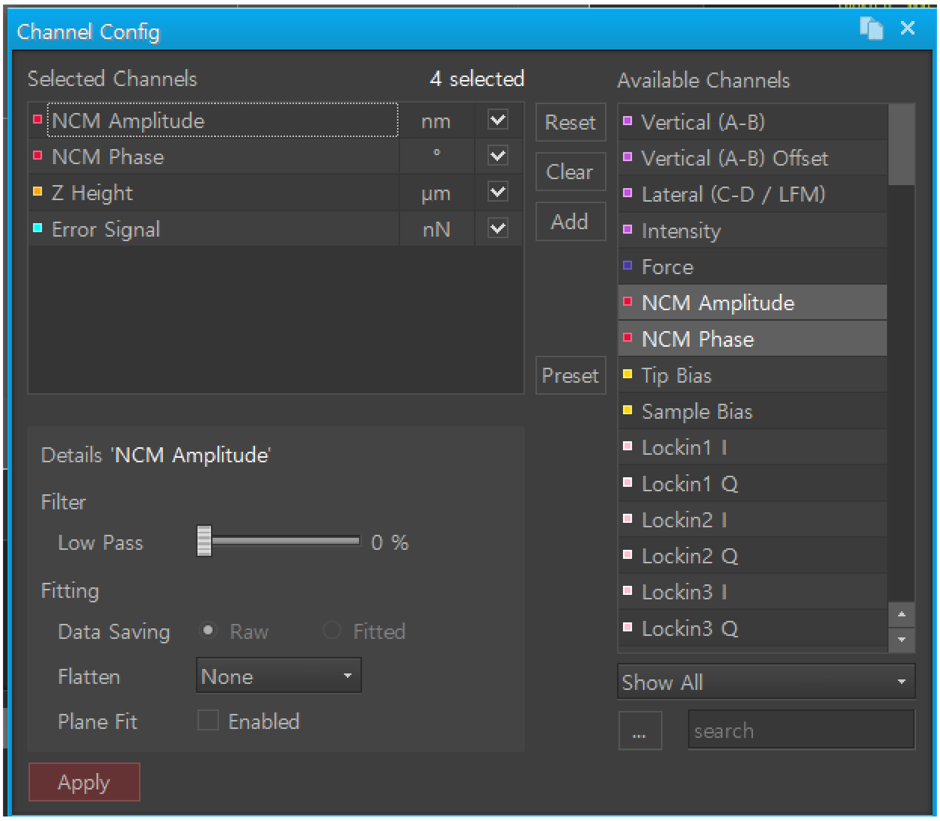
  Click the desired preset to highlight it. Then click the **rename** button to open a dialog window to set the new name. Click **OK** to finish.

- **Deleting a Presets Group**

  On the Presets list, select the presets group to remove, and then click the **delete** button.

Edit

The **Edit** button opens the Channel Config dialog. You can select the desired signal channels to be acquired by checking the box beside the channel name. The display of channels for selection can be simplified by signal group setting (all, selected, recently used, PSPD related, detector, XY scanner, Z scanner, each head mode, and lock-in signals are grouped). You can also use the signal filter field to filter your results. Click **Clear** to delete signals from the displayed channels. See Section 8-3-1 for more information about using the Channel Config dialog.



4 selected

Selected Channels	Unit	
NCM Amplitude	nm	☑
NCM Phase	°	☑
Z Height	µm	☑
Error Signal	nN	☑

Available Channels:
- Vertical (A-B)
- Vertical (A-B) Offset
- Lateral (C-D / LFM)
- Intensity
- Force
- NCM Amplitude
- NCM Phase
- Tip Bias
- Sample Bias
- Lockin1 I
- Lockin1 Q
- Lockin2 I
- Lockin2 Q
- Lockin3 I
- Lockin3 Q

Show All

Details 'NCM Amplitude'

Filter

Low Pass 0 %

Fitting

Data Saving ● Raw ○ Fitted

Flatten None

Plane Fit ☐ Enabled

Figure 13-2-5. Channel Config

Z Servo

Turns on the Z Servo during the sweep test. Clicking the ▤ button opens the Z Servo Configuration dialog. See Section 8-4-5 for more information about the Z Servo Config dialog.

XY Servo

Turns on the XY servo during the sweep test. Clicking the ▤ button opens the XY Servo Configuration dialog. See Section 8-4-11 for more information about the XY Servo Config dialog.

Start/Cancel

Clicking the **Start** button initiates sweeping the selected driving channel in order to generate the sweep trace plot. After clicking **Start**, the button is changed to the **Cancel** button. Click **Cancel** to stop sweeping the driving signal.

Index

A

A-B, 73, 74, 93, 94, 95

Adaptive, 145

Advanced, 138

Approach, 40, 52

Aux DAC, 64

C

Calibration

  Cantilever, 216, 219

Change NCM Drive, 155

Contrast

  Level Adjustment, 200

  Max, 199

  Min, 199

  range, 199

Copy/Capture Plots, 24

Current Amplifier, 58, 60, 62

D

Data Count

  F/d Spectroscopy, 176

deflection signal, 95

Detector driven sampling, 143

Down Speed

  F/d Spectroscopy, 176

Drive, 47

E

End Voltage

  I/V Spectroscopy, 179

Error Bound, 147

F

F/d curve, 160

feedback signal, 95

Flattening, 88, 121

Follow Slope Line, 155

Force Limit

  F/d Spectroscopy, 176

Freq Sweep, 43

frictional information, 74, 94

H

Hardware Info, 25

Highest

  F/d Spectroscopy, 175

  I/V Spectroscopy, 178

histogram, 201

Hold

  XY Servo Scan, 153

Hold time, 181

HoldTime

  I/V Spectroscopy, 176, 179

I

I Gain, 139

Incremental Approach, 130

Input Config

  Flattening, 88, 121

  Low Pass Filtering(LPF), 88, 120

  Plane Fit, 89, 121

Intensity, 74, 94, 95

I/V curve, 160

K

Key Input, 39

Keyboard Control

  Z/Focus, 39

L

Lateral, 93

LATERAL, 74, 94

Lateral Deflection, 74, 94

License Qt, 25

Lift Height

  Spectroscopy Config, 162

Load Speed, New Nanoindentation, 181

Low Pass Filtering(LPF)

  Input Config, 88, 120

Lowest

  I/V Spectroscopy, 178

M

Monitor view

  Z Scanner bar, 96

O

Offset X, Y, 106, 135

Oscilloscope screen, 112

Over scan, 143

P

P Gain, 139

Palette panel, 198

Param

  TwoPass Scan, 154

Parameters Control

  Advanced, 138

  Offset X,Y, 135

  Pixels, 134

  Pulse Generation, 141

  Rotation, 135

  Sample Bias, 140

  Scan Rate, 132

  Set Point, 137

  Size, 134

  Tip Bias, 140

  Tip-Sample Distance, 154

Park Systems Logo, 19

Pixels, 134

Plane Fit, 89, 121

PSPD, 73, 93, 94

Q

Quick & Safe Approach, 129

Quick Approach, 129

R

reference signal, 95, 137

Reset Stages, 39

Reset(XY), 43

Retract Z All, 40

Reverse

  I/V Spectroscopy, 178

Rotation, 135

S

Sample Bias, 140

Scan Area Mode

  Rotate Scan Area, 107, 192

Scan Options

  Detector driven sampling, 143

  Over scan, 143

  Sine scan, 142

  Skip scan, 144

  Two-way Scan, 144

Scan Rate, 132

Scan Traces View, 90, 111

scanner nonlinearity, 153

PowerScript, 53, 54

Servo error bar, 95

Servo error bar, 95

Servo error signal, 94, 95

Servo Error signal, 136

Set Point, 137

  F/d Spectroscopy, 176

Settling Time, 163

Show Pair Cursor, 114

Sidebar, 16

Signal Name List, 114

Sine scan, 142

Size, 134

Skip scan, 144

Start Voltage

  I/V Spectroscopy, 179

T

Tiff

  What is, 2

  Why, 2

Tip Bias, 140

Title Bar, 13, 14

Toggle Line Sync Output, 155

Topographic information, 73, 94

Trace control Window

  Signal Name List, 114

Trace Line Analysis

  - Show Pair Cursor, 114
- Turn Off AFM Laser, 155
- TwoPass Scan
  - **Change NCM Drive**, 155
  - **Follow Slope Line**, 155
  - Preference, 154
  - Toggle Line Sync Output, 155
  - Turn off AFM Laser, 155
- Two-way Scan, 144

U

- Uninstallation, 9
- **Unload limit**, 181
- **Up Speed**
  - **F/d Spectroscopy**, 176
- **Use Current Set Point**, 162

V

- vertical deflection, 73, 94
- Vision View, 71

X

- XEI, 1
- **XY Move Speed**, 161
- XY Servo
  - Hold, 153
- XY Stage, 40

Z

- Z feedback loop, 95
- **Z Offset**
  - **F/d Spectroscopy**, 176
  - **F/d Spectroscopy**, 177
- Z scanner bar, 96
- Z Slope, 132
- Z Stage
  - Z Stage pad, 36
- Z/F Stage, 30, 31, 36

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If during the course of using this manual you come upon any errors, inaccuracies, or procedural inconsistencies, or if you have other content suggestions, please take the time to forward your comments to us for consideration in future manual revisions.

Please check that you think this comment is critical ( ) or moderate ( ) or minor ( ).

Comments:

Customer Information

Name:	Date:
Company/Institution:	System model:
Address:	E-mail:
Country:	Fax:
	Phone:

Please email this form to Park Systems:

Email:	CS@parksystems.com
Website:	www.parksystems.com

XEI

Powerful Image Processing Tool for SPM Data

Software Manual

Version 1.8.5

XEI Software 4.3.4 Build22

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Preface

This document is an instruction manual for XEI, an Image Processing Program for SPM data developed by Park Systems. XEI, developed in Java, can be run on any machine that supports Java Virtual Machine (JVM). This manual discusses in detail the software features of the XEI program.

This manual explains the image analysis features in accordance with the standard analyzing features useful for handling SPM data. This document describes, in detail, every item that is displayed in XEI's user interface, and offers a wealth of information regarding the use of a variety of analyzing tools and image processing modes to produce enhanced images. It is quite important to make good use of the XEI image processing program, just as it is important to collect the best possible data utilizing the XEP data acquisition program. The XEI software will allow you to maximize the system's potential, however, by providing the ability to remove certain artifacts from scan data and by allowing you to extract more information from the sample surface by utilizing various analysis tools.

The contents of this manual are organized as follows. First, an overview of the main categories in the XEI is provided so that you may browse for items of interest. Then, the main processing and analyzing tools are more elaborately discussed in each chapter. This software manual pays attention to all available modes and toolbars and discusses their basic functions so that you can apply them to your data with ease.

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Contents

Contents* *1

Figure Contents* *5

Chapter 1. Overview of XEI* *1

1-1. Overall Features in XEI 1

1-2. Installation of Park Systems XEI' Software 7

Chapter 2. Menus & Toolbar* *17

2-1. File 17

2-2. Edit 25

2-3. Mode 26

2-4 Navigator 26

2-5. Analysis 26

2-6. Process 36

2-7. Effect 49

2-8. Help 49

Chapter 3. Analysis View* *51

3-1. Information View 51

3-2. Line View 67

3-3. Region View 85

3-4. Grain View 96

3-5. PSD View 106

3-6. Roughness View 113

3-7. Fractal View 117

3-8. 3D View 120

3-9. Multi Line View 137

3-10. Multi View 138

Chapter 4. Crop* *141

4-1. Crop Process Dialog 141

4-2. Crop an Image 142

Chapter 5. Arithmetic Filter 145
5-1. Filter Process Dialog 145
5-2. Smoothing 146
5-3. Sharpening 148
5-4. Edge Enhancement 148
5-5. Custom 149
Chapter 6. Flatten 151
6-1. Flatten Process Dialog 152
6-2. Flatten an Image 157
Chapter 7. Deglitch 159
7-1. Deglitch Process Dialog 159
7-2. Deglitch an Image 161
Chapter 8. Region Deglitch 163
8-1. Region Deglitch Process Dialog 163
8-2. Region Deglitch an Image 165
Chapter 9. Fourier Filter 169
9-1. Fourier Filter Process Dialog 169
9-2. 2D Power Spectrum 170
9-3. Apply the Fourier Filter to an Image 171
Chapter 10. Tip Estimation 175
10-1. Tip Estimation Process Dialog 176
10-2. Applying Tip Estimation process to the Image 178
Chapter 11. Rotate & Flip 180
11-1. Rotate & Flip Process Dialog 180
11-2. Rotate & Flip an Image 181
Chapter 12. Pixel Manipulation 183
12-1. Pixel Manipulation Process Dialog 183
12-2. Applying Pixel Manipulation 184
Chapter 13. Unary Arithmetic 185
13-1. Unary Arithmetic Process Dialog 185
13-2. Applying Unary Arithmetic 186
Chapter 14. Binary Arithmetic 187
14-1. Binary Arithmetic Process Dialog 187

14-2. Applying Binary Arithmetic 188

Chapter 15. Spectroscopy Mode 191

15-1. Views 191

15-2. Processes 211

Chapter 16. Surface Analysis 217

16-1. Palette Panel, Image Display Panel and Histogram 219

16-2. Region Selection toolbar 219

16-3. Surface Statistics Panel 220

15-4. Angle Statistics Panel 222

16-5. Space Statistics Panel 223

Chapter 17. Stitch 225

17-1. Stitch Process Dialog 225

17-2. Stitching Images 226

Appendix A. XEI Keyboard Shortcut 229

Figure Contents

FIGURE 1-1-1. XEI - IMAGE PROCESSING PROGRAM 1
FIGURE 1-1-2. TITLE BAR IN A PREVIEW SCREEN 2
FIGURE 1-1-3. MENU BAR 3
FIGURE 1-1-4. TOOLBAR 3
FIGURE 1-1-5. ANALYSIS VIEW (IN LINE VIEW) 4
FIGURE 1-1-6. NAVIGATOR VIEW 5
FIGURE 1-1-7. DRAG AND DROP IMAGES INTO THE NAVIGATOR VIEW 6
FIGURE 1-1-8. CONTEXT MENU IN THE NAVIGATOR VIEW 7
FIGURE 2-1. MENU BAR 17
FIGURE 2-1-1. FILE MENU 18
FIGURE 2-1-2. OPEN DIALOG 18
FIGURE 2-1-3. 'SAVE' WARNING MESSAGE BOX 19
FIGURE 2-1-4. SAVE AS DIALOG 19
FIGURE 2-1-5. PREVIEW SCREEN 20
FIGURE 2-1-6. EXPORT DIALOG 21
FIGURE 2-1-7. PREFERENCES DIALOG 22
FIGURE 2-1-8. 'EXIT' CONFIRMATION MESSAGE BOX 23
FIGURE 2-1-9. BATCH EXPORT DIALOG 24
FIGURE 2-2-1. EDIT MENU 25
FIGURE 2-5-1. ANALYSIS MENU AND TABS 27
FIGURE 2-5-2. INFORMATION VIEW 27
FIGURE 2-5-3. LINE VIEW 28
FIGURE 2-5-4. REGION VIEW 29
FIGURE 2-5-5. GRAIN VIEW 30
FIGURE 2-5-6. PSD VIEW 31
FIGURE 2-5-7. FRACTAL VIEW 32
FIGURE 2-5-8. SURFACE VIEW 33
FIGURE 2-5-9. 3D VIEW 34
FIGURE 2-5-10. MULTI VIEW 35

FIGURE 2-6-1. PROCESS MENU AND TOOLBAR 36
FIGURE 2-6-2. CROP PROCESS DIALOG 37
FIGURE 2-6-3. FILTER PROCESS DIALOG 38
FIGURE 2-6-4. FLATTEN PROCESS DIALOG 39
FIGURE 2-6-5. DEGLITCH PROCESS DIALOG 40
FIGURE 2-6-6. FOURIER FILTER PROCESS DIALOG 41
FIGURE 2-6-7. FOURIER FILTER PROCESS DIALOG 42
FIGURE 2-6-8. FOURIER FILTER PROCESS DIALOG 43
FIGURE 2-6-9. ROTATE & FLIP PROCESS DIALOG 44
FIGURE 2-6-10. PIXEL MANIPULATION PROCESS DIALOG 45
FIGURE 2-6-11. UNARY ARITHMETIC PROCESS DIALOG 46
FIGURE 2-6-12. BINARY ARITHMETIC PROCESS DIALOG 47
FIGURE 2-6-13. STITCH PROCESS DIALOG 48
FIGURE 2-7-1. EFFECT MENU 49
FIGURE 2-8-1. ABOUT DIALOG 49
FIGURE 3-1-1. INFORMATION VIEW 51
FIGURE 3-1-2. PALETTE PANEL 52
FIGURE 3-1-3. CONTRAST RANGE ADJUSTMENT 54
FIGURE 3-1-4. CONTRAST LEVEL ADJUSTMENT 55
FIGURE 3-1-5. ENHANCED COLOR 55
FIGURE 3-1-6. (UPPER) ZOOM IN, (DOWN) ZOOM OUT 56
FIGURE 3-1-7. PAN 57
FIGURE 3-1-8. IMAGE DISPLAY PANEL OF THE INFORMATION VIEW 58
FIGURE 3-1-9. ‘LOAD’ CONFIRMATION MESSAGE BOX 58
FIGURE 3-1-10. HISTOGRAM 59
FIGURE 3-1-11. CURSORS ON HISTOGRAM 60
FIGURE 3-1-12. CURSORS ON HISTOGRAM 61
FIGURE 3-1-13. CURSORS ON HISTOGRAM 61
FIGURE 3-1-14. INFORMATION TABLE (HIDE DETAILS) 62
FIGURE 3-2-1. PROCEDURE FOR LINE VIEW 68
FIGURE 3-2-2. LINE VIEW 69
FIGURE 3-2-3. LINE SELECTION TOOLBAR 71
FIGURE 3-2-4. MOVE A LINE FOR LINE VIEW 72
FIGURE 3-2-5. CREATE A SLANTED LINE 73
FIGURE 3-2-6. CONTROL AN AVERAGE LINE REGION 74
FIGURE 3-2-7. SHOW ANGLE BETWEEN TWO LINES 76

FIGURE 3-2-8. USE ENHANCED COLOR 76
FIGURE 3-2-9. CONTEXT MENU IN THE LINE PROFILE 77
FIGURE 3-2-10. CURSOR PAIR AND DISPLAYED INFORMATION 79
FIGURE 3-2-11. MOVING CURSORS BY MOUSE 79
FIGURE 3-2-12. PROFILE RANGE 80
FIGURE 3-2-13 POWER SPECTRUM PANEL 82
FIGURE 3-2-14. LINE STATISTICS TABLE 82
FIGURE 3-2-15. LINE HISTOGRAM PANEL 85
FIGURE 3-3. PROCEDURE FOR REGION VIEW 86
FIGURE 3-3-1. REGION VIEW 86
FIGURE 3-3-2. REGION GROUP 88
FIGURE 3-3-3. REGION VIEW 89
FIGURE 3-3-4. REGION VIEW 91
FIGURE 3-3-5. REGION HISTOGRAM PANEL 92
FIGURE 3-3-6. BEARING RATIO DISPLAY 93
FIGURE 3-3-7. CURSOR PAIR AND DISPLAYED INFORMATION 94
FIGURE 3-3-8. LINE STATISTICS TABLE 95
FIGURE 3-4-1. THRESHOLD GRAIN DETECTION 98
FIGURE 3-4-2. THRESHOLD GRAIN DETECTION PROCESS 99
FIGURE 3-4-3. WATERSHED GRAIN DETECTION PROCESS 100
FIGURE 3-4-4. EFFECT OF FILTERING ON 'WATERSHED' GRAIN DETECTION 101
FIGURE 3-4-5. EFFECT OF FILTER LEVEL ON GRAIN DETECTION. GRAIN DETECTION RESULTS WITH FILTER LEVEL 4 (LEFT) AND FILTER LEVEL 2.5 (RIGHT). 101
FIGURE 3-4-6. MULTIPLE GRAIN SELECTION 102
FIGURE 3-4-7. SHOW ALL AND SHOW VALLEY 103
FIGURE 3-4-8. STATISTICS TABLE 105
FIGURE 3-4-9. STATISTICS TABLE 105
FIGURE 3-5. PSD VIEW 106
FIGURE 3-5-1A. TWO SYNTHETIC IMAGES OF SAME ROUGHNESS 107
FIGURE 3-5-1B. PSD OF TWO SYNTHETIC IMAGES OF SAME ROUGHNESS 108
FIGURE 3-5-2A. PSD 2D 109
FIGURE 3-5-2B. PSD X AXIS 109
FIGURE 3-5-2C. PSD Y AXIS 109
FIGURE 3-5-2D. PSD CONTEXT MENU 110
FIGURE 3-5-2E. PSD SHOW CURSOR PAIR 110
FIGURE 3-5-2F. PSD AXIS OPTIONS 111

FIGURE 3-5-3. PSD STATISTICS & HISTOGRAM...112
FIGURE 3-6. ROUGHNESS VIEW 113
FIGURE 3-6-1. CALCULATION OF SK, SMR1 AND SMR2...115
FIGURE 3-7. PROCEDURE FOR FRACTAL VIEW...117
FIGURE 3-7-1. LAYOUT OF FRACTAL VIEW 118
FIGURE 3-8. PROCEDURE FOR 3D VIEW 121
FIGURE 3-8-1. LAYOUT OF 3D VIEW...122
FIGURE 3-8-2. 3D IMAGE DISPLAY PANEL...123
FIGURE 3-8-3. 3D RENDERING PARAMETERS...124
FIGURE 3-8-4. SAMPLING NUMBERS 125
FIGURE 3-8-5. TRANSFORMED 3D IMAGE 126
FIGURE 3-8-6. ENABLE PERSPECTIVE 129
FIGURE 3-8-7. SHOW WIRE FRAME 130
FIGURE 3-8-8. SHOW XY AXIS 131
FIGURE 3-8-9. SHOW Z AXIS..132
FIGURE 3-8-10. FILL BORDER 133
FIGURE 3-8-11. USE ENHANCED COLOR 134
FIGURE 3-8-12. IMAGE OVERLAY 135
FIGURE 3-8-13. RESTORE DEFAULTS 136
FIGURE 3-9. LAYOUT OF MULTI LINE VIEW...137
FIGURE 3-9-1.TOP OF TOOLBAR 137
FIGURE 3-10. PROCEDURE TO GENERATE MULTI IMAGES..138
FIGURE 3-10-1. MULTI VIEW WITH DIFFERENT NUMBERS OF IMAGES LOADED.....................139
FIGURE 3-10-2. COMPARE IMAGES USING FIGURES 140
FIGURE 4-1-1. CROP PROCESS DIALOG 142
FIGURE 4-1-2. ROTATION...143
FIGURE 5-1. FILTER PROCESS DIALOG 146
FIGURE 6-1. 1D EXAMPLE OF THE FLATTENING..151
FIGURE 6-1-1. FLATTEN PROCESS DIALOG..152
FIGURE 6-1-2. HEIGHT RESTRICTION MARKERS IN THE HISTOGRAM 154
FIGURE 6-1-3. LINE PROFILES WITH FITTING CURVES...156
FIGURE 6-2. PROCEDURE TO FLATTEN AN IMAGE..158
FIGURE 7-1-1. DEGLITCH PROCESS DIALOG 159
FIGURE 7-1-2. DEGLITCHED IMAGE...160
FIGURE 7-2-1. PROCEDURE TO DEGLITCH AN IMAGE...162
FIGURE 8-1-1. REGION DEGLITCH PROCESS DIALOG 163

FIGURE 8-2-1. AUTO REGION DEGLITCH......165
FIGURE 8-2-2. AUTO DEGLITCHED IMAGE......166
FIGURE 8-2-3. MANUAL REGION DEGLITCH......167
FIGURE 8-2-4. MANUAL DEGLITCHED IMAGE......167
FIGURE 9-1-1. FOURIER FILTER PROCESS DIALOG......170
FIGURE 9-2-1. 2D POWER SPECTRUM......171
FIGURE 9-3-1. PROCEDURE TO APPLY THE FOURIER FILTER TO AN IMAGE......173
FIGURE 9-3-2. FOURIER FILTER APPLIED TO ATOMIC LATTICE IMAGE......173
FIGURE 10-1. EXAMPLE OF TIP CONVOLTION......175
FIGURE 10-1-1. TIP ESTIMATION PROCESS DIALOG......176
FIGURE 10-1-2. ESTIMATED TIP SHAPE SAVED AS TIFF FILE......177
FIGURE 10-2-1. APPLICATION OF TIP ESTIMATION......179
FIGURE 11-1-1. ROTATE & FLIP PROCESS DIALOG......180
FIGURE 12-1-1. PIXEL MANIPULATION PROCESS DIALOG......183
FIGURE 12-2-1. PERFORM PIXEL MANIPULATION......184
FIGURE 13-1-1. UNARY ARITHMETIC PROCESS DIALOG......185
FIGURE 13-2-1. APPLY UNARY ARITHMETIC......186
FIGURE 14-1-1. BINARY ARITHMETIC PROCESS DIALOG......187
FIGURE 14-2-1. START BINARY ARITHMETIC......188
FIGURE 14-2-2. SELECT SECOND IMAGE......189
FIGURE 14-2-3. BINARY ARITHMETIC RESULT......189
FIGURE 15-1-1. INFORMATION VIEW......192
FIGURE 15-1-2. BATCH VIEW FIGURE......192
FIGURE 15-1-3. REFERENCE AND VOLUME......193
FIGURE 15-1-4. VOLUME IMAGE EXPORT......193
FIGURE 15-1-5. VOLUME OPTION......194
FIGURE 15-1-6. IMAGE DISPLAY PANEL (ENLARGED AND NORMAL VIEW)......195
FIGURE 15-1-7. POINTS TABLE......196
FIGURE 15-1-8. LINE DISPLAY PANEL......197
FIGURE 15-1-9. ZOOM IN......197
FIGURE 15-1-10. LINE DISPLAY CONTEXT MENU......198
FIGURE 15-1-11. CURSOR STATISTICS TABLE......200
FIGURE 15-1-12. ADDDING TRACE LINES TO POINT DATA......201
FIGURE 15-1-13. POINT DATA TABLE......201
FIGURE 15-1-14. EXPORT PANEL......202
FIGURE 15-1-15. BASIC INFORMATION PANEL......202

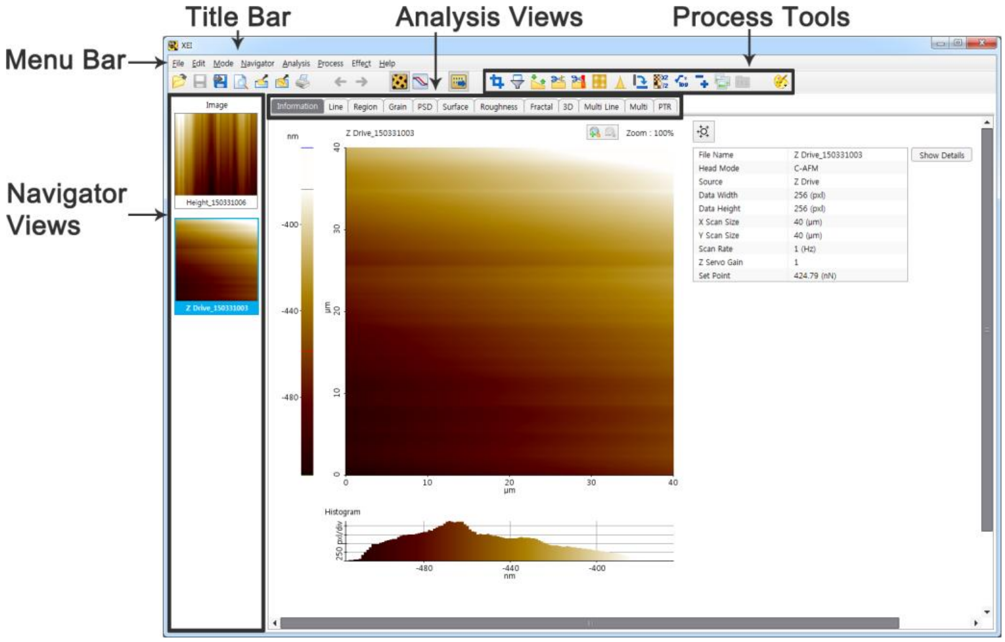
FIGURE 15-1-16. MULTI VIEW 203
FIGURE 15-1-17. POINTS TABLE 204
FIGURE 15-1-18. LINE DISPLAY PANEL.. 205
FIGURE 15-1-19. CURSOR STATISTICS TABLE 205
FIGURE 15-1-20. YOUNG'S MODULUS VIEW.. 206
FIGURE 14-1-21. CALCULATING YOUNG'S MODULUS AND HARDNESS(OLIVER & PHARR) .. 209
FIGURE 15-1-22. ACQUIRING YOUNG'S MODULUS AND HARDNESS(HERTZIAN) 210
FIGURE 15-1-23. ACQUIRING YOUNG'S MODULUS AND HARDNESS (OLIVER AND PHARR).. 211
FIGURE 15-2-1. PROCESS TOOL BAR 211
FIGURE 15-2-2. OFFSET PROCESS DIALOG 212
FIGURE 15-2-3. FORCE CONSTANT PROCESS DIALOG.. 213
FIGURE 15-2-4. SENSITIVITY CALIBRATION.. 214
FIGURE 15-2-5. FILTER PROCESS DIALOG 215
FIGURE 15-2-6. FILTERING WITH VARIOUS KERNEL SIZES 216
FIGURE 16-1. PROCEDURE FOR REGION VIEW 218
FIGURE 16-2. SURFACE VIEW.. 219
FIGURE 16-3-1. 1 BY 1 PIXEL SURFACE AREA.. 221
FIGURE 16-3-2. FILTER.. 222
FIGURE 16-3-3. A45.. 223
FIGURE 17-1-1. STITCH PROCESS DIALOG.. 225

Chapter 1. Overview of XEI

XEI is an excellent software program that provides user-friendly and dynamic tools for image processing, quantitative analysis and statistics, and export and printing of processed images and measurement results. This chapter provides an overview of the features and controls in the XEI program so that you can be more familiar with its layout and capabilities.

1-1. Overall Features in XEI

To open the XEI program, double click the XEI icon on your computer's desktop. Figure 1-1-1 shows the XEI screen appearance that is displayed when starting up the XEI program.

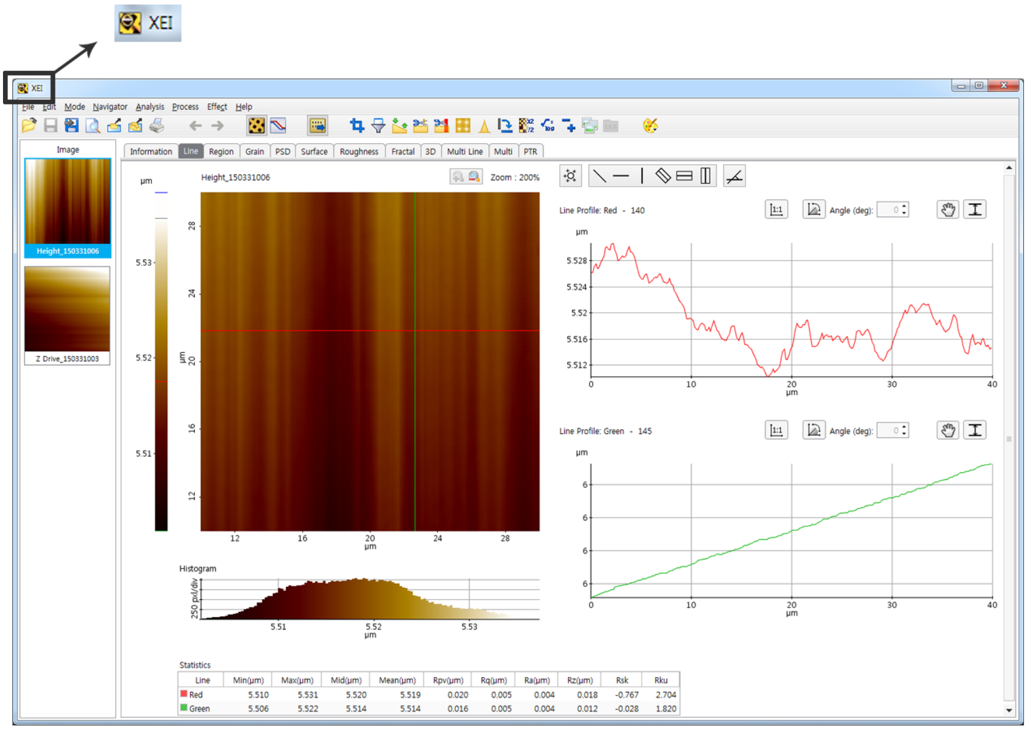


File Name	Z Drive_150331003
Head Mode	C-AFM
Source	Z Drive
Data Width	256 (pxl)
Data Height	256 (pxl)
X Scan Size	40 (µm)
Y Scan Size	40 (µm)
Scan Rate	1 (Hz)
Z Servo Gain	1
Set Point	424.79 (nN)

Figure 1-1-1. XEI - Image Processing Program

1-1-1. Title Bar

The Title bar displays the title of the image processing program, XEI. Also, in the preview screen, it indicates the Analysis view type (Information, Line, Region, 3D, and Multi) you want to preview. For example, in Figure 1-1-2, the Title bar indicates that the screen is displaying the preview of the Line view of the selected image.



Statistics

Line	Min(µm)	Max(µm)	Mid(µm)	Mean(µm)	Rpv(µm)	Rq(µm)	Ra(µm)	Rz(µm)	Rsk	Rku
🟥 Red	5.510	5.531	5.520	5.519	0.020	0.005	0.004	0.018	-0.767	2.704
🟩 Green	5.506	5.522	5.514	5.514	0.016	0.005	0.004	0.012	-0.028	1.820

Figure 1-1-2. Title bar in a preview screen

1-1-2. Menu Bar

The Menu bar includes several groups of menu items that are available for working with SPM images. A more detailed explanation is provided in Chapter 2. “Menus & Toolbar”. Figure 1-1-3 shows menus, menu items and related icons.

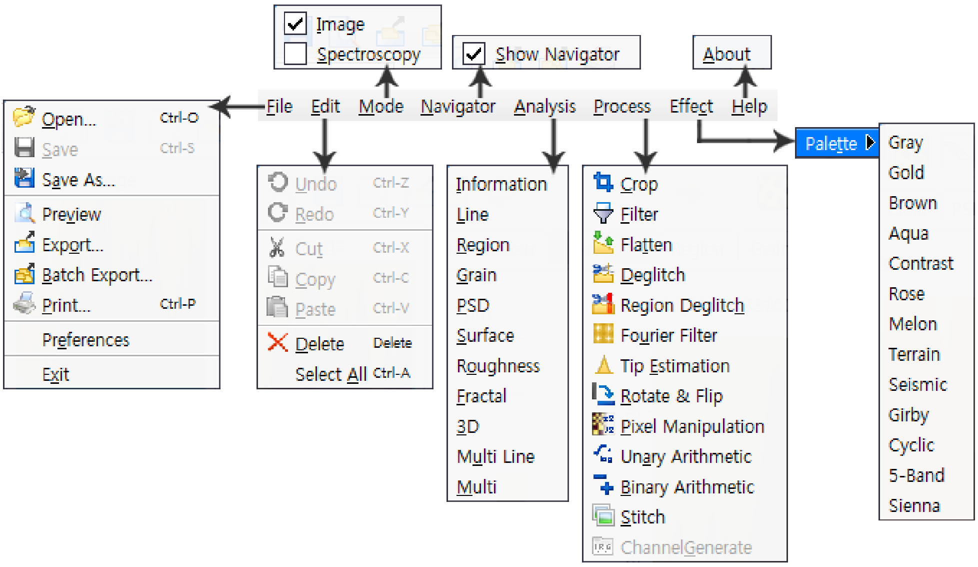


Figure 1-1-3. Menu bar

1-1-3. Toolbar

The Toolbar, shown in Figure 1-1-4, offers many icons for direct access to the most frequently used basic functions. A more detailed description of the Toolbar is also provided in Chapter 2. “Menus & Tool bar”

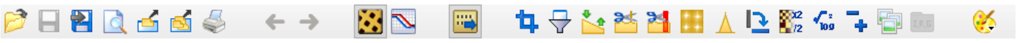


Figure 1-1-4. Toolbar

1-1-4. Analysis View

The Analysis view is a worktable that allows you to work with the selected image and to perform image processing and quantitative analysis on an image. As shown in Figure 1-5-1, the Analysis view of the XEI has three parts: Analysis view tabs, Image display panel and Analysis result & parameters display panel.

Above the Analysis view, there are seven tabs for opening the analysis view: Information, Line, Region, Grain, PSD, 3D, and Multi. When you click each tab, the Analysis view will be switched to the view you selected.

At the left side of the Analysis view, is the Image display panel that displays an image with the palette panel and Histogram panel. You can display the image that you want to process and analyze in the Image display. To bring an image file into the Image display panel, double-click the image from the Navigator view.

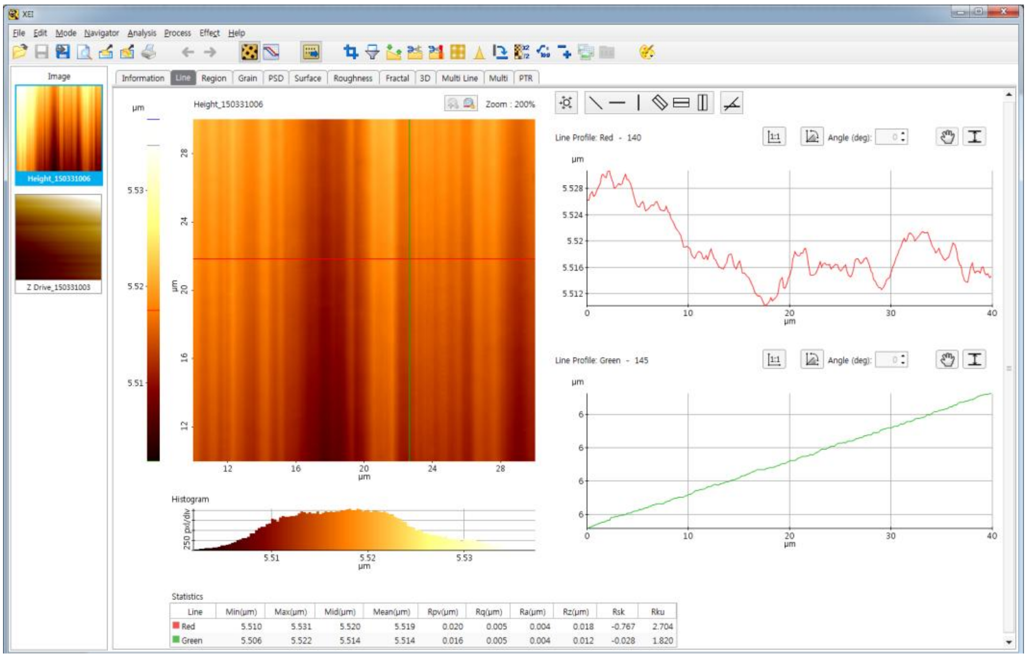
WARNING!

The contrast color in an image that was generated in the older version XEP program (XEP 1.0) may be reversed. The darker color represents a higher height and the brighter color represents a lower height value. Please, reset the contrast settings so that the brighter color should be the higher height.

In the Image display panel, you can do the following things:

- Load an image from your hard disk into the Image display panel via the Navigator view
- Adjust the color scale of an image with the palette panel
- Preview and print an image in the Image display panel

The right panel of the Analysis view varies according to the selected Analysis view. That is, it displays an information table in the Information view; several data plots in the Line or Region view; and 3D rendering parameters in the 3D view. Also, in the Multi view, the Analysis view displays multiple images at one time. Figure 1-5-1 shows the Analysis view of the Information view. Each Analysis view is described further in each related chapter.



Line	Min(μm)	Max(μm)	Mid(μm)	Mean(μm)	Rpv(μm)	Rq(μm)	Ra(μm)	Rz(μm)	Rsk	Rku
🟥 Red	5.510	5.531	5.520	5.519	0.020	0.005	0.004	0.018	-0.767	2.704
🟩 Green	5.506	5.522	5.514	5.514	0.016	0.005	0.004	0.012	-0.028	1.820

Figure 1-1-5. Analysis View (in Line view)

1-1-5. Navigator View

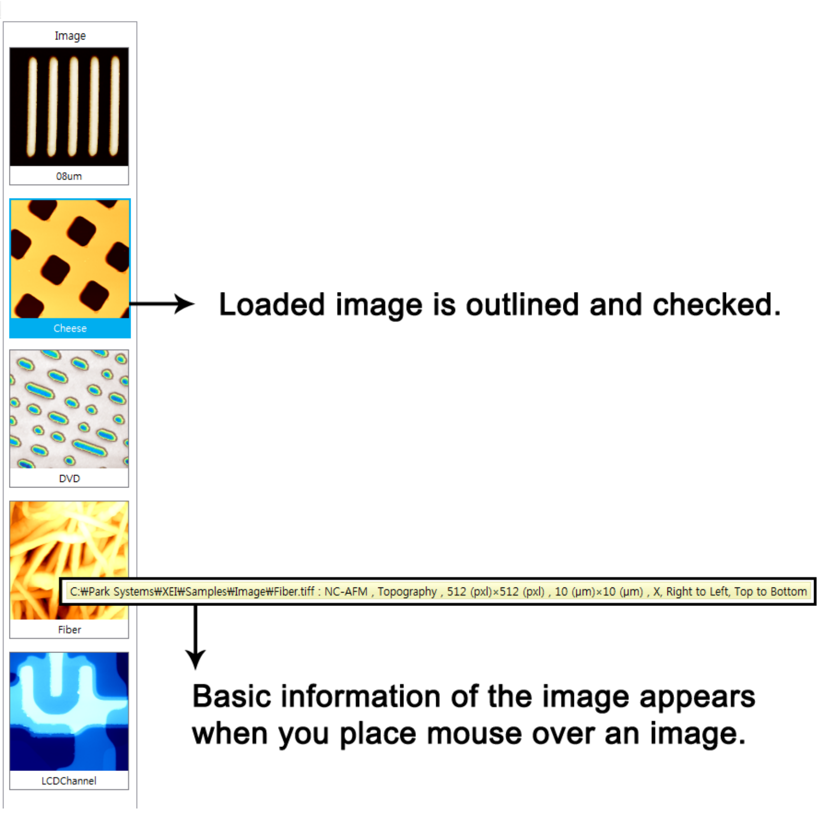
The Navigator view serves as a buffer for the images that you have already opened in XEI. You can view basic information of each images in the navigator view by placing mouse pointer over an image. (see the box in Figure 1-1-6)

To load a certain image from the ‘Navigator View’ to the ‘Analysis View’, double click the image you want to load and then click ‘Yes’ to the warning message saying that *“This will initialize all the analysis views. Do you want to continue?”*

Only one image can be loaded at a time. The loaded image is outlined in blue color and check box beside its name is checked. Figure 1-6-1 shows the Navigator view.

WARNING!

When the new image is loaded, the analysis results of the previously loaded image (line profile, statistics table, histogram, etc.) in all the analysis views (Grain, PSD, 3D…) and any changes made by imageprocessing will be removed as all the analysis view is initialized. Therefore you should save all the necessary analysis results and changes made to the image before you load new image to the analysis view from the navigator view.



Loaded image is outlined and checked.

C:₩Park Systems₩XEI₩Samples₩Image₩Fiber.tiff : NC-AFM , Topography , 512 (pxl)×512 (pxl) , 10 (μm)×10 (μm) , X, Right to Left, Top to Bottom

Basic information of the image appears when you place mouse over an image.

Figure 1-1-6. Navigator view

There are three ways to bring images into the Navigator view:

- Drag and drop the selected images from your image directory into the Navigator view (Figure 1-1-7).
- Select the ‘Open’ option in the File menu or click the ‘open data file’ icon to find an image you want to load (Figure 2-1-2).
- Use Send to XEI menu in the buffer window of the XEP.

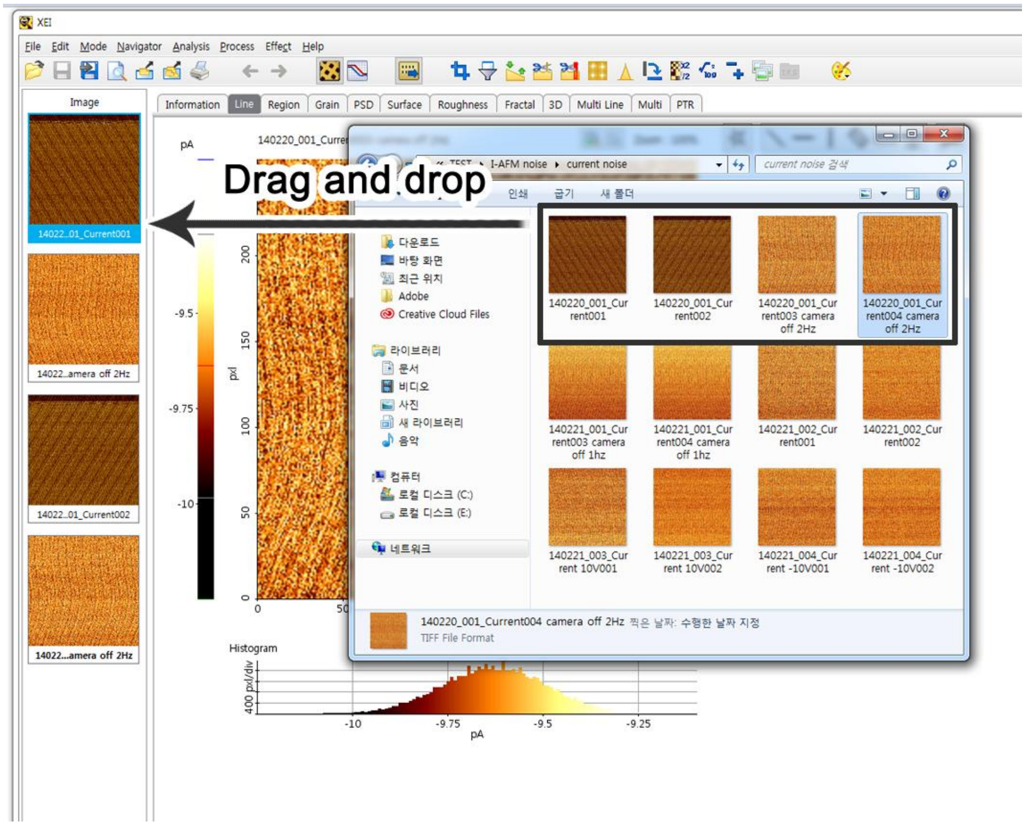

XEI
File Edit Mode Navigator Analysis Process Effect Help
Image
Information Line Region Grain PSD Surface Roughness Fractal 3D Multi Line Multi PTR
14022..01_Current001
14022..amera off 2Hz
14022..01_Current002
14022...amera off 2Hz
pA
140220_001_Curre
Drag and drop
I-AFM noise ▸ current noise
current noise 검색
인쇄 굽기 새 폴더
다운로드
바탕 화면
최근 위치
Adobe
Creative Cloud Files
라이브러리
문서
비디오
사진
새 라이브러리
음악
컴퓨터
로컬 디스크 (C:)
로컬 디스크 (E:)
네트워크
140220_001_Current001
140220_001_Current002
140220_001_Current003 camera off 2Hz
140220_001_Current004 camera off 2Hz
140221_001_Current003 camera off 1hz
140221_001_Current004 camera off 1hz
140221_002_Current001
140221_002_Current002
140221_003_Current 10V001
140221_003_Current 10V002
140221_004_Current -10V001
140221_004_Current -10V002
140220_001_Current004 camera off 2Hz 찍은 날짜: 수행한 날짜 지정
TIFF File Format
-9.5
-9.75
-10
pxl
200
150
100
50
0
0
50
Histogram
400 pxl/div
-10
-9.75
-9.5
-9.25
pA

Figure 1-1-7. Drag and drop images into the Navigator view

When you right-click the cursor on an image in the Navigator view, a context menu as shown in Figure 1-1-8 is generated allowing you to execute the following actions: Load, Reopen, Delete, and Delete All.

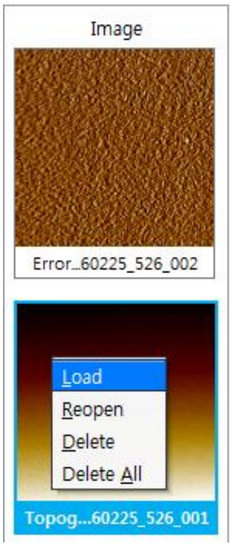


Figure 1-1-8. Context menu in the Navigator view

- **Load**

You can load the selected image into the Analysis view for image processing and quantitative analysis.

- **Reopen**

You can reopen the original image again in the Analysis view for a new session or to refresh the image in order to perform image processing and analysis again.

- **Delete**

Removes the selected images from the Navigator view.

- **Delete All**

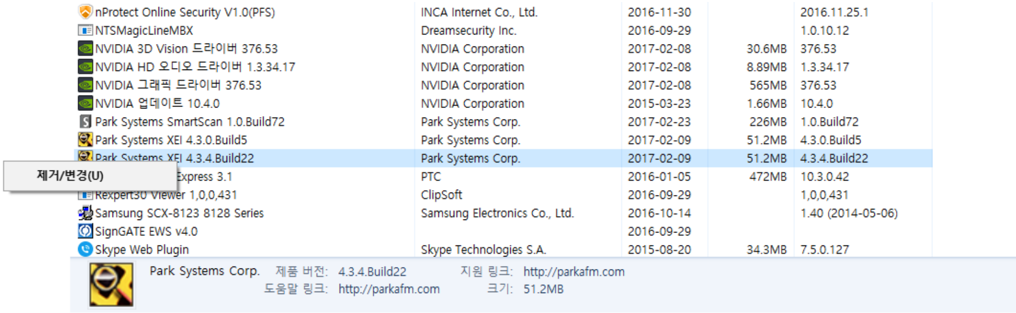
Removes all images from the Navigator view.

1-2. Installation of Park Systems XEI' Software

The XEI software program for XE systems can be run properly in : **Windows XP Service Pack 2 or Windows 7(32bit) and Java SE Runtime Environment 6 or higher**. The Java Runtime Environment must be installed prior to installing 'Park Systems XEI' software.

1-2-1. Uninstallation of the old version ‘Park Systems XEI’ program

1. Remove old ‘PSIA XEI or Park Systems XEI’ program by using ‘Add or Remove Program’ in the Control panel.

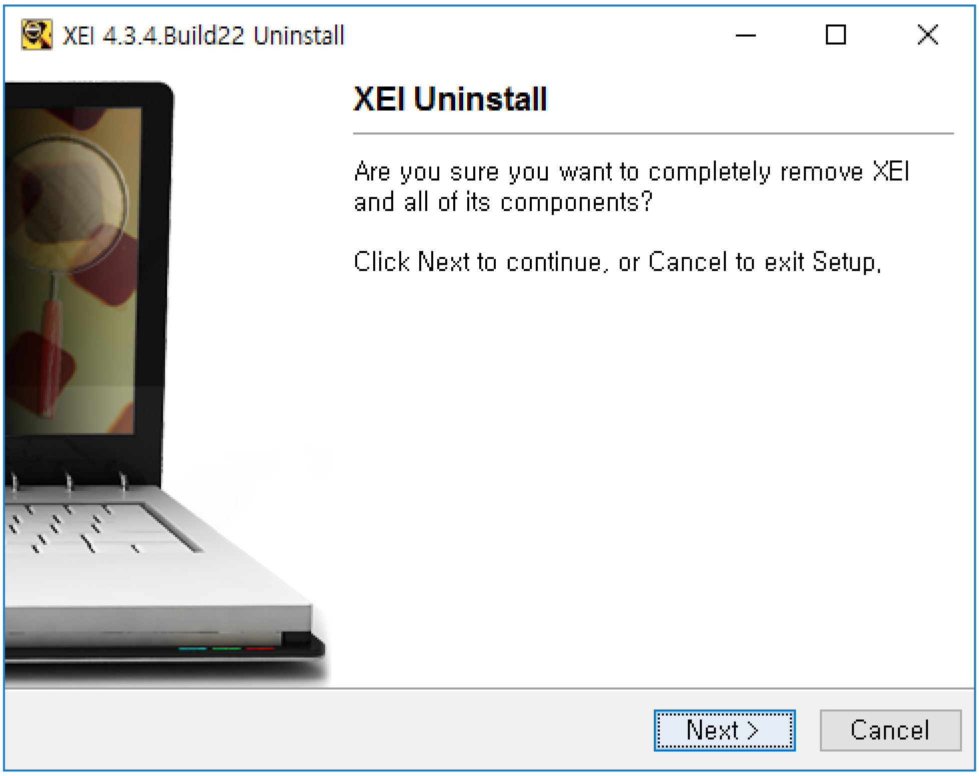


nProtect Online Security V1.0(PFS)	INCA Internet Co., Ltd.	2016-11-30		2016.11.25.1
NTSMagicLineMBX	Dreamsecurity Inc.	2016-09-29		1.0.10.12
NVIDIA 3D Vision 드라이버 376.53	NVIDIA Corporation	2017-02-08	30.6MB	376.53
NVIDIA HD 오디오 드라이버 1.3.34.17	NVIDIA Corporation	2017-02-08	8.89MB	1.3.34.17
NVIDIA 그래픽 드라이버 376.53	NVIDIA Corporation	2017-02-08	565MB	376.53
NVIDIA 업데이트 10.4.0	NVIDIA Corporation	2015-03-23	1.66MB	10.4.0
Park Systems SmartScan 1.0.Build72	Park Systems Corp.	2017-02-23	226MB	1.0.Build72
Park Systems XEI 4.3.0.Build5	Park Systems Corp.	2017-02-09	51.2MB	4.3.0.Build5
Park Systems XEI 4.3.4.Build22	Park Systems Corp.	2017-02-09	51.2MB	4.3.4.Build22
Express 3.1	PTC	2016-01-05	472MB	10.3.0.42
Rexpert30 Viewer 1,0,0,431	ClipSoft	2016-09-29		1,0,0,431
Samsung SCX-8123 8128 Series	Samsung Electronics Co., Ltd.	2016-10-14		1.40 (2014-05-06)
SignGATE EWS v4.0		2016-09-29		
Skype Web Plugin	Skype Technologies S.A.	2015-08-20	34.3MB	7.5.0.127

Park Systems Corp. 제품 버전: 4.3.4.Build22 지원 링크: http://parkafm.com
도움말 링크: http://parkafm.com 크기: 51.2MB

Figure 1-2-1. ‘Add and Remove Program’ window

2. The ‘Uninstall Shield Wizard’ dialog will be opened. When ‘Confirm Uninstall’ message box asks you again if you want to completely remove this ‘PSIA XEI or Park Systems XEI’ program, click ‘OK’ to proceed uninstallation.



XEI 4.3.4.Build22 Uninstall

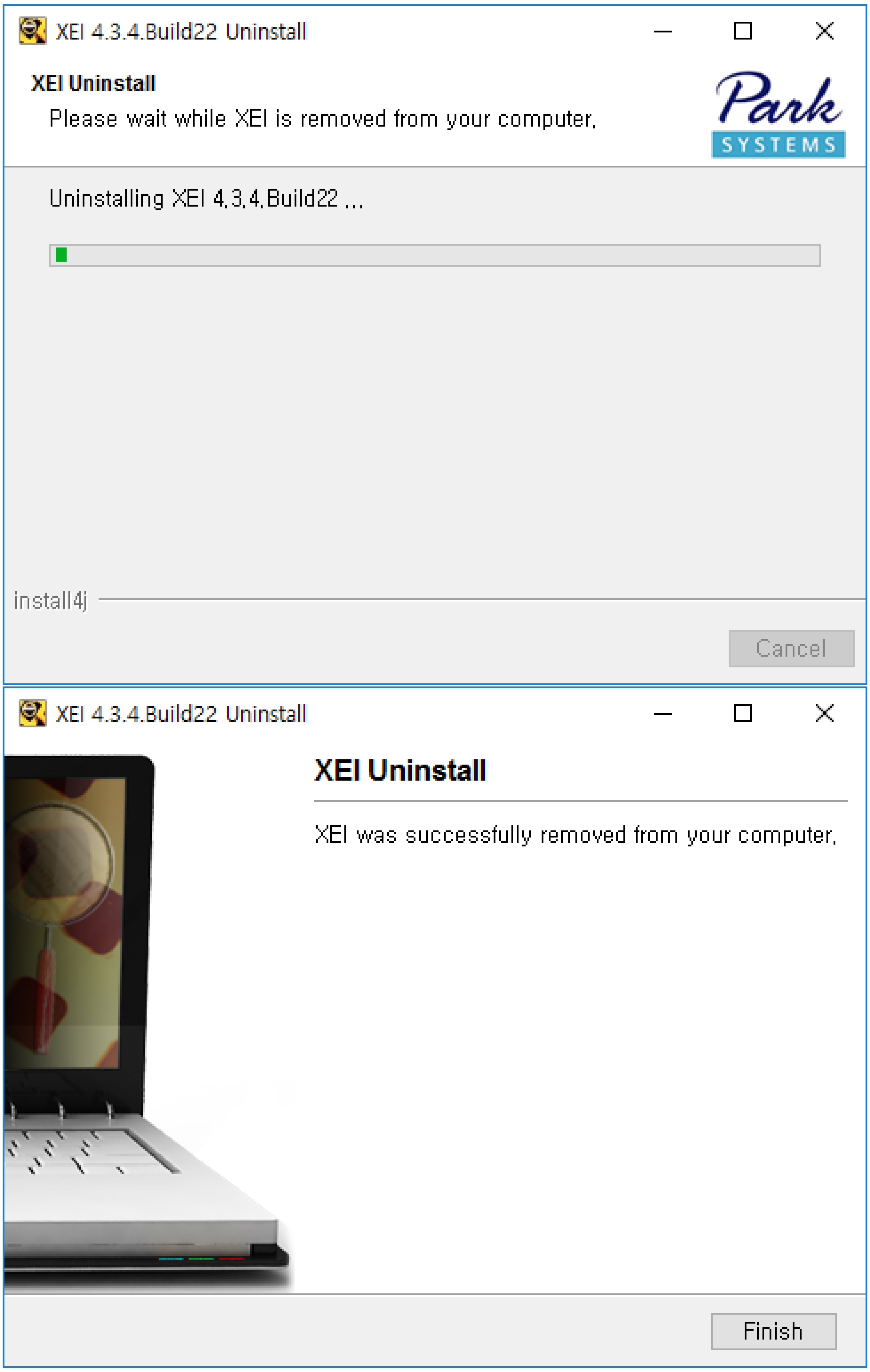
XEI Uninstall

Are you sure you want to completely remove XEI and all of its components?

Click Next to continue, or Cancel to exit Setup.

Figure 1-2-2. Confirm Uninstall Message

3. The figure below will be shown when uninstallation is successfully done.



XEI 4.3.4.Build22 Uninstall

XEI Uninstall

Please wait while XEI is removed from your computer.

Uninstalling XEI 4.3.4.Build22 ...

install4j

XEI 4.3.4.Build22 Uninstall

XEI Uninstall

XEI was successfully removed from your computer.

Figure 1-2-3. Confirm Uninstall Message

1-2-2. Installation of the new version 'Park Systems XEI' program

The procedure to install the new version 'Park Systems XEI' is as follows:

1. Insert the Unified XE-Software Installer CD and Installation Dialog will be opened as seen in Figure 1-2-4.

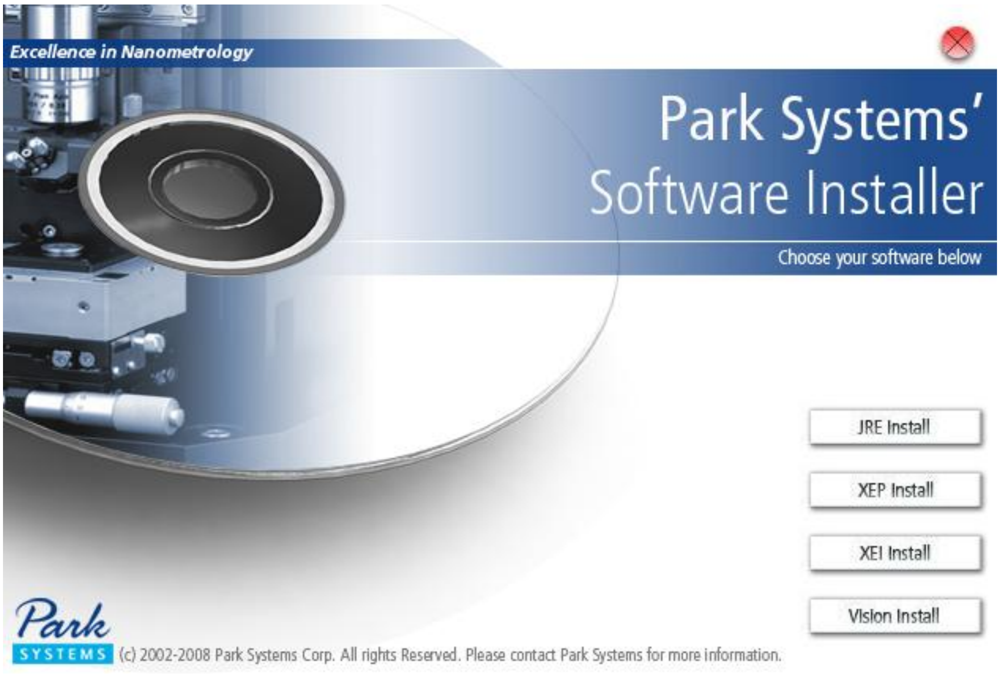
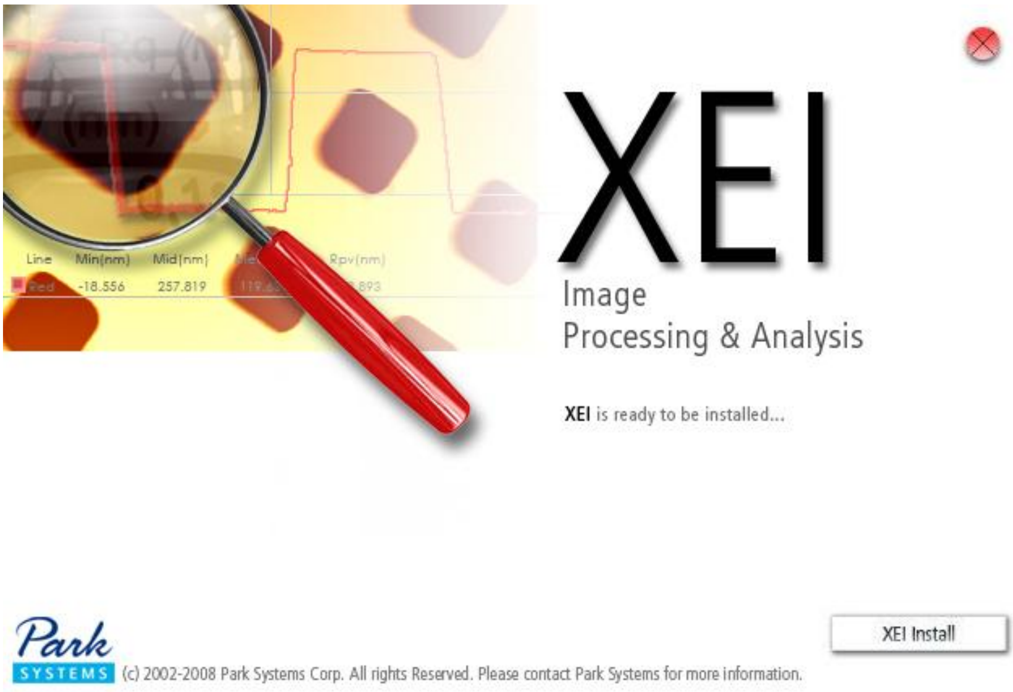

Excellence in Nanometrology
Park Systems'
Software Installer
Choose your software below
JRE Install
XEP Install
XEI Install
Vision Install
Park SYSTEMS
(c) 2002-2008 Park Systems Corp. All rights Reserved. Please contact Park Systems for more information.

Figure 1-2-4. Installation Dialog of Unified XE-Software Installer CD

2. The XEI software is run properly in Java SE Runtime Environment 6 or higher. If necessary, install java program included in CD by clicking 'JRE Install'.

3. Clicking 'XEI Install' opens following dialog.



XEI is ready to be installed...

(c) 2002-2008 Park Systems Corp. All rights Reserved. Please contact Park Systems for more information.

Figure 1-2-5. Installation Dialog of XEI

4. Click ‘XEI Install’ to Install XEI program by following the steps below.

   Step1: **Preparing to Install** - Installation will start as shown as in Figure 1-2-6.

   Step2: **Installer Language –** Choose the installer language in Figure 1-2-7.

   Step3**: Welcome to the XEI Setup Wizard** - Click the ‘Next’ button to continue the install setup as shown in Figure 1-2-7.

   Step4: **License Agreement** – Read the License Agreement. You must accept this agreement before continuing with the installation by checking ‘I accept the agreement’ and click the ‘Next’ button to continue the install setup as shown in Figure 1-2-7.

   Step5: **Select Destination Directory** - The ‘Park Systems’ folder is made in the C directory by this installation procedure. This is the base directory of XE software. You may also select other destination in your computer by selecting

‘Browse’. Click the ‘Next’ button as shown in Figure 1-2-7.

Step6: **Select Start Menu Folder** – Select the Start Menu folder in which you would like Setup to create the program's shortcuts, then click ‘Next’ button as shown in Figure 1-2-7.

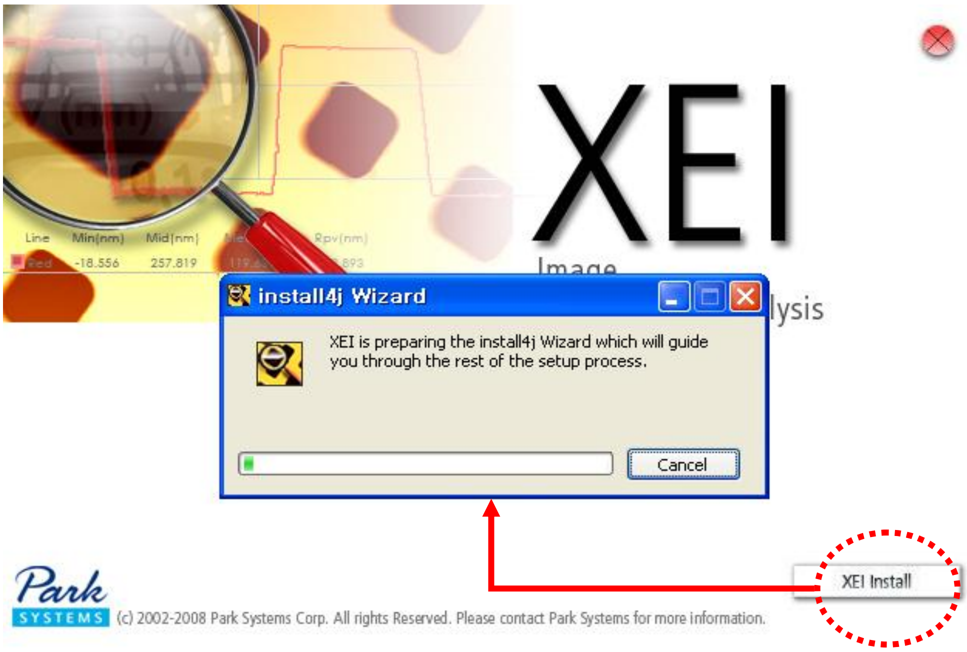
Step7: **Select File Associations** – Select file association you want to create and click ‘Next’ button when you are ready to continue as shown in Figure 1-2-7.

Step8: **Select Graphic Option** – Select the graphic type according to your graphics driver. If not selected correctly, the XEI program will not open properly. The most common graphic type will be ‘OpenGL’.

NOTE!

If you select the wrong graphic type, the XEI program will not open properly. To correct this problem, you must uninstall XEI completely and reinstall the program again.

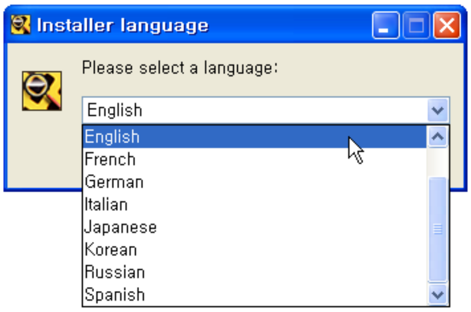
Step9: **Select Additional Tasks** – Check if you want to create a desktop icon and click ‘Next’ button as shown in Figure 1-2-7.



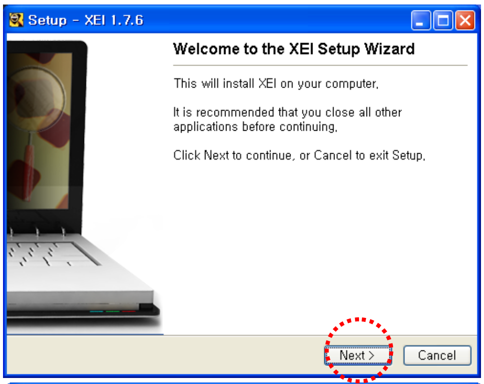
XEI is preparing the install4j Wizard which will guide you through the rest of the setup process.

(c) 2002-2008 Park Systems Corp. All rights Reserved. Please contact Park Systems for more information.

Figure 1-2-6. Setup the ‘Park Systems XEI’ program



Please select a language:

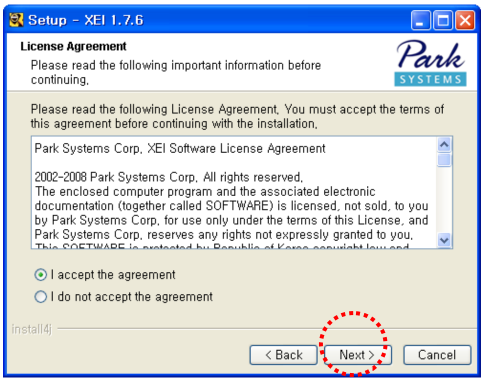


Welcome to the XEI Setup Wizard

This will install XEI on your computer.

It is recommended that you close all other applications before continuing.

Click Next to continue, or Cancel to exit Setup.



License Agreement

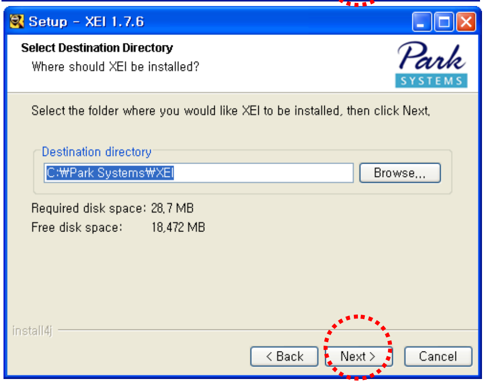
Please read the following important information before continuing.

Please read the following License Agreement. You must accept the terms of this agreement before continuing with the installation.

Park Systems Corp. XEI Software License Agreement

2002-2008 Park Systems Corp. All rights reserved.
The enclosed computer program and the associated electronic documentation (together called SOFTWARE) is licensed, not sold, to you by Park Systems Corp. for use only under the terms of this License, and Park Systems Corp. reserves any rights not expressly granted to you.

● I accept the agreement
○ I do not accept the agreement



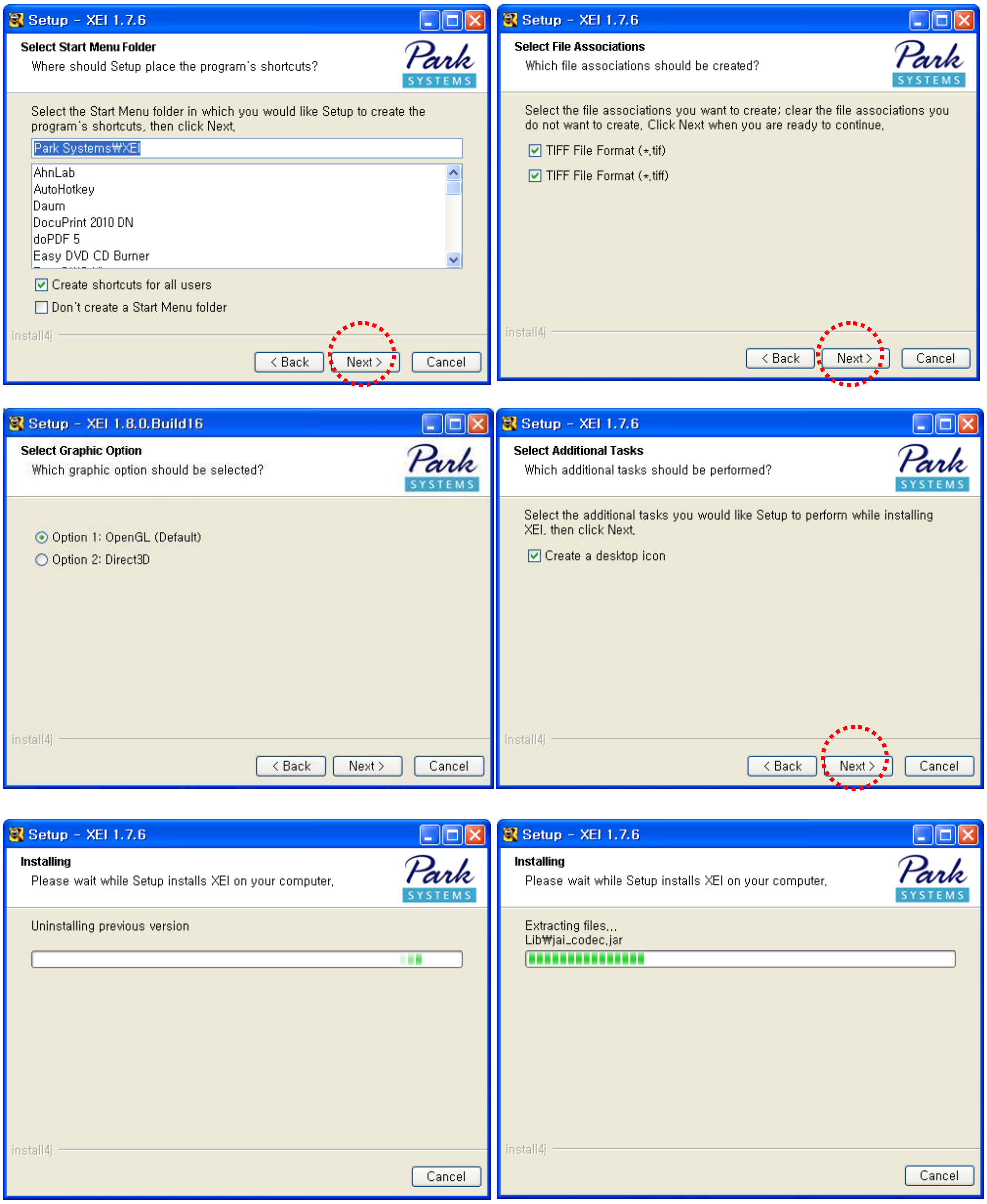
Select Destination Directory

Where should XEI be installed?

Select the folder where you would like XEI to be installed, then click Next.

Destination directory: C:₩Park Systems₩XEI

Required disk space: 28.7 MB
Free disk space: 18,472 MB



Setup - XEI 1.7.6

Select Start Menu Folder

Where should Setup place the program's shortcuts?

Select the Start Menu folder in which you would like Setup to create the program's shortcuts, then click Next.

Park Systems₩XEI

AhnLab
AutoHotkey
Daum
DocuPrint 2010 DN
doPDF 5
Easy DVD CD Burner

☑ Create shortcuts for all users
☐ Don't create a Start Menu folder

Setup - XEI 1.7.6

Select File Associations

Which file associations should be created?

Select the file associations you want to create; clear the file associations you do not want to create. Click Next when you are ready to continue.

☑ TIFF File Format (*.tif)
☑ TIFF File Format (*.tiff)

Setup - XEI 1.8.0.Build16

Select Graphic Option

Which graphic option should be selected?

● Option 1: OpenGL (Default)
○ Option 2: Direct3D

Setup - XEI 1.7.6

Select Additional Tasks

Which additional tasks should be performed?

Select the additional tasks you would like Setup to perform while installing XEI, then click Next.

☑ Create a desktop icon

Setup - XEI 1.7.6

Installing

Please wait while Setup installs XEI on your computer.

Uninstalling previous version

Setup - XEI 1.7.6

Installing

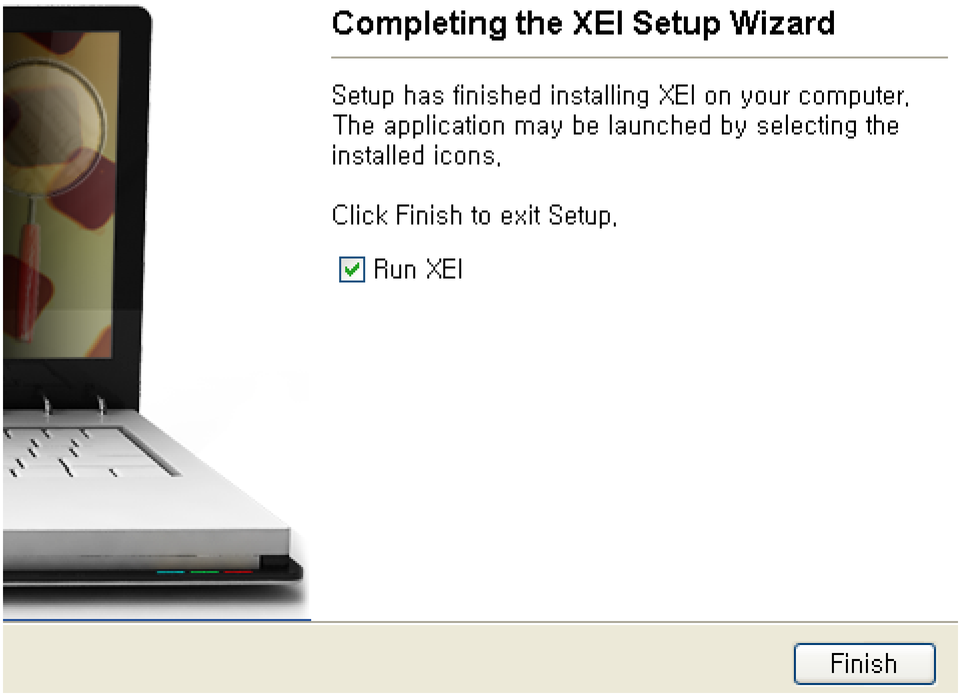
Please wait while Setup installs XEI on your computer.

Extracting files...
Lib₩jai_codec.jar

Figure 1-2-7. Procedure to install the 'Park Systems XEI' program

When the setup is completed, the 'Completing the XEI Setup Wizard' window appears, click the 'Finish' button as shown in Figure 1-2-8.

When you have finished the XEI installation procedure, XEI folder is created in the 'Park Systems' folder as a subfolder. Its shortcut will be automatically created in your desktop and the 'Park Systems XEI' program will be made.



Completing the XEI Setup Wizard

Setup has finished installing XEI on your computer. The application may be launched by selecting the installed icons.

Click Finish to exit Setup.

☑ Run XEI

Figure 1-2-8. ‘Completing the XEI Setup Wizard’ dialog

Chapter 2. Menus & Toolbar

The Menu bar contains a list of all available menus from which you can access the basic functions of the XEI image analysis program. Also, the most frequently used menu items are provided as icons on the Toolbar. Figure 2-1 shows the several menu items and the related icons.

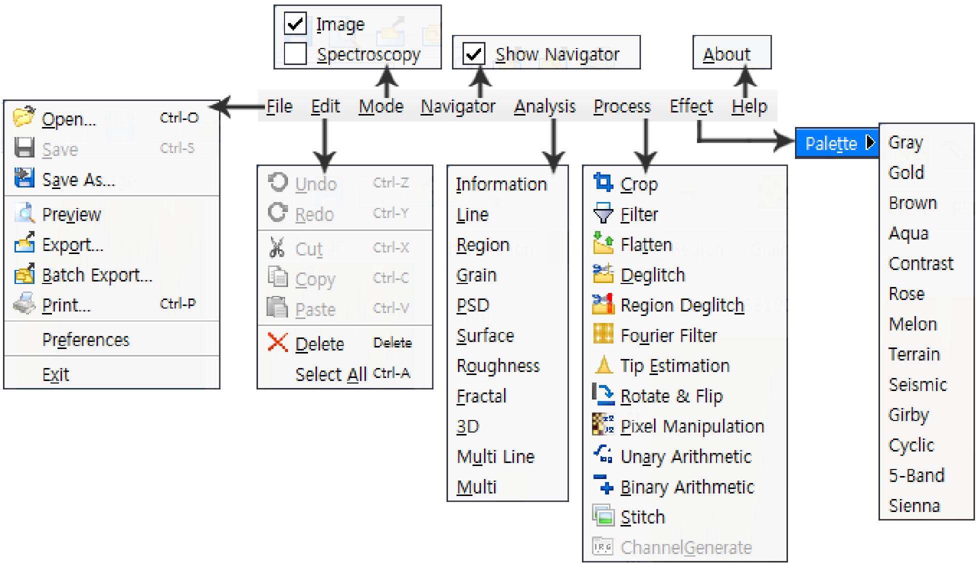


Figure 2-1. Menu bar

2-1. File

Contains several menu items that allow you to Open, Save, Save As, Preview, Export, Batch Export and Print image data files as shown in Figure 2-1-1.

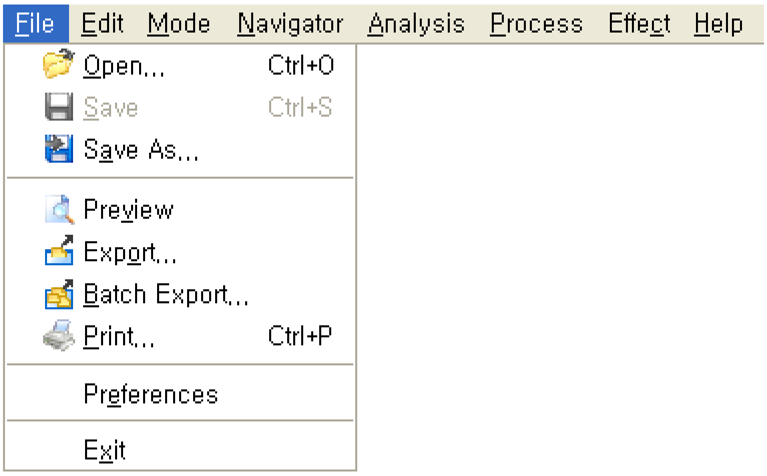
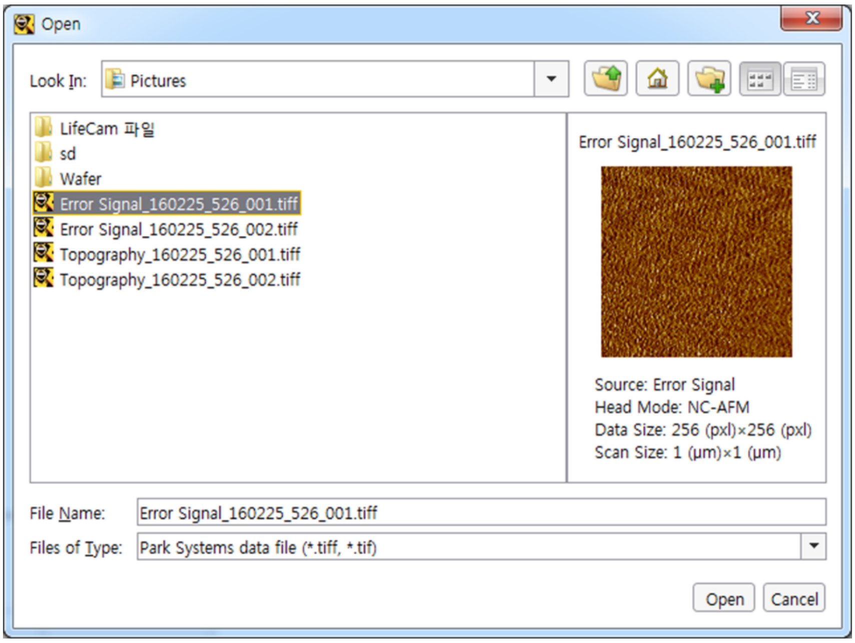


Figure 2-1-1. File menu

2-1-1. Open

Opens the 'Open' dialog as shown in Figure 2-1-2. In order to bring an image into the Analysis view, select the 'File>Open' in the Menu or click the 'Open' icon. Then, select the image file you want to analyze in the Open dialog. This image file is loaded into the Navigator view. If the image file is the first file loaded into the Navigator view, it is automatically loaded into the Analysis view of the Information view. Otherwise, double clicking the image in the Navigator view loads the image into the current analysis view.


Open
LifeCam 파일
sd
Wafer
Error Signal_160225_526_001.tiff
Error Signal_160225_526_002.tiff
Topography_160225_526_001.tiff
Topography_160225_526_002.tiff
Error Signal_160225_526_001.tiff
Open
Cancel

Look In: Pictures

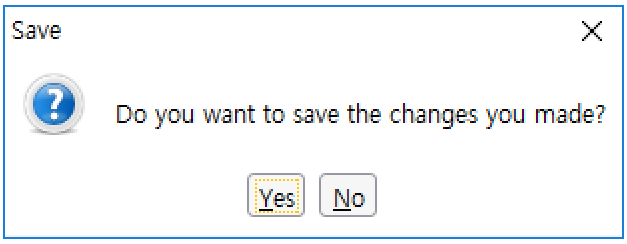
Source: Error Signal
Head Mode: NC-AFM
Data Size: 256 (pxl)×256 (pxl)
Scan Size: 1 (μm)×1 (μm)

File Name: Error Signal_160225_526_001.tiff
Files of Type: Park Systems data file (*.tiff, *.tif)

Figure 2-1-2. Open dialog

2-1-2. Save

Allows you to save the processed image or result in the Image display panel to the original image data file, overwriting the original data. When you select the 'Save' menu, the 'Save' warning message box as seen in Figure 2-1-3 appears to remind you that this command may replace the original image file.



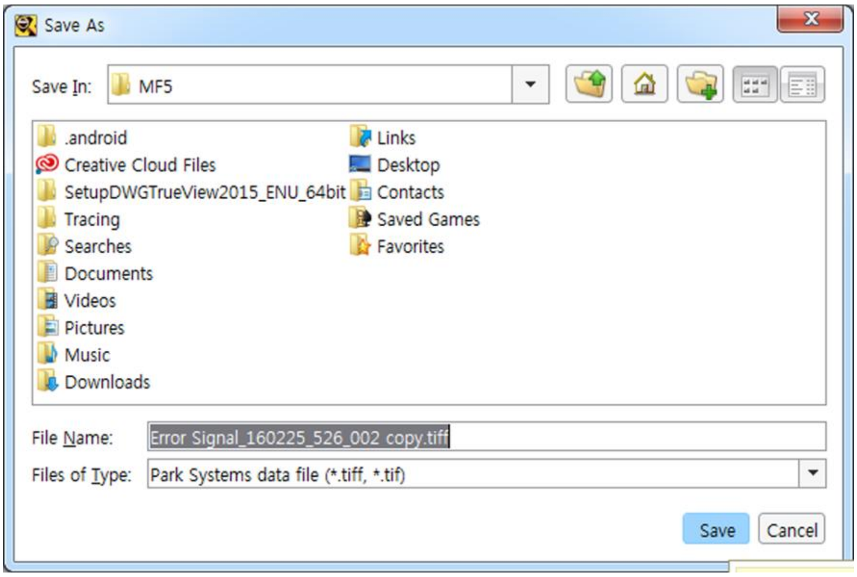
Save

Do you want to save the changes you made?

Figure 2-1-3. 'Save' warning message box

2-1-3. Save As

Opens the 'Save As' dialog as shown in Figure 2-1-4. In this dialog, you can save the transformed image or statistics data as a new image data file. Unlike the 'Save' menu, it does not overwrite the data in the original data file but create another data file.



Save As

Save In: MF5

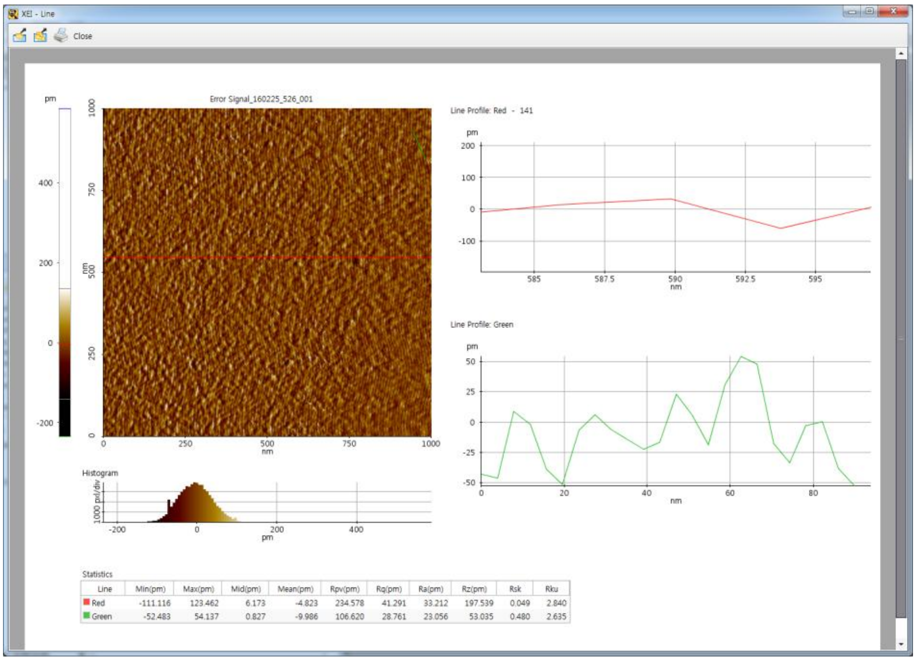
File Name: Error Signal_160225_526_002 copy.tiff

Files of Type: Park Systems data file (*.tiff, *.tif)

Figure 2-1-4. Save As dialog

2-1-4. Preview

Allows you to preview the processed image with its analysis data. You can export and print this result in the preview mode. As an example of the preview screen, Figure 2-1-5 shows the preview screen of the selected image in the Line view.

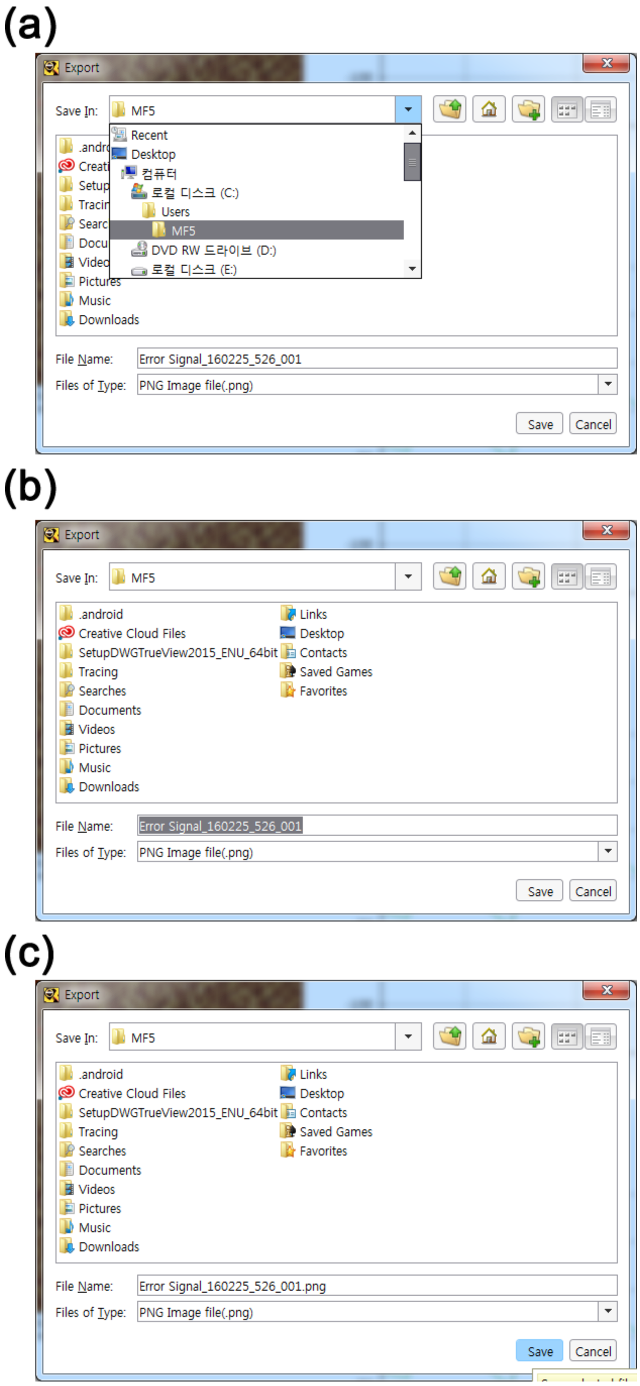


Line	Min(pm)	Max(pm)	Mid(pm)	Mean(pm)	Rpv(pm)	Rq(pm)	Ra(pm)	Rz(pm)	Rsk	Rku
🟥 Red	-111.116	123.462	6.173	-4.823	234.578	41.291	33.212	197.539	0.049	2.840
🟩 Green	-52.483	54.137	0.827	-9.986	106.620	28.761	23.056	53.035	0.480	2.635

Figure 2-1-5. Preview screen

2-1-5. Export

Allows you to export the data file as a Portable Network Graphics(PNG) file, a Bitmap Image(BMP) file and a Joint Photography Experts Groups(JPEG) file. This 'export' file format is selected by default considering the images' quality and size. In order to export the data file, select click the 'Export' option in the File menu or clicking the 'Export' icon and find the directory you want to export the data file. Then, save this file as a new file name. Figure 2-1-6 shows the procedure to export your data file in the 'Export' dialog.



(a) Save In: MF5
File Name: Error Signal_160225_526_001
Files of Type: PNG Image file(.png)

(b) Save In: MF5
File Name: Error Signal_160225_526_001
Files of Type: PNG Image file(.png)

(c) Save In: MF5
File Name: Error Signal_160225_526_001.png
Files of Type: PNG Image file(.png)

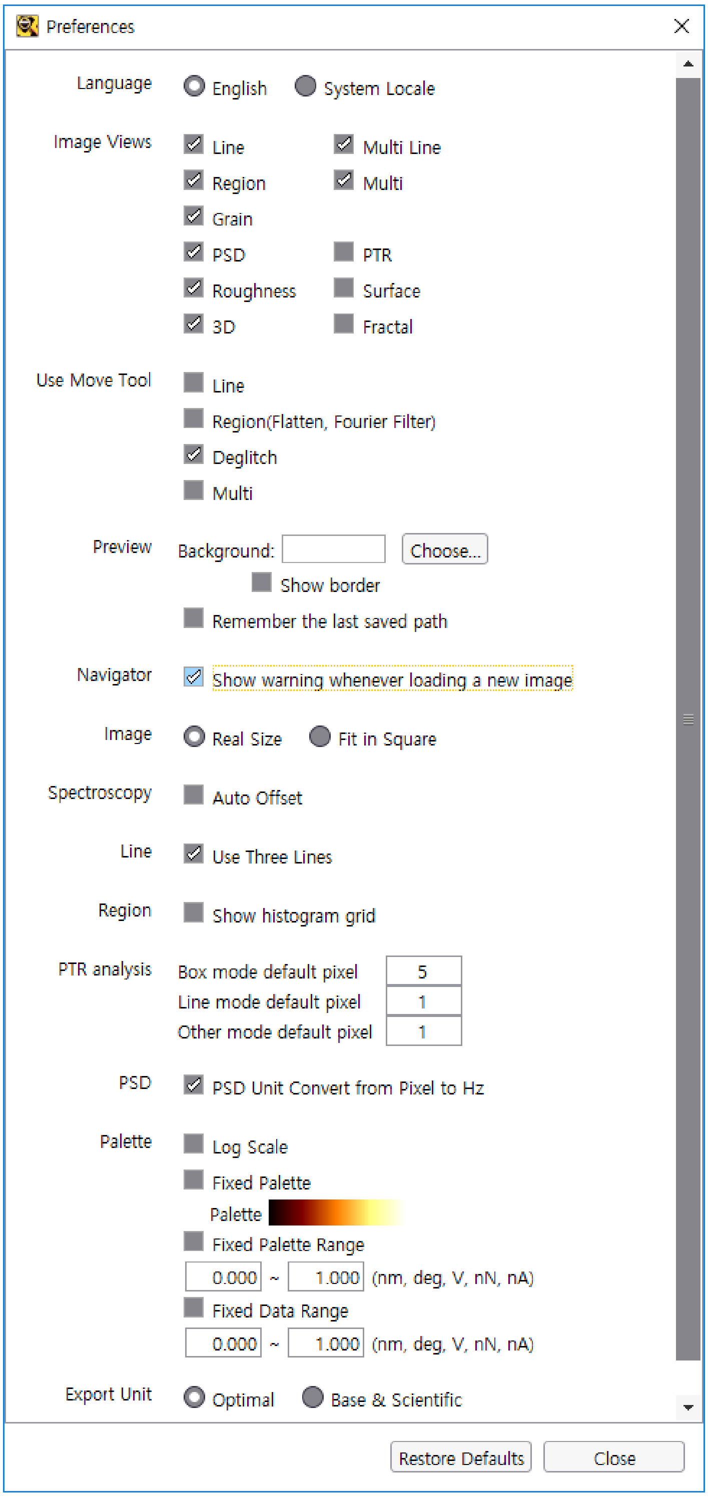
Figure 2-1-6. Export dialog

2-1-6. Print

Allows you to print the selected view. Before printing, you can preview the newly processed image or analysis data in the preview screen. This preview can be printed by selecting the ‘File>Print’ or clicking the print icon .

2-1-7. Preferences

Through the ‘preferences’ menu, you can change several settings in accordance with your preferences.



Preferences

Language ● English ○ System Locale

Image Views
☑ Line ☑ Multi Line
☑ Region ☑ Multi
☑ Grain
☑ PSD ☐ PTR
☑ Roughness ☐ Surface
☑ 3D ☐ Fractal

Use Move Tool
☐ Line
☐ Region(Flatten, Fourier Filter)
☑ Deglitch
☐ Multi

Preview Background:
☐ Show border
☐ Remember the last saved path

Navigator ☑ Show warning whenever loading a new image

Image ● Real Size ○ Fit in Square

Spectroscopy ☐ Auto Offset

Line ☑ Use Three Lines

Region ☐ Show histogram grid

PTR analysis
Box mode default pixel 5
Line mode default pixel 1
Other mode default pixel 1

PSD ☑ PSD Unit Convert from Pixel to Hz

Palette
☐ Log Scale
☐ Fixed Palette
Palette
☐ Fixed Palette Range
0.000 ~ 1.000 (nm, deg, V, nN, nA)
☐ Fixed Data Range
0.000 ~ 1.000 (nm, deg, V, nN, nA)

Export Unit ● Optimal ○ Base & Scientific

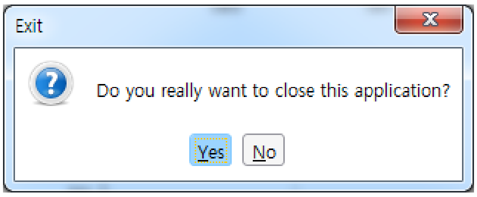
Figure 2-1-7. Preferences Dialog

The settings that can be changed from the 'Preferences' window are

- Language for the XEI software. English or language of your computer system OS (Currently Korean and Japanese are supported)
- You can shorten the opening time of a file when you open a new data file by setting the image analysis function to use as desired..
- The type of 3D Renderer(OpenGL, Direct3D) suitable for your system.
- The type of Move Tool you wish to use
- Background color and border settings of the image data files that are created when the analysis view is exported
- Notify the user when a new image is being loaded for analysis
- Preserve the original image's dimensions, or fit them into a square
- Add a constant value to Spectroscopy data for normalization
- Use multiple (up to 3) lines for analysis in Line View(As default, it is not unchecked and you can use two lines).
- Change original condition of palette(color of palette, palette range, palette data range).

2-1-8. Exit

You can close the XEI program by selecting the 'File>Exit' menu. Then, the 'Exit' confirmation message box appears as seen in Figure 2-1-8.

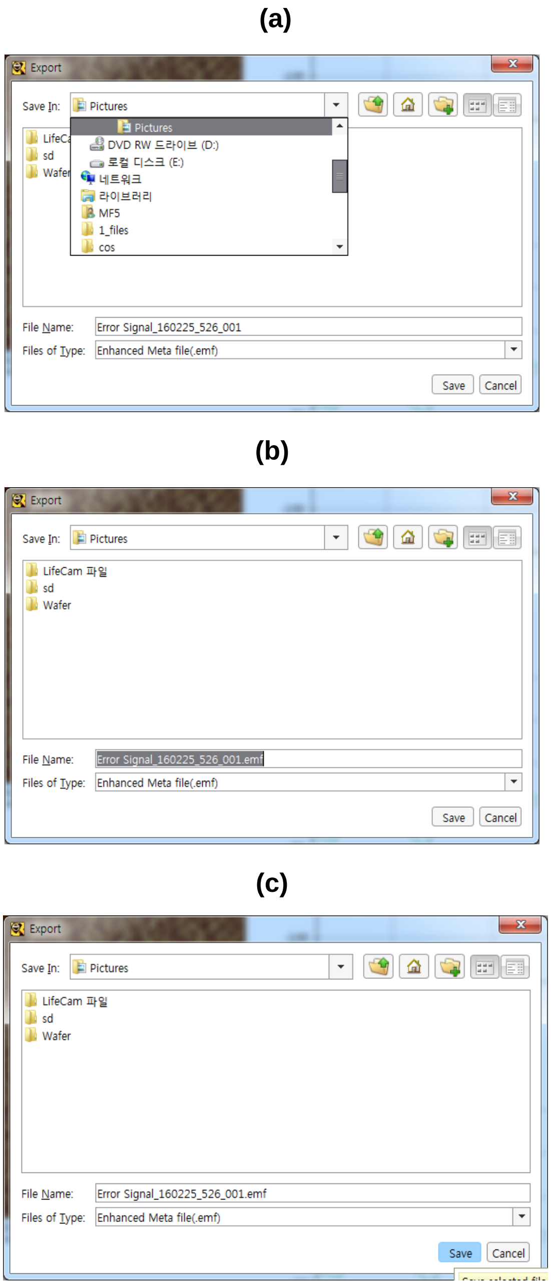


Do you really want to close this application?

Figure 2-1-8. 'Exit' confirmation message box

2-1-9. Batch Export

Batch Export icon will allow users to export the screen or displaying image, as an "Enhanced Meta" file or ".emf" file (one of the vector file formats). Vector file format contains each shape's geometric information, and displays the best resolution of screen image, whereas previous versions of XEI, the saving file resolution depended on size of screen display. Hence, when saving the screen display files as an "*.emf" file, the resolution quality will maintain its visual quality. This image file separates information for line, shape, and color's graphic components. In order to export the screen display image as an ".emf" file, select the 'Batch Export' option in the File menu or click the ‘Batch Export’ icon and locate the directory where data will be saved. Then save the file with a new file name. Figure 2-1-9 shows the procedure to export data file in the ‘Batch Export’ dialog.



(a)

File Name: Error Signal_160225_526_001

Files of Type: Enhanced Meta file(.emf)

(b)

File Name: Error Signal_160225_526_001.emf

Files of Type: Enhanced Meta file(.emf)

(c)

File Name: Error Signal_160225_526_001.emf

Files of Type: Enhanced Meta file(.emf)

Figure 2-1-9. Batch Export dialog

2-2. Edit

Has common function necessary to edit the image for processing and analysis. Figure 2-2-1 shows several Edit menu items.

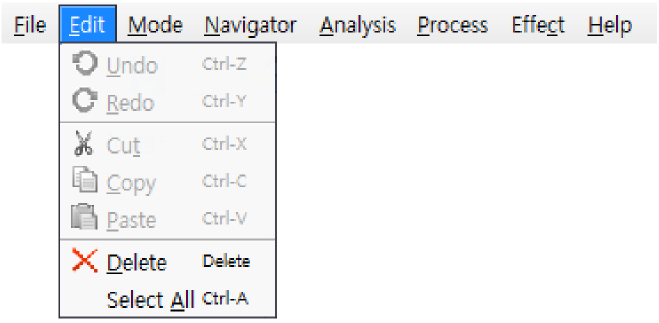


Figure 2-2-1. Edit menu

2-2-1. Undo

Undoes the previous command.

2-2-2. Redo

Redoes the previous command.

2-2-3. Cut

Cuts the selected line or region related to analysis of the image.

2-2-4. Copy

Copies the selected line or region in the image.

2-2-5. Paste

Allows you to paste the cut or copied ‘line or region’ to the location of your choice

2-2-6. Delete

Deletes the selected line or region of the image in the Analysis view.

2-2-7. Select All

Selects all lines or regions in the image.

2-3. Mode

Used for switching between Image and Spectroscopy modes.

2-3-1. Image

This item enters Image Mode. Except for Chapter 18, Spectroscopy Mode, this manual assumes that XEI is being used in Image mode.

2-3-2. Spectroscopy

This item enters Spectroscopy Mode. Used for analysis of F/D and I/V spectroscopy curves, Spectroscopy Mode is explained in further detail in Chapter 18, Spectroscopy Mode.

2-4 Navigator

2-4-1. Show Navigator

User can choose to show or hide the Navigator View through this command.

2-5. Analysis

The Analysis menu provides you direct access to carry out quantitative analysis of the selected line, region, grain and PSD of an image and to view the 3D rendered image. As shown in Figure 2-5-1, the Analysis menu has seven items: Information, Line, Region, Grain, PSD, Surface, Fractal, 3D, and Multi. You can start any one of these analysis by selecting the option in the Analysis menu or by clicking the corresponding tab below the Toolbar.

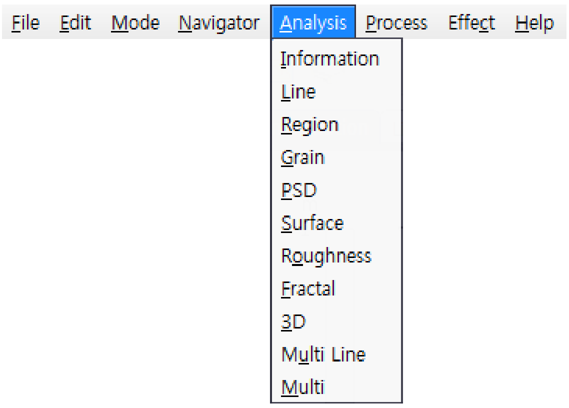
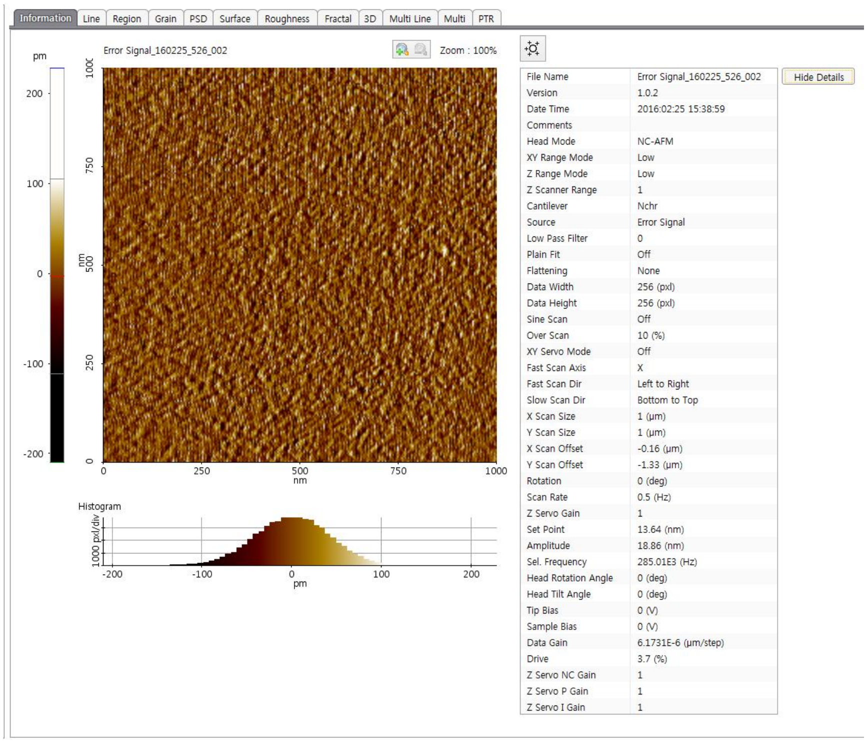


Figure 2-5-1. Analysis menu and tabs

2-5-1. Information

In the Information view, you can display the 2D image with basic information of the image that you selected from the Navigator view or loaded by using the 'Open' dialog. The Information view shows the original image and much of the scan information associated with the image data. Figure 2-5-2 shows the Information view of the selected image. The Information view is described further in Chapter 3. "Information View".

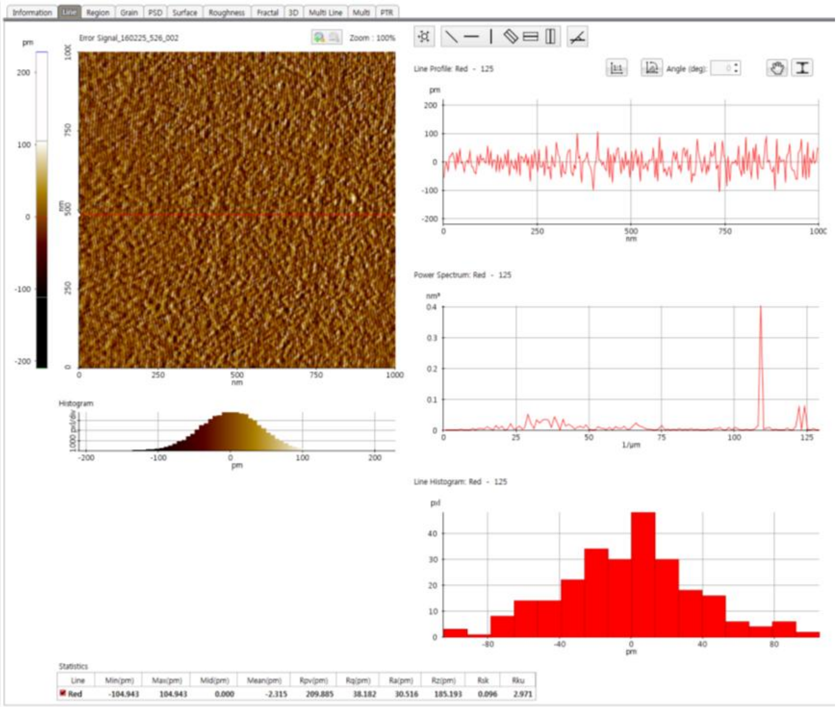


File Name	Error Signal_160225_526_002
Version	1.0.2
Date Time	2016:02:25 15:38:59
Comments	
Head Mode	NC-AFM
XY Range Mode	Low
Z Range Mode	Low
Z Scanner Range	1
Cantilever	Nchr
Source	Error Signal
Low Pass Filter	0
Plain Fit	Off
Flattening	None
Data Width	256 (pxl)
Data Height	256 (pxl)
Sine Scan	Off
Over Scan	10 (%)
XY Servo Mode	Off
Fast Scan Axis	X
Fast Scan Dir	Left to Right
Slow Scan Dir	Bottom to Top
X Scan Size	1 (μm)
Y Scan Size	1 (μm)
X Scan Offset	-0.16 (μm)
Y Scan Offset	-1.33 (μm)
Rotation	0 (deg)
Scan Rate	0.5 (Hz)
Z Servo Gain	1
Set Point	13.64 (nm)
Amplitude	18.86 (nm)
Sel. Frequency	285.01E3 (Hz)
Head Rotation Angle	0 (deg)
Head Tilt Angle	0 (deg)
Tip Bias	0 (V)
Sample Bias	0 (V)
Data Gain	6.1731E-6 (μm/step)
Drive	3.7 (%)
Z Servo NC Gain	1
Z Servo P Gain	1
Z Servo I Gain	1

Figure 2-5-2. Information view

2-5-2. Line

In the Line view, you can get information about the cross section or height profile of the surface in the selected image. You can see a Line Profile, a Power Spectrum, and a Line Histogram of a selected line, all at one time. Also, the surface statistics table of the selected line is displayed. Figure 2-5-3 shows the Line view of the analyzed image. A more detailed description of the Line view is offered in Chapter 4. “Line View”.



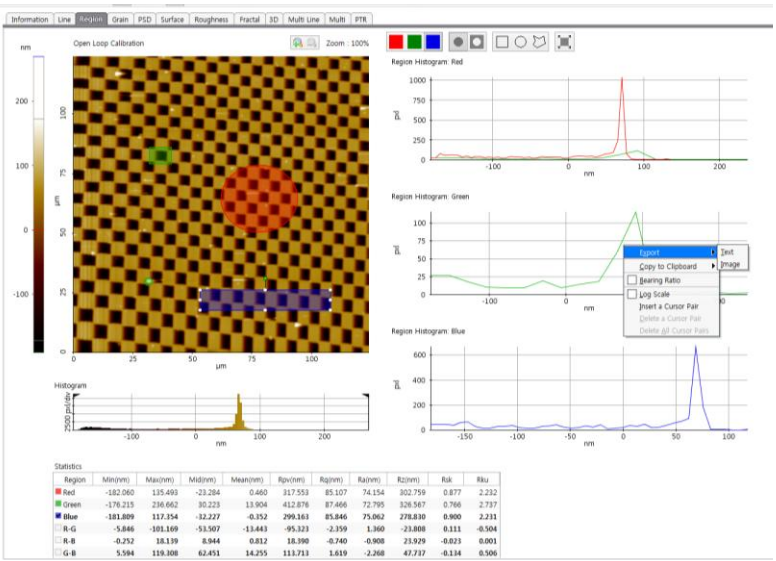
Statistics

Line	Min(pm)	Max(pm)	Mid(pm)	Mean(pm)	Rpv(pm)	Rq(pm)	Ra(pm)	Rz(pm)	Rsk	Rku
☑ Red	-104.943	104.943	0.000	-2.315	209.885	38.182	30.516	185.193	0.096	2.971

Figure 2-5-3. Line view

2-5-3. Region

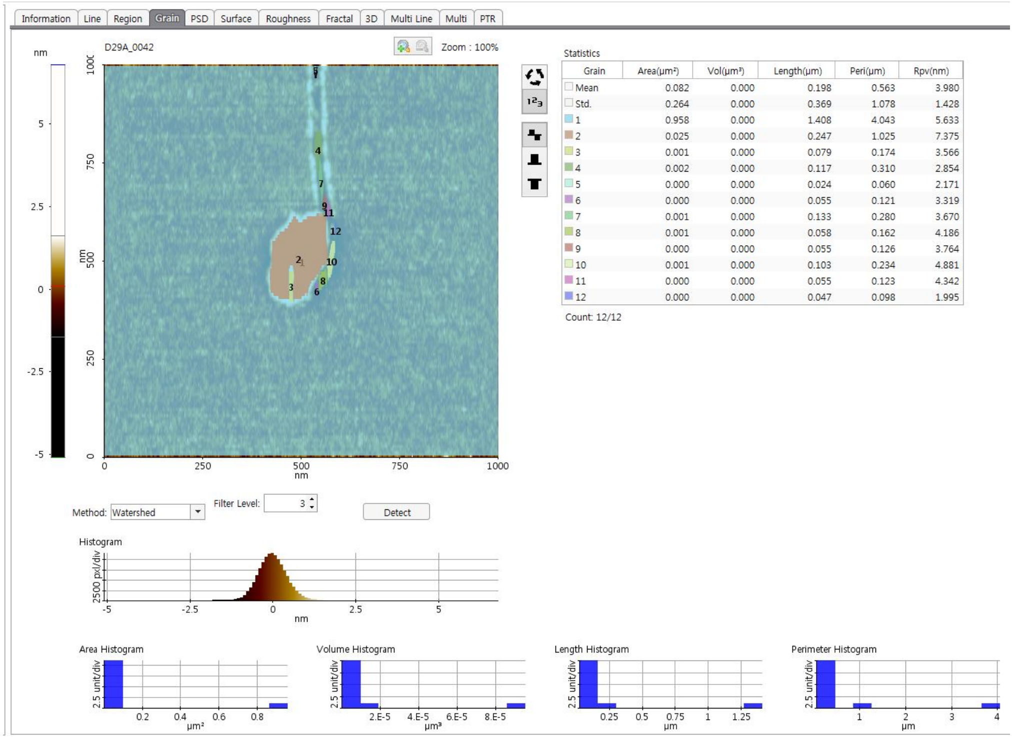
In the Region view, you can get information about a region of the sample surface in the selected image. You can see a Region Histogram of the selected region as well as a surface Statistics table such as the maximum and minimum height value, mean height and RMS roughness. Figure 2-5-4 shows the Region view of an analyzed image. A more detailed description of the Region view is offered in Chapter 5. “Region View”.



Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
🟥 Red	-182.060	135.493	-23.284	0.460	317.553	85.107	74.154	302.759	0.877	2.232
🟩 Green	-176.215	236.662	30.223	13.904	412.876	87.466	72.795	326.567	0.766	2.737
☑ Blue	-181.809	117.354	-32.227	-0.352	299.163	85.846	75.062	278.830	0.900	2.231
☐ R-G	-5.846	-101.169	-53.507	-13.443	-95.323	-2.359	1.360	-23.808	0.111	-0.504
☐ R-B	-0.252	18.139	8.944	0.812	18.390	-0.740	-0.908	23.929	-0.023	0.001
☐ G-B	5.594	119.308	62.451	14.255	113.713	1.619	-2.268	47.737	-0.134	0.506

Figure 2-5-4. Region view

In the Grain view, user can perform grain analysis on the loaded image. System automatically detects grains in the image, calculates important surface profile parameters of each detected grain, and displays the distribution of surface parameters among detected grains Figure 2-5-5 shows the Grain view of an analyzed image. A more detailed description of the Region view is offered in Chapter 6. “Grain view”.



Method: Watershed

Filter Level: 3

Statistics

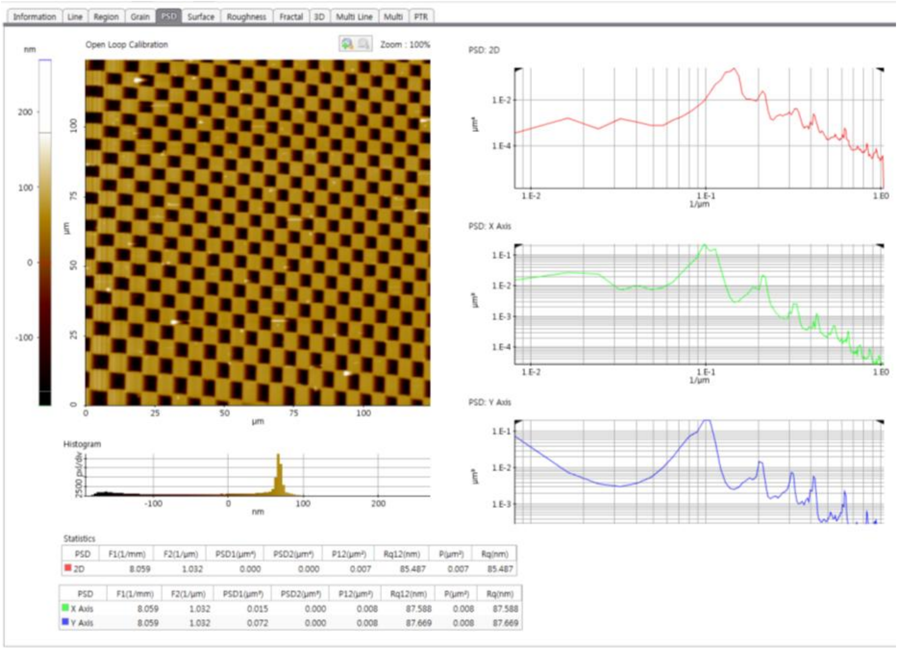
Grain	Area(µm²)	Vol(µm³)	Length(µm)	Peri(µm)	Rpv(nm)
☐ Mean	0.082	0.000	0.198	0.563	3.980
☐ Std.	0.264	0.000	0.369	1.078	1.428
■ 1	0.958	0.000	1.408	4.043	5.633
■ 2	0.025	0.000	0.247	1.025	7.375
■ 3	0.001	0.000	0.079	0.174	3.566
■ 4	0.002	0.000	0.117	0.310	2.854
■ 5	0.000	0.000	0.024	0.060	2.171
■ 6	0.000	0.000	0.055	0.121	3.319
■ 7	0.001	0.000	0.133	0.280	3.670
■ 8	0.001	0.000	0.058	0.162	4.186
■ 9	0.000	0.000	0.055	0.126	3.764
■ 10	0.001	0.000	0.103	0.234	4.881
■ 11	0.000	0.000	0.055	0.123	4.342
■ 12	0.000	0.000	0.047	0.098	1.995

Count: 12/12

Figure 2-5-5. Grain view

2-5-5 PSD

In the PSD view, user can analyze roughness of the sample surface through PSD graph of the loaded image and obtain relevant data. Figure 2-5-6 shows the PSD view of an analyzed image. A more detailed description of the Region view is offered in Chapter 7. "PSD View".



Statistics

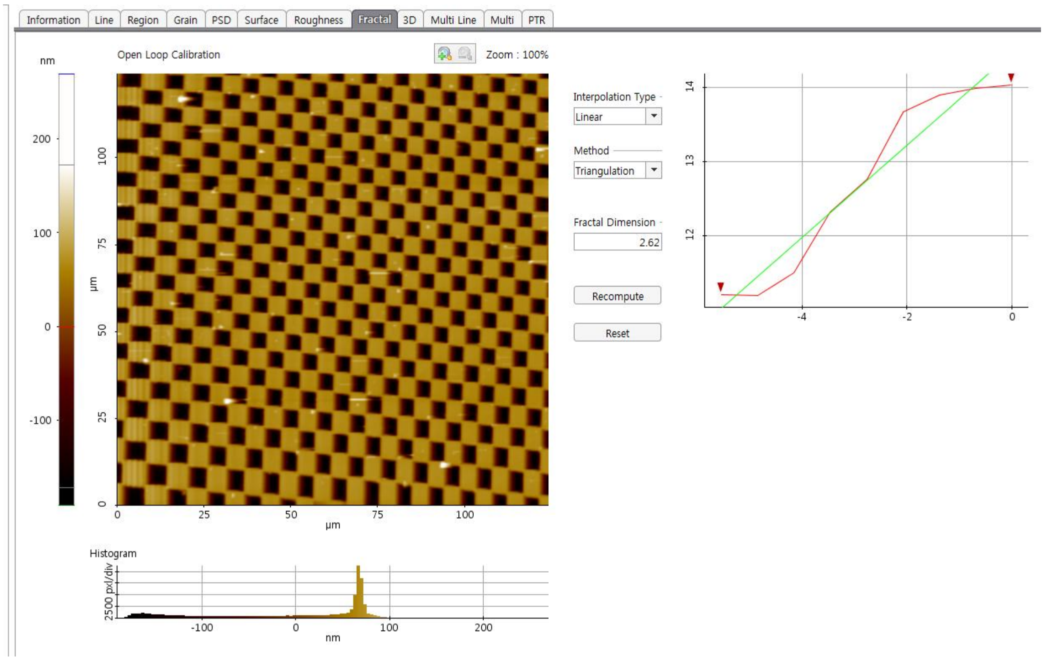
PSD	F1(1/mm)	F2(1/µm)	PSD1(μm^4)	PSD2(μm^4)	P12(μm^2)	Rq12(nm)	P(μm^2)	Rq(nm)
🟥 2D	8.059	1.032	0.000	0.000	0.007	85.487	0.007	85.487

PSD	F1(1/mm)	F2(1/µm)	PSD1(μm^4)	PSD2(μm^4)	P12(μm^2)	Rq12(nm)	P(μm^2)	Rq(nm)
🟩 X Axis	8.059	1.032	0.015	0.000	0.008	87.588	0.008	87.588
🟦 Y Axis	8.059	1.032	0.072	0.000	0.008	87.669	0.008	87.669

Figure 2-5-6. PSD view

2-5-6. Fractal

In the Fractal view, user can analyze fractal dimension of the sample surface through fractal graph of the loaded image. Figure 2-5-7 shows the Fractal view of an analyzed image. A more detailed description of the Fractal view is offered in Chapter 8.



Interpolation Type: Linear

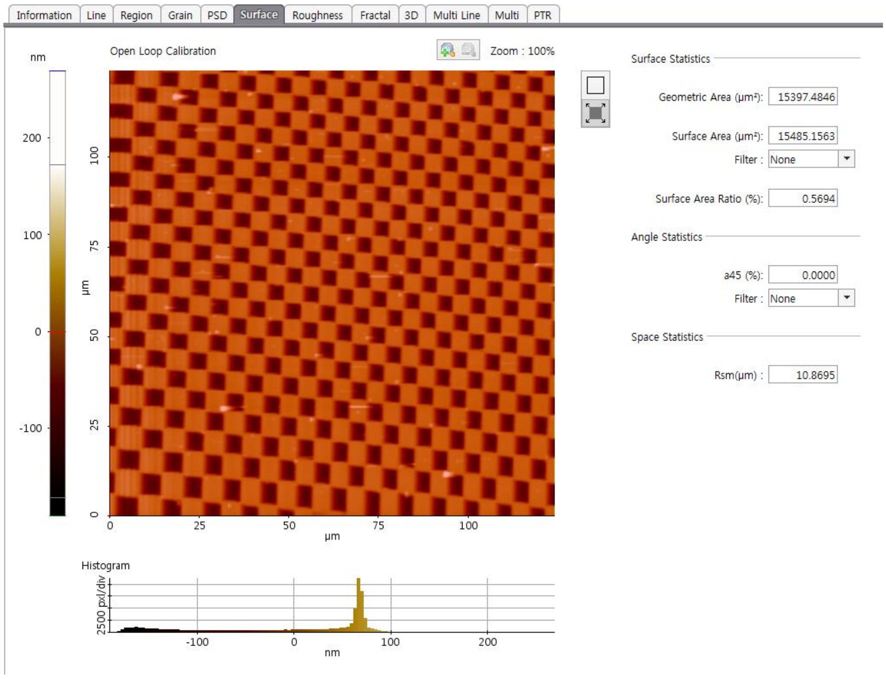
Method: Triangulation

Fractal Dimension: 2.62

Figure 2-5-7. Fractal view

2-5-7. Surface

In the Surface view, user can analyze surface area of the sample image in the selected image. You can collect surface statistics such as geometric area, surface area and surface area ratio. Figure 2-5-8 shows the Surface view of an analyzed image. A more detailed description of the Surface view is offered in Chapter 23.



Surface Statistics

Geometric Area (μm²): 15397.4846

Surface Area (μm²): 15485.1563

Filter : None

Surface Area Ratio (%): 0.5694

Angle Statistics

a45 (%): 0.0000

Filter : None

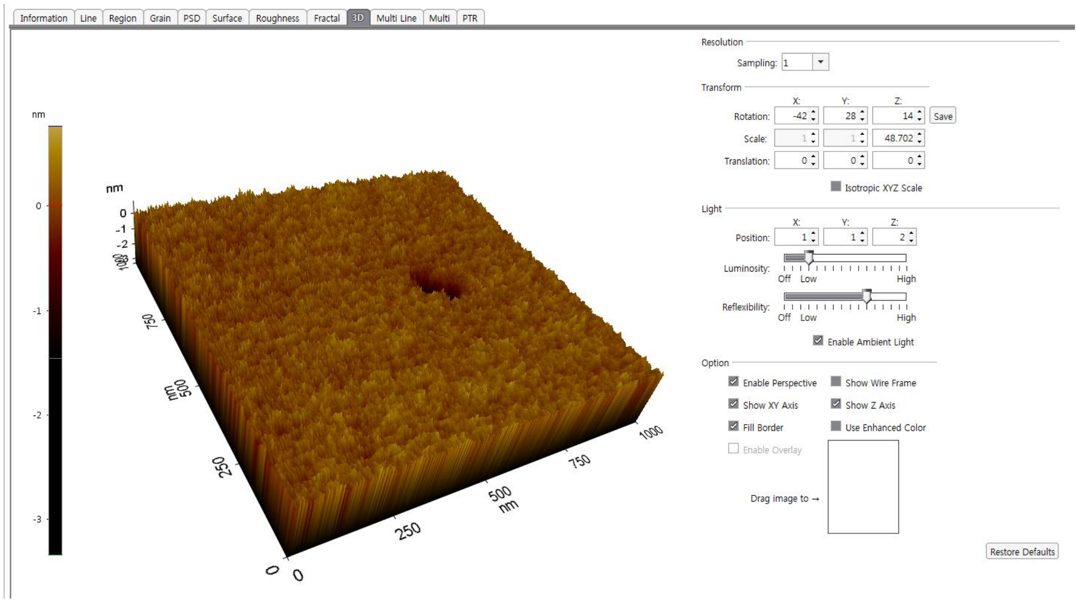
Space Statistics

Rsm(μm) : 10.8695

Figure 2-5-8. Surface view

2-5-8. 3D

In 3D view, you can view and generate 3D rendered images using many display parameters. The 3D view helps you to see the features of the image and the relationships between those features more clearly. Figure 2-5-9 shows the 3D view of a 3D rendered image. The 3D view is discussed more in Chapter 9.



Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	-42	28	14
Scale:	1	1	48.702
Translation:	0	0	0

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity:

Reflexibility:

☑ Enable Ambient Light

Option

☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Figure 2-5-9. 3D view

2-5-9. Multi

In Multi view, you can display and print out several images, up to 6 at a time, with their file name and the palette panel for the contrast and adjustment of the images. You can load multiple images into the empty display panel. Figure 2-5-8 shows the Multi view of the selected images from the Navigator view. A further detailed description is provided in Chapter 10. “Multi View”.

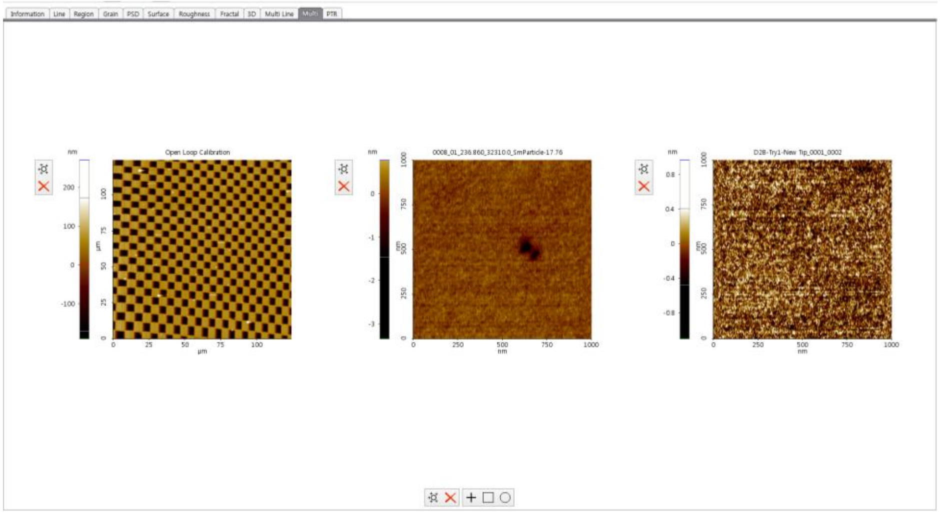


Figure 2-5-10. Multi view

2-6. Process

The Process menu offers you eleven image processing tools: Crop, Filter, Flatten, Deglitch, Region Deglitch, Fourier Filter, Tip Estimation, Rotate & Flip, Pixel Manipulation, Unary Arithmetic, Binary Arithmetic and Stitch as shown in Figure 2-6-1. Commonly, this Process menu provides several controls for improving image resolution or removing artifacts such as high or low frequency noise, curvature, tip effect and glitches from an image without modifying the actual surface features. Several process dialogs are implemented. You can use one of them from the Process menu or click the icon from the toolbar. .

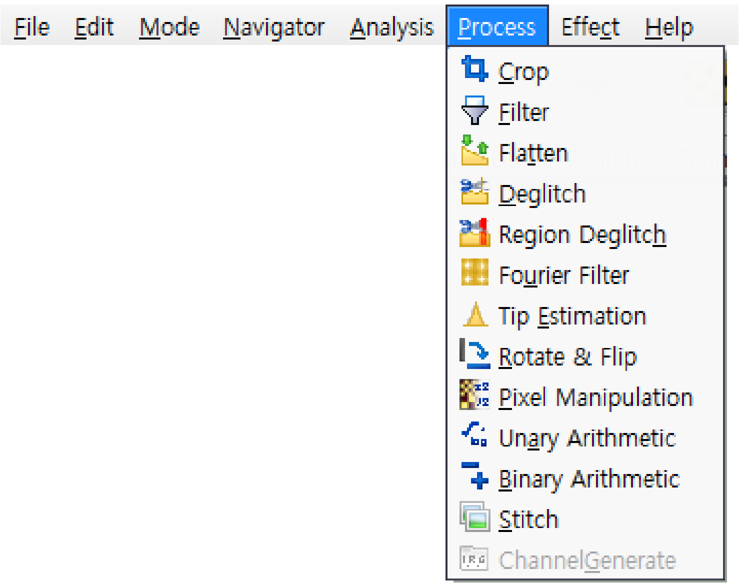
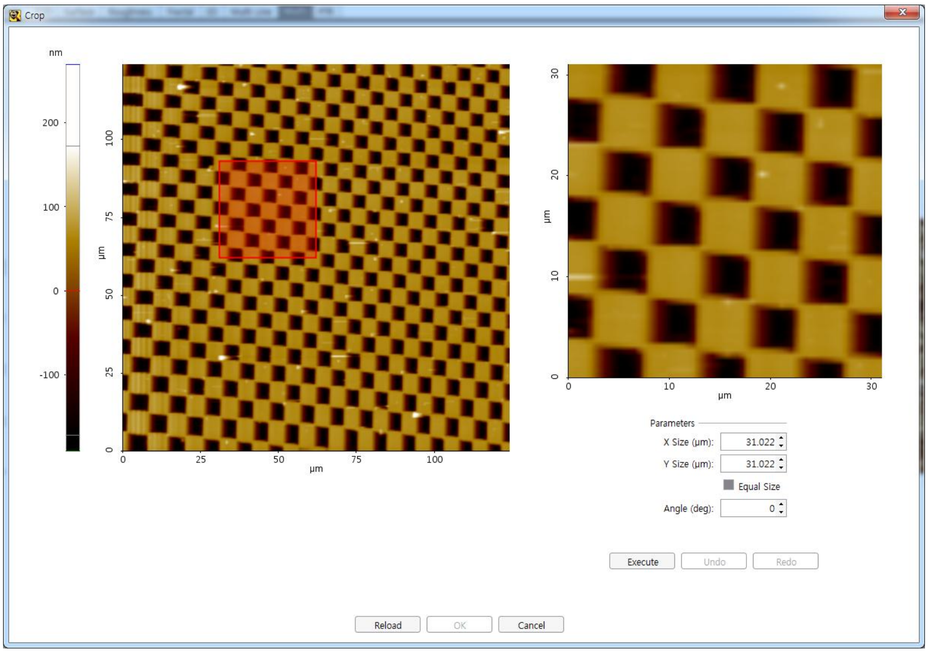


Figure 2-6-1. Process menu and Toolbar

2-6-1. Crop

In the Crop process dialog, you can crop a part of an image which is a region of interest. Figure 2-6-2 shows the Crop process dialog. The Crop menu is described more in Chapter 11. “Crop”.

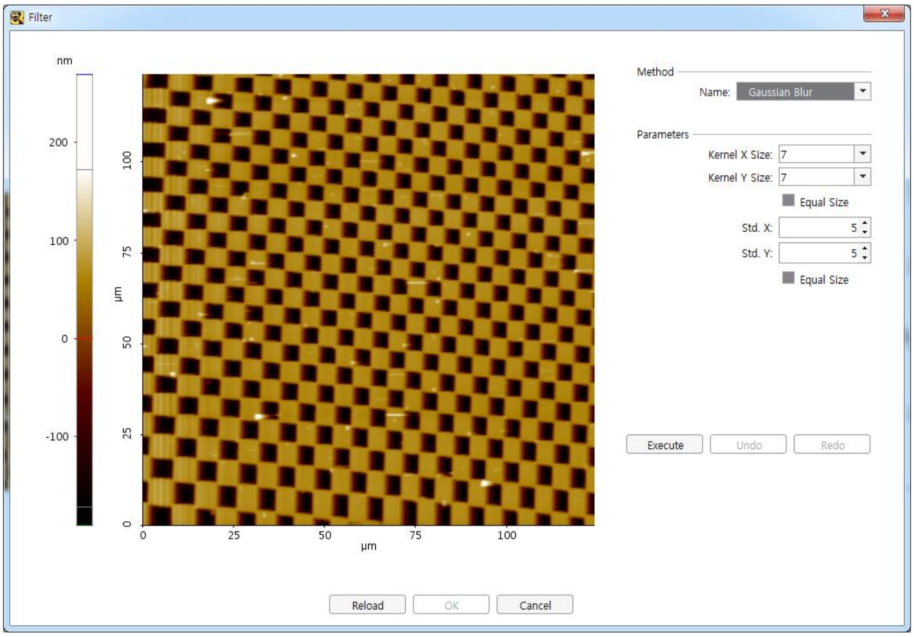


Parameters
X Size (µm): 31.022
Y Size (µm): 31.022
■ Equal Size
Angle (deg): 0

Figure 2-6-2. Crop process dialog

2-6-2. Filter

Using the Filter process dialog, you can remove some artifacts from the sample surface that are not real data. Figure 2-6-3 shows the Filter process dialog. A further detailed description is offered in Chapter 12. “Arithmetic Filter”.



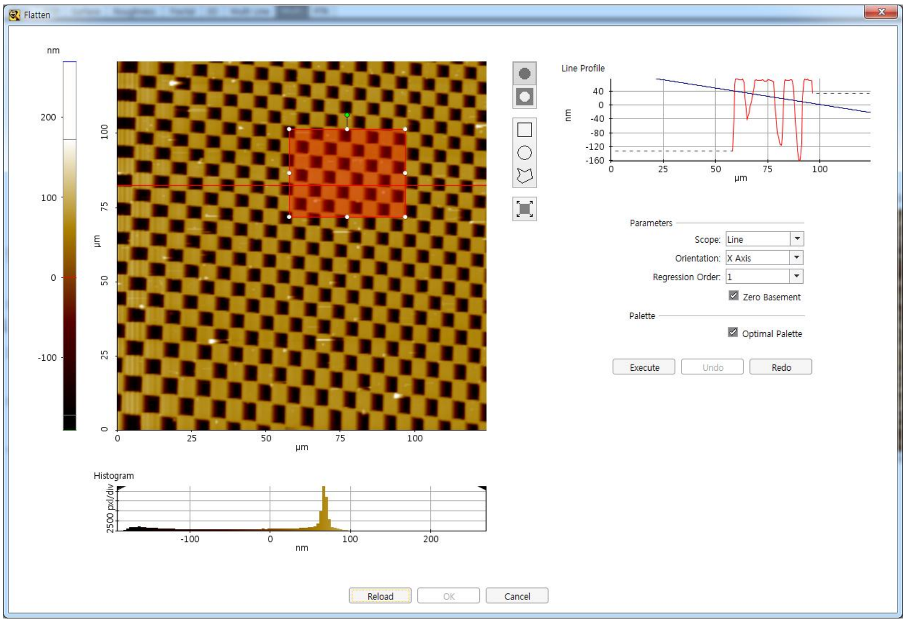
Method
Name: Gaussian Blur

Parameters
Kernel X Size: 7
Kernel Y Size: 7
☐ Equal Size
Std. X: 5
Std. Y: 5
☐ Equal Size

Figure 2-6-3. Filter process dialog

2-6-3. Flatten

In the Flatten process dialog, you can remove curvatures and slopes from your image data. For more information about the Flatten processing feature, you can refer to Chapter 13. “Flatten” in this document. Figure 2-6-4 shows the Flatten process dialog.



Parameters

Scope: Line

Orientation: X Axis

Regression Order: 1

☑ Zero Basement

Palette

☑ Optimal Palette

Figure 2-6-4. Flatten process dialog

2-6-4. Deglitch

In the Deglitch process dialog, you can remove small glitches or vertical and horizontal streaks in an image. Figure 2-6-5 shows the Deglitch process dialog. Deglitch is described further in Chapter 14. “Deglitch”.

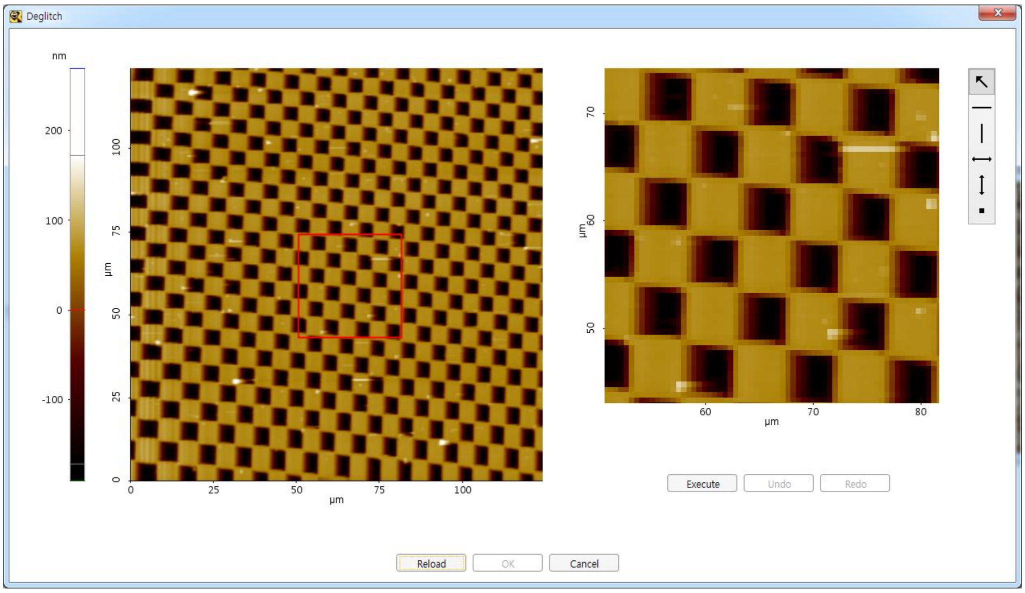


Figure 2-6-5. Deglitch process dialog

2-6-5. Fourier Filter

In the Fourier Filter process dialog, you can use the Fourier Filter to remove unwanted frequency components from your data. About the Fourier Filter, consult Chapter 16. “Fourier Filter”. Figure 2-6-6 shown below is the Fourier Filter process dialog.

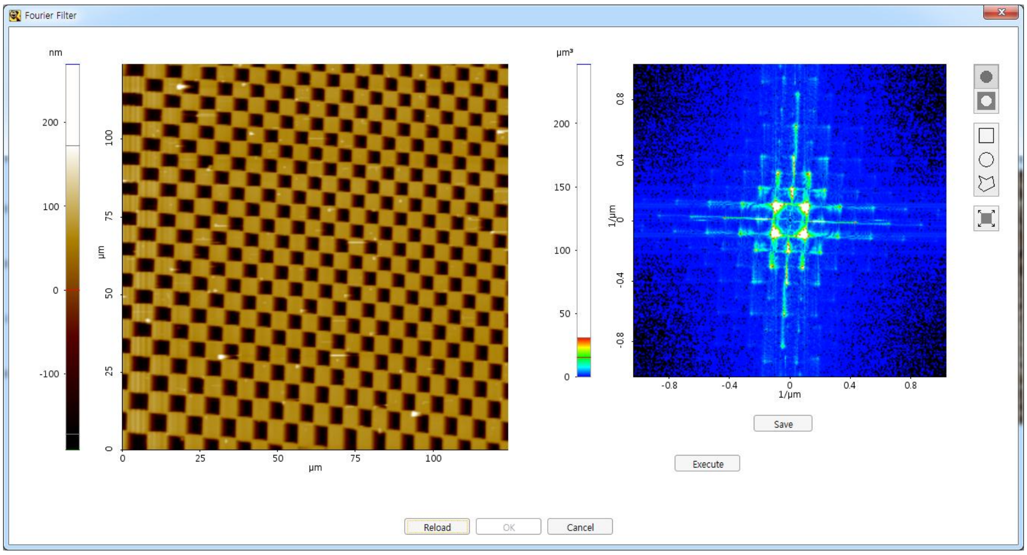
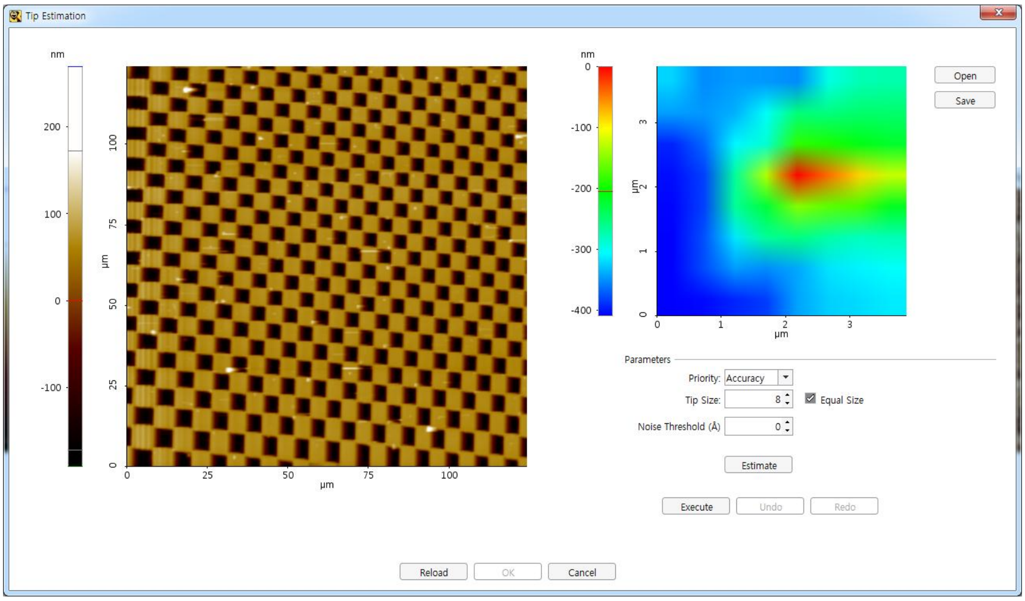


Figure 2-6-6. Fourier Filter process dialog

2-6-6. Tip Estimation

In the Tip Estimation process dialog, you can estimate the shape of the tip used to obtain the image and remove the artifacts generated by tip shape (known as ‘Tip Convolution’) from the loaded image to obtain more accurate image. Consult Chapter 17 for more information on Tip Estimation. Figure 2-6-7 shows the Tip Estimation process dialog.

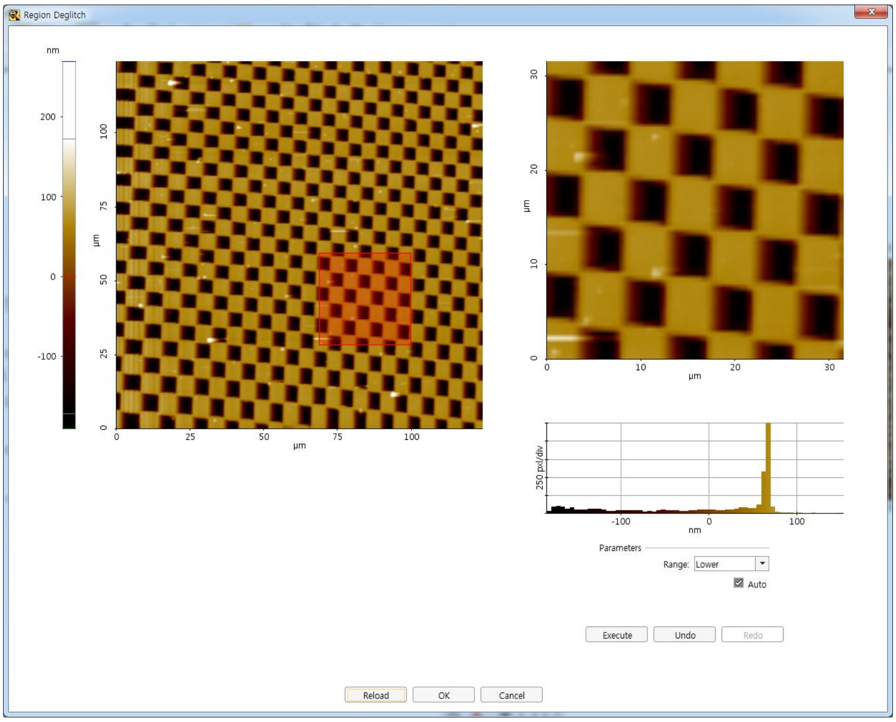


Priority: Accuracy
Tip Size: 8 ☑ Equal Size
Noise Threshold (Å) 0

Figure 2-6-7. Fourier Filter process dialog

2-6-7. Region Deglitch

In the Region Deglitch process dialog, you can remove small artifact in an image that does not represent the true surface topography to obtain more accurate image. Consult Chapter 15 for more information on Region Deglitch. Figure 2-6-8 shows the Region Deglitch process dialog.



Parameters

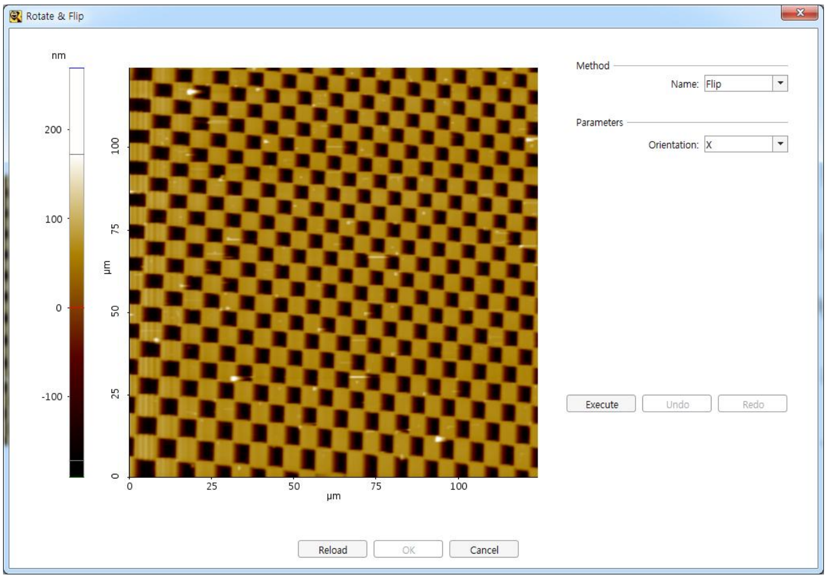
Range: Lower

☑ Auto

Figure 2-6-8. Fourier Filter process dialog

2-6-8. Rotate & Flip

In the Rotate & Flip process dialog, you can change the orientation of the obtained image. It may be helpful comparison of images taken at different orientations. Consult Chapter 18 for more information on Rotate & Flip. Figure 2-6-9 shows the Rotate & Flip process dialog.



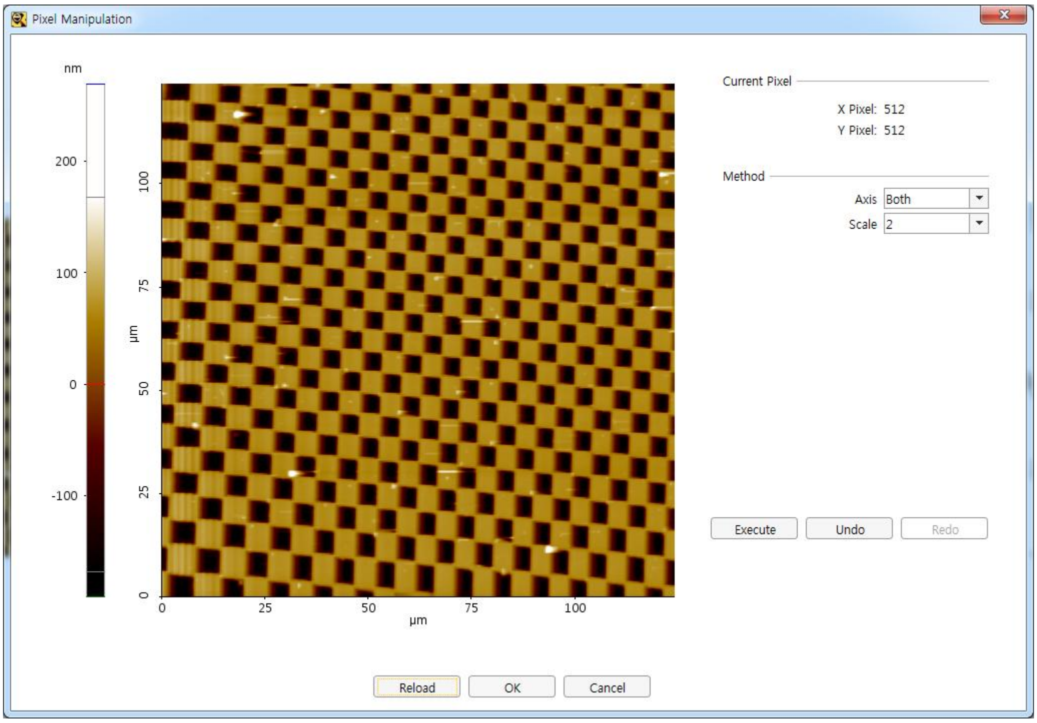
Name: Flip

Orientation: X

Figure 2-6-9. Rotate & Flip process dialog

2-6-9. Pixel Manipulation

In the Pixel Manipulation process dialog, you can increase or decrease the number of pixels in the obtained image. This is useful when comparing images of differing resolutions. Consult Chapter 19 for more information on Rotate & Flip. Figure 2-6-10 shows the Pixel Manipulation process dialog.



Pixel Manipulation

Current Pixel

X Pixel: 512

Y Pixel: 512

Method

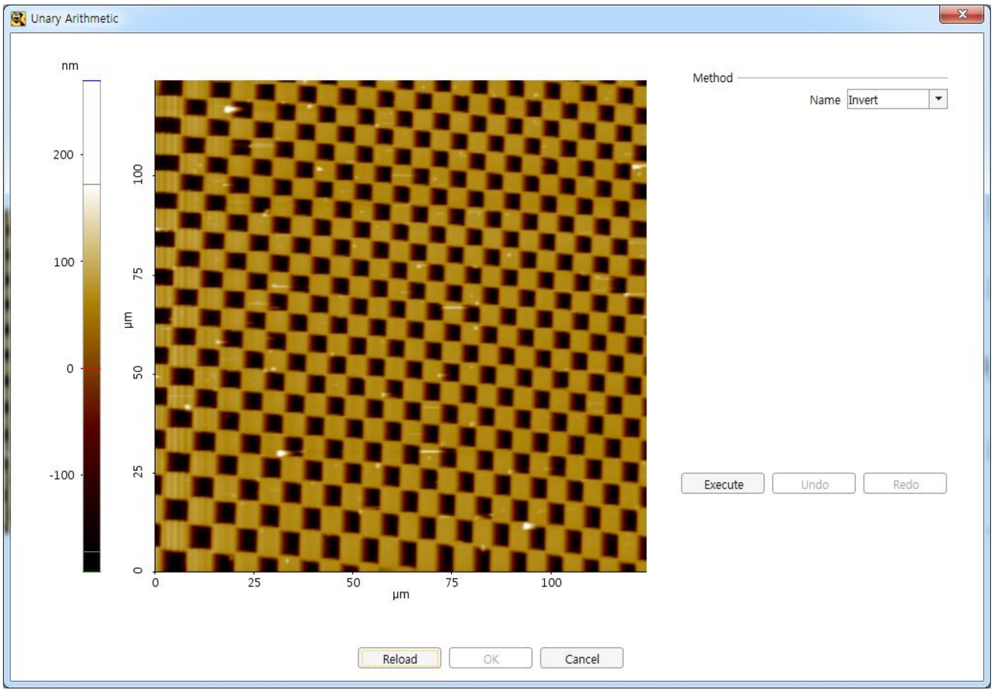
Axis Both

Scale 2

Figure 2-6-10. Pixel Manipulation process dialog

2-6-10. Unary Arithmetic

In the Unary Arithmetic process dialog, you can perform arithmetic operation on image such as invert, square and square root. Consult Chapter 20 for more information on Unary Arithmetic. Figure 2-6-11 shows the Unary Arithmetic process dialog.



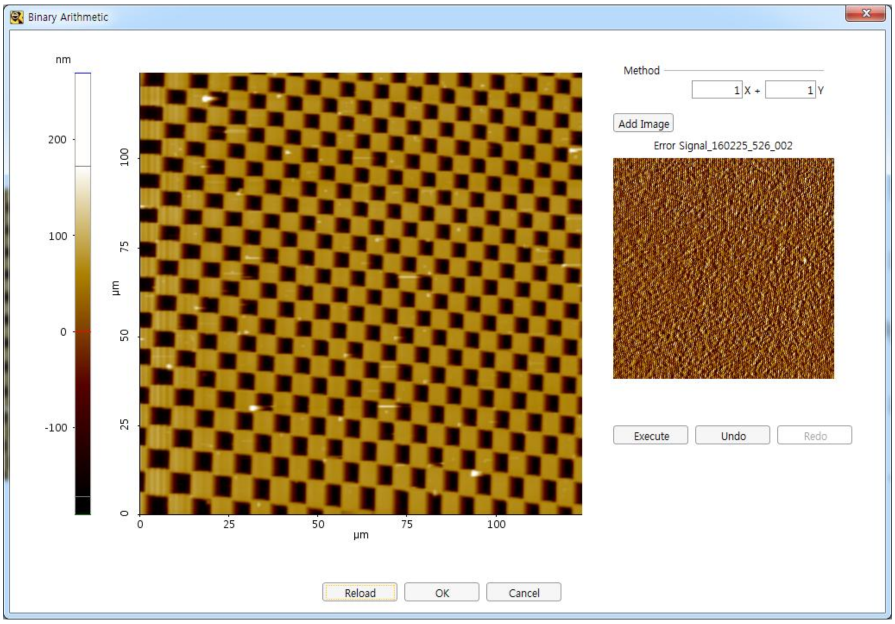
Method

Name Invert

Figure 2-6-11. Unary Arithmetic process dialog

2-6-11. Binary Arithmetic

In the Binary Arithmetic process dialog, you can perform arithmetic operation on two images such as +/-. It may be useful for the direct comparison of two images. Consult Chapter 21 for more information on Binary Arithmetic. Figure 2-6-12 shows the Binary Arithmetic process dialog.



Binary Arithmetic

Method

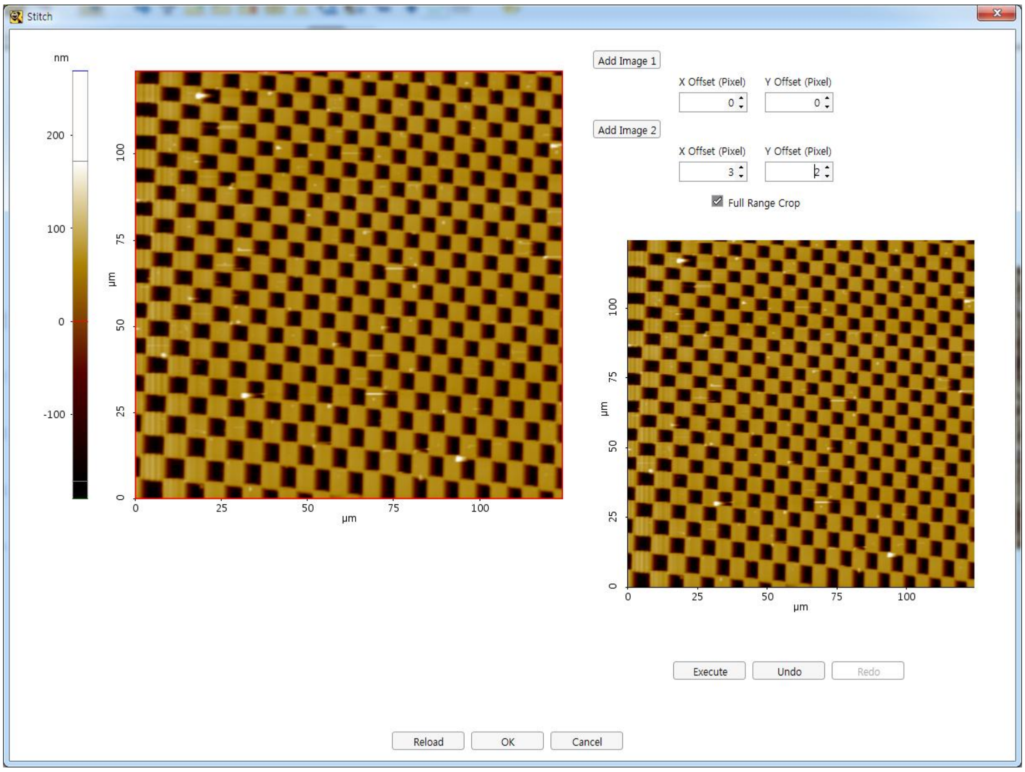
1 X + 1 Y

Error Signal_160225_526_002

Figure 2-6-12. Binary Arithmetic process dialog

2-6-12. Stitch

In the Stitch process dialog, you can stitch several images together and make an image. It may be useful that you want to get a bigger sized image than the obtain image. Consult Chapter 24 for more information on Stitch. Figure 2-6-13 shows the Stitch process dialog.



Add Image 1

X Offset (Pixel) 0 Y Offset (Pixel) 0

Add Image 2

X Offset (Pixel) 3 Y Offset (Pixel) 2

☑ Full Range Crop

Figure 2-6-13. Stitch process dialog

2-7. Effect

2-7-1. Palette

You can select the palette that is to be used for the contrast adjustment in the 'Effect>Palette' menu or by clicking the 'Palette' icon .

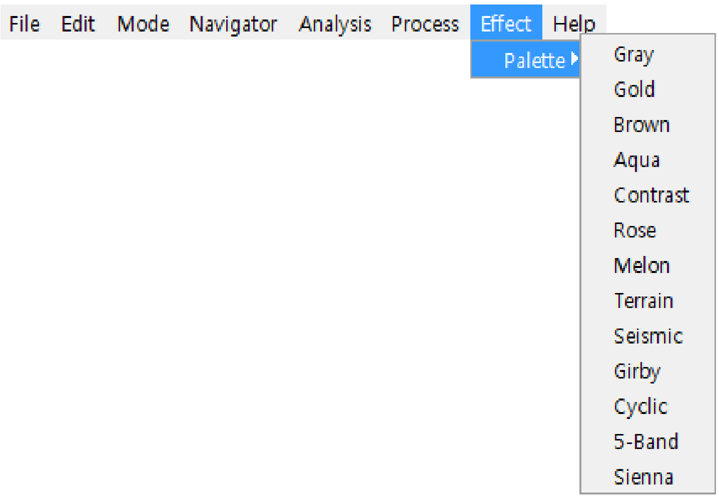
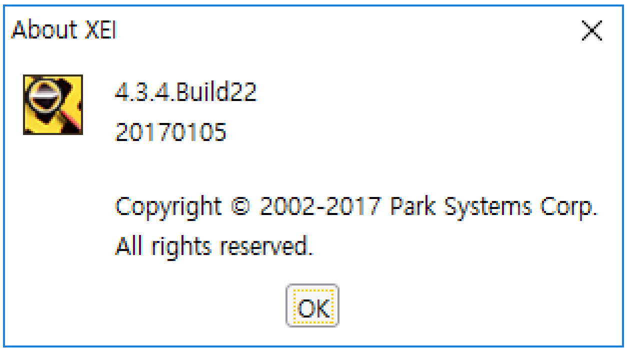


Figure 2-7-1. Effect menu

2-8. Help

2-8-1. About

This item opens a dialog with information(Version and build data) on this program.


About XEI

4.3.4.Build22
20170105

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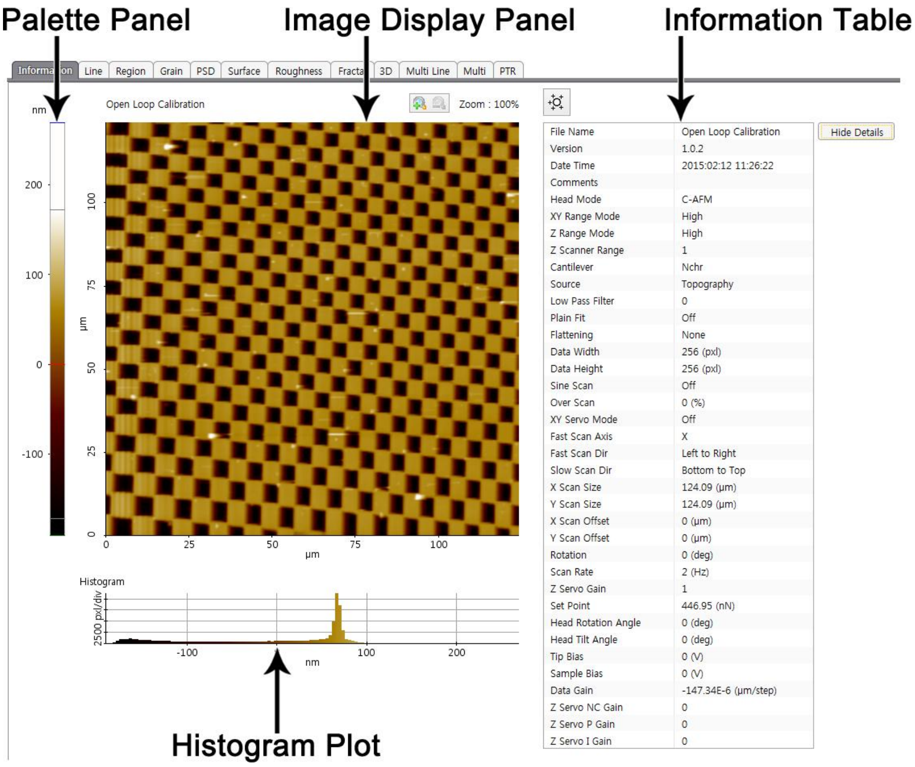
Figure 2-8-1. About dialog

Chapter 3. Analysis View

3-1. Information View

In the Information view, the loaded image and its essential information, such as the scan conditions and parameters that were used in acquiring data, are displayed on the XEI screen. You can preview the original image and data through the Information view before performing an image processing or analysis. The Information view is automatically enabled when you execute the XEI program, but you can switch to the Information view from other views by selecting ‘Analysis>Information’ in the Menu or by clicking the Information view tab below the menu bar. Figure 3-1-1 shows the layout of the Information view.



File Name	Open Loop Calibration
Version	1.0.2
Date Time	2015:02:12 11:26:22
Comments	
Head Mode	C-AFM
XY Range Mode	High
Z Range Mode	High
Z Scanner Range	1
Cantilever	Nchr
Source	Topography
Low Pass Filter	0
Plain Fit	Off
Flattening	None
Data Width	256 (pxl)
Data Height	256 (pxl)
Sine Scan	Off
Over Scan	0 (%)
XY Servo Mode	Off
Fast Scan Axis	X
Fast Scan Dir	Left to Right
Slow Scan Dir	Bottom to Top
X Scan Size	124.09 (μm)
Y Scan Size	124.09 (μm)
X Scan Offset	0 (μm)
Y Scan Offset	0 (μm)
Rotation	0 (deg)
Scan Rate	2 (Hz)
Z Servo Gain	1
Set Point	446.95 (nN)
Head Rotation Angle	0 (deg)
Head Tilt Angle	0 (deg)
Tip Bias	0 (V)
Sample Bias	0 (V)
Data Gain	-147.34E-6 (μm/step)
Z Servo NC Gain	0
Z Servo P Gain	0
Z Servo I Gain	0

Figure 3-1-1. Information view

3-1-1. Palette Panel

The Palette Panel is used to adjust the contrast level range of an image. The Palette panel displays the range of the image data values of the measured signal. Also, the Palette panel shows the relationship between the color of the pixel in the image and corresponding data values of the measured signal. Different colors or shades in the Palette panel represent different height values of the data in the image. The default palette is based on gold color palette scale in which darker colors indicate lower heights and the brighter colors indicate higher height values. As shown in the Figure 3-1-2, there are 3 cursors in the scale bar that indicates the level and range of the scale bar and can be adjusted.

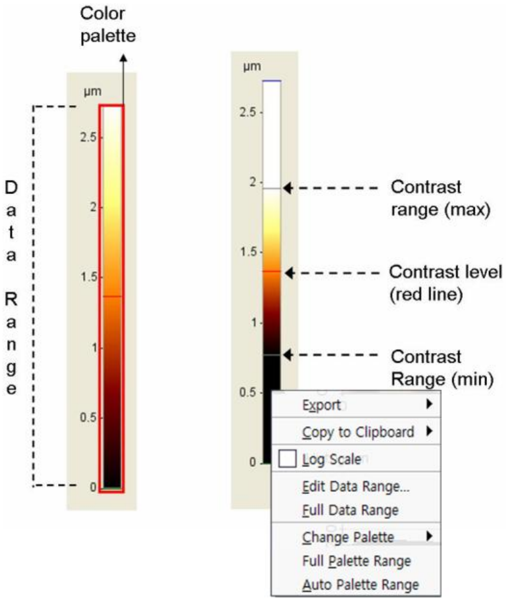


Figure 3-1-2. Palette Panel

3-1-1-1. Data Range Adjustment

On the left side of the Palette panel, the vertical data scale indicates the height range of the image. By default, maximum (minimum) value of the data range corresponds to the maximum (minimum) data of the pixel data. This data range can be edited manually by 'Edit Data Range' command in the context menu of the palette panel.

- **Full data range**

Full data range command automatically sets maximum (minimum) value of the data range to the maximum value of the pixel data.

3-1-1-2. Contrast Range Adjustment

There are two cursors in the palette panel that helps users to change the contrast range. They are Contrast Max and Min cursors. The contrast range is set by adjusting the vertical length of the color palette by dragging these two cursors. Also contrast range can be adjusted by 'Full Palette range' command in the context menu of the palette panel.

- **Contrast Max cursor**

'Contrast max' cursor indicates the data value on the data scale that corresponds to the brightest color of the current color palette (generally white). Any pixels with the data value that exceeds the value indicated by 'Contrast range max' will be displayed in brightest color of the color palette (generally white) regardless of their value.

- **Contrast Min cursor**

'Contrast min' cursor indicates the data value on the data scale that corresponds to the darkest color of the current color palette (generally black). Any pixels with the data value that is under the value indicated by 'Contrast range min' will be displayed in darkest color of the color palette (generally black) regardless of their value.

- **Full Palette Range**

Full palette range command automatically brings 'Contrast Max' cursor to the maximum value of the data range and ‘Contrast in’ cursor to the minimum value of the data range. Therefore, Full palette range command adjusts contrast range such that the contrast range matches the full range of the data range. Thus, the scale maximum corresponds to the data maximum and the scale minimum corresponds to the data minimum.

Adjusting contrast range is useful when you are interested in a specific height range in an image. You can narrow the contrast range so that it covers smaller features in an image (Figure 3-1-3). In this way, you can scale up a specific height range in an image to see smaller features in greater detail.

■ Auto palette range

The contrast range can be automatically determined by the XEI program. Double click on the contrast bar to set the contrast range with this feature.

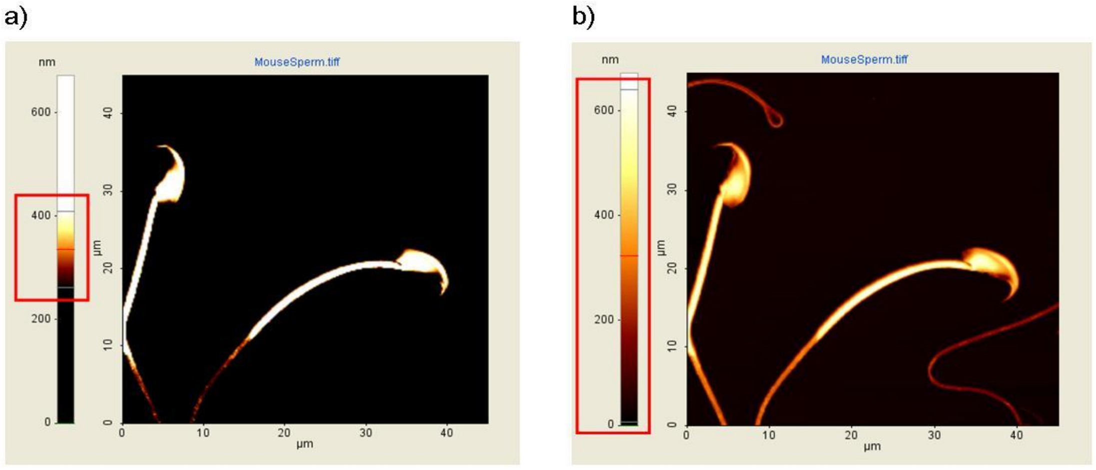


Figure 3-1-3. Contrast range adjustment

3-1-1-3. Contrast Level Adjustment

‘Contrast level marker’ is a red line on the palette panel. ‘Contrast level marker’ indicates the data value on the data scale that corresponds to the middle of the current color palette. As shown in Figure 3-1-4, the contrast level is adjusted by click and dragging the ‘Contrast level marker’ on the palette panel.

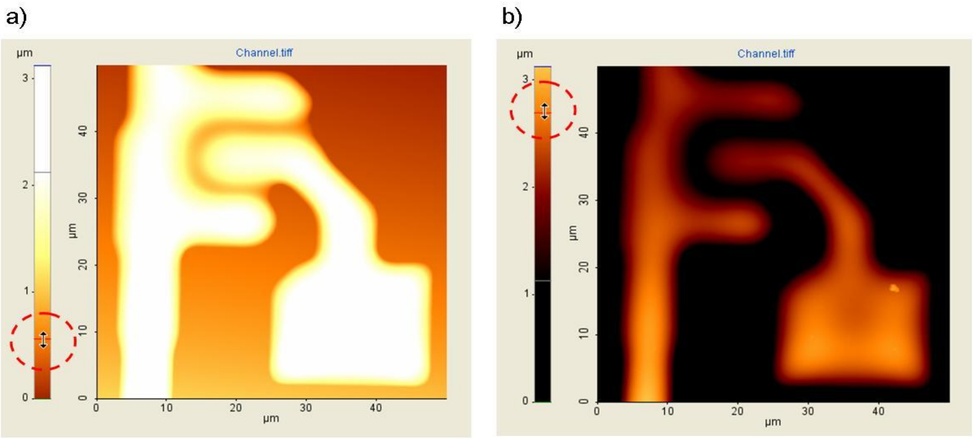


Figure 3-1-4. Contrast level adjustment

3-1-1-4. Palette Change

You can change the palette for the contrast adjustment by selecting the ‘Palette’ option in the Effect menu (see Figure 2-6-1).

3-1-1-5. Enhanced Color

The Enhanced Color button changes the way colors are displayed. In the Enhanced Color scheme, the color of a pixel is determined by how much of a change it has compared to its neighbors. Therefore, it is not linearly representative of the data. You can toggle Enhanced Color using the button. Enhanced Color also has its own palette, accessible by right-clicking the Enhanced Color button.

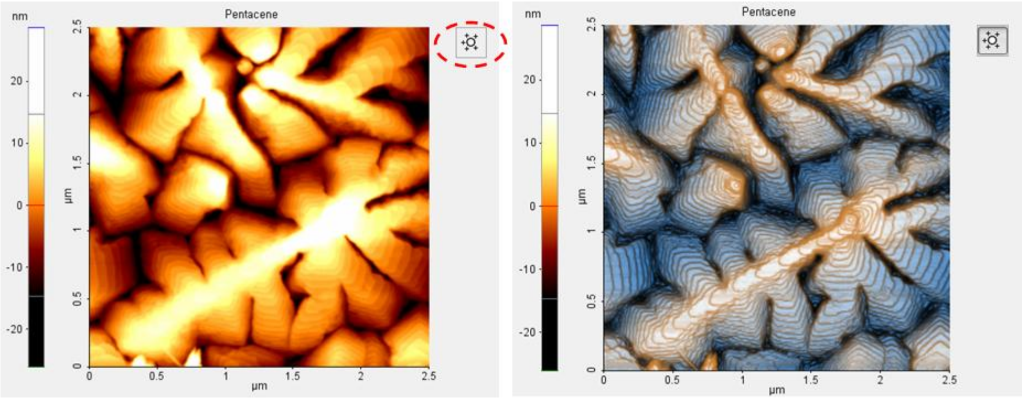


Figure 3-1-5. Enhanced Color

3-1-1-6. Zoom In/Out

Loaded images can be zoomed in by clicking the icon and can be zoomed out by clicking the icon. Adjusting the mouse wheel can also be used to increase or decrease the zoom percentage. The zoom percentage of the original image size is set to 100%, this is the minimum percentage that the image can be zoomed out to. The zoom percentage is displayed at the upper right corner of image display panel. The image resulting from the zoom in or out will be displayed within scan image display. Due to the size of the display, some of the image area will not be visible. The panning tool can be used to change the available visible area by adjusting the image offset.

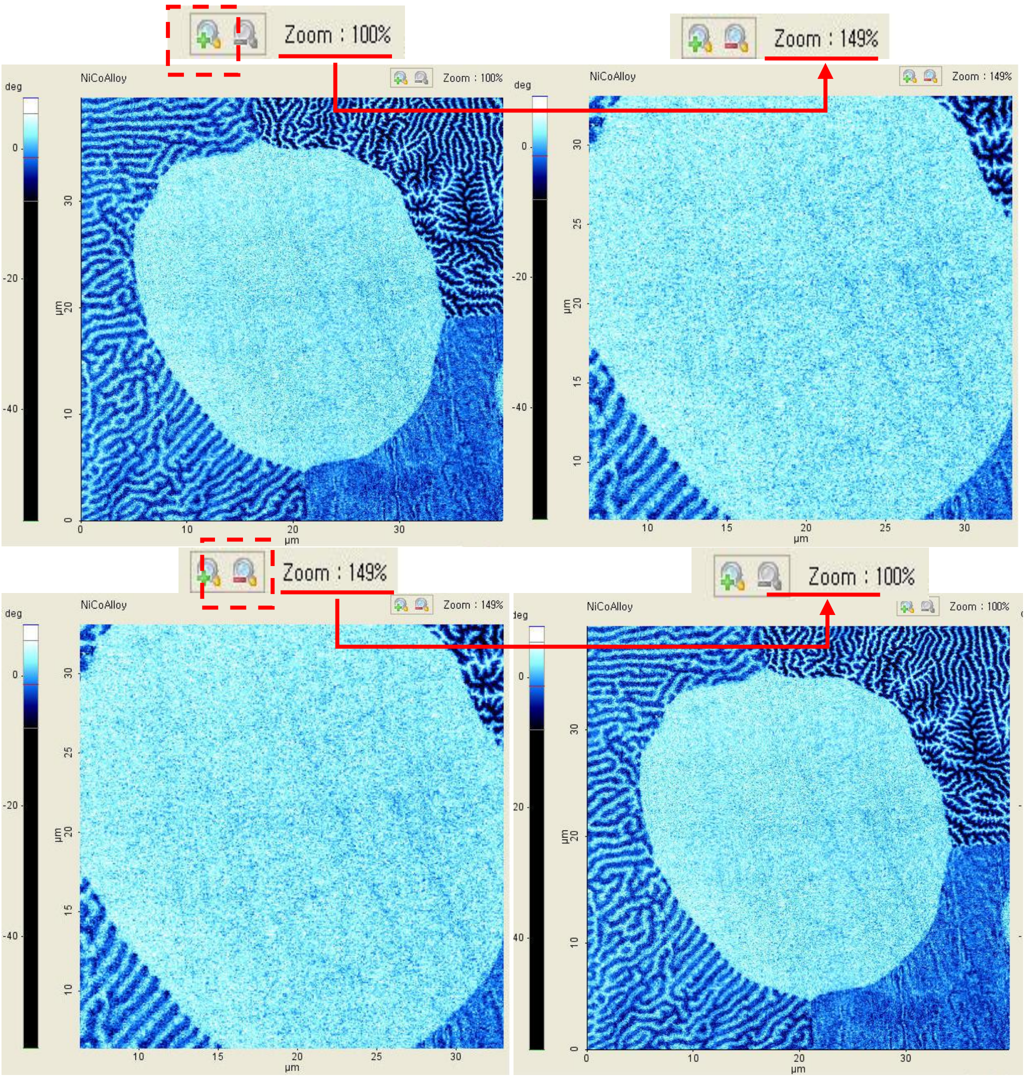


Figure 3-1-6. (Upper) Zoom In, (Down) Zoom Out

To bring up the panning tool, click the wheel button after putting the cursor on the image, and the ✋ icon will be appear. At this time, drag a location on the image to a different position.

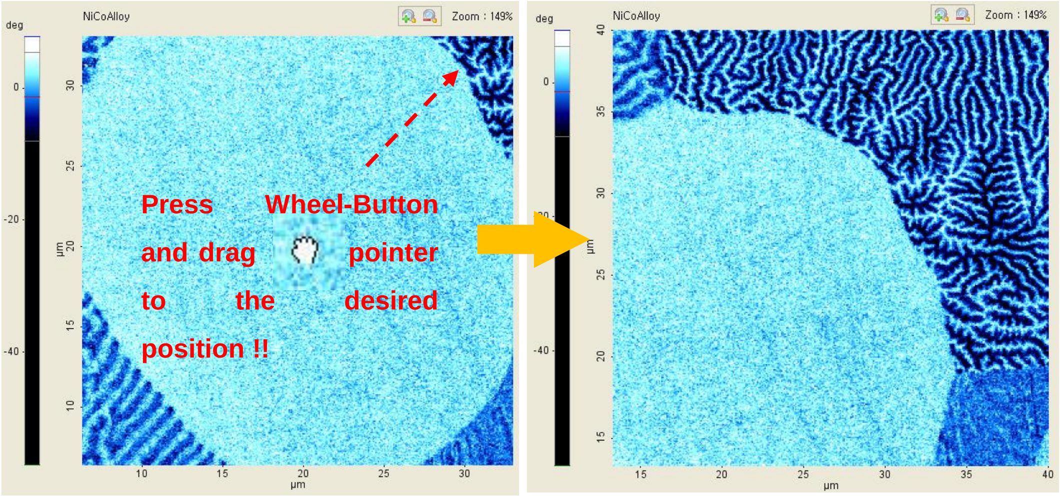

Press Wheel-Button and drag pointer to the desired position !!

Figure 3-1-7. Pan

3-1-2. Image Display Panel

As shown in Figure 3-1-8, the Image display panel shows the 2D image you selected in the Navigator view.

3-1-2-1 Loading Image to the Image Display Panel

When you want to change the image in this panel, you can double-click another image in the Navigator view. At this time, you can see the ‘Load’ confirmation message box which asks if you want to initialize the selected image (Figure 3-1-9).

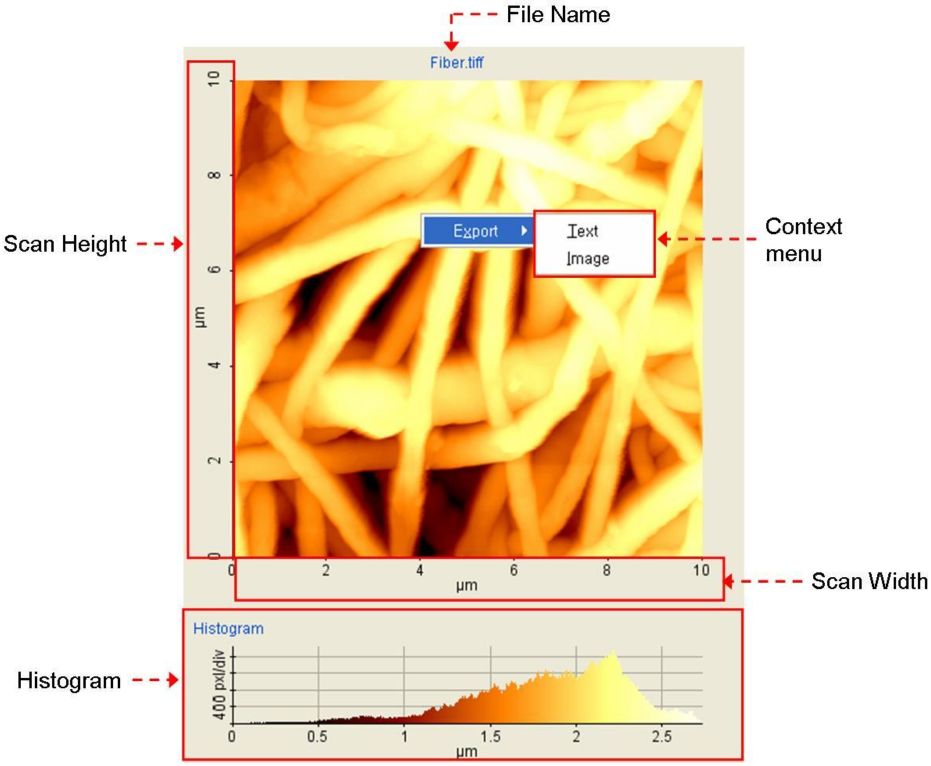
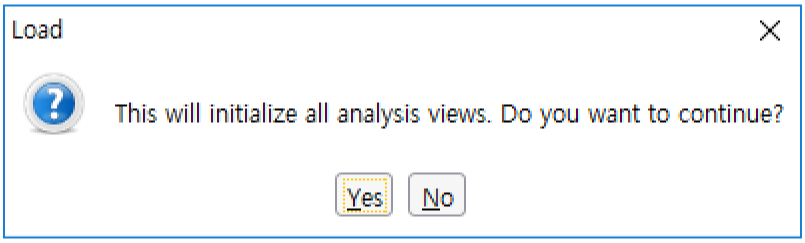


Figure 3-1-8. Image display panel of the Information view



This will initialize all analysis views. Do you want to continue?

Figure 3-1-9. 'Load' confirmation message box

3-1-2-2 Export

Tiff files, loaded in XEI, can be exported in the form of a text file or an image file (jpg, png, bmp, and emf) from the 'Export' command in the context menu of the Image display panel. The raw tiff file consists of two parts, the scan data and the image. When the tiff file is exported as a text file, the file will contain basic information about the tiff file and the data array of the scan data. On the other hand, when the tiff file is exported as an image file, the exported image file only includes the image of the tiff file but not the scan data within it; the image will not include any dimensional information.

3-1-2-3 Copy to Clipboard

This command copies the scan data onto the clipboard as a text file or an image. Text files will contain basic image information and the data array. The command will copy an image file to the clipboard. Right click on the image to open the context menu in the Image display panel. From the 'Copy to Clipboard' command in the context menu, choose text or image, then paste the copied data in the corresponding document file by clicking [Ctrl+V] button.

3-1-2-4 Histogram

The Histogram shown below (Figure 3-1-10) is a bar graph that shows the distribution of heights along a height profile. When you load an image, a histogram is automatically displayed.

The x axis represents the height of data points in the sample surface and its unit can be Å, nm, µm and so on. The width of a bar depends on the overall height range of the sample and the number of data points of the line profile. The y axis is the number of data points with the same height values and its unit is pixel.

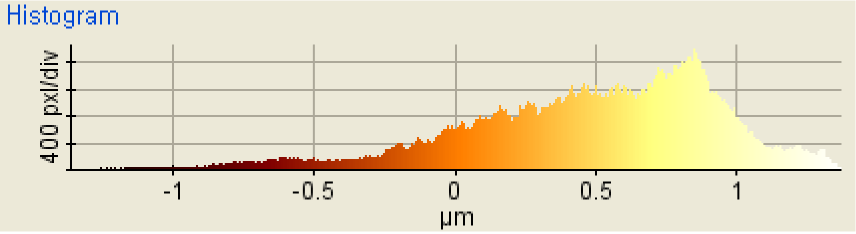


Figure 3-1-10. Histogram

When right click on Histogram, menu will pop-up. Below is context of menu.

- **Use Gaussian Fitting**

It displays a Gaussian Fitting curve of height distribution, according to the function below, on histogram chart. Gaussian Fitting curve contains;

a: Number of pixels according to m,

m: Average,

σ: Average deviation.

Gaussian curves can be useful for acquiring height data from the image Histogram.

$$f(x) = a\,e^{-\frac{(x-m)^2}{2\sigma^2}}$$

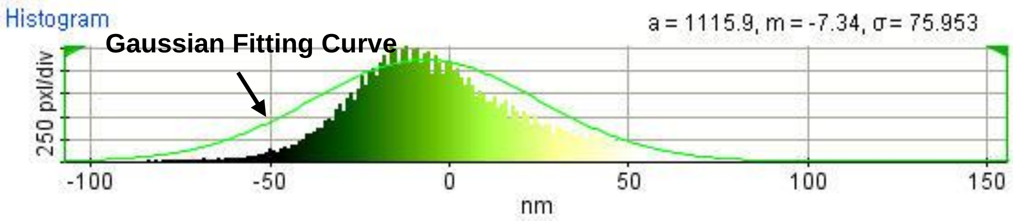


Figure 3-1-11. Cursors on Histogram

Cursors can be placed on the Histogram to acquire single point data. Paired cursors can be placed on the Histogram to acquire distances between two areas of the Gaussian function. After adding the cursor(s), the cursors can be dragged to different positions on the Histogram.

■ Export

Same as Export feature in Image Display panel. Refer to Section 3-3-2.

■ Copy to Clipboard

Copies the histogram data to the clipboard as a text file (txt) or an image file. Open the context menu by right clicking on the histogram, choose the ‘Copy to Clipboard’ command in the context menu and paste the data in the corresponding document file by clicking [Ctrl+V] button.

■ Insert a Cursor

Insert a single cursor on the histogram, similar to Line Profile panel. Up to three single cursors can be added. In figure 3-1-12, below, two single cursors are shown on the histogram. Numbers in the rectangle indicate each single cursor’s X, Y position. Red single cursor indicates (22.116nm, 38.841pxl).

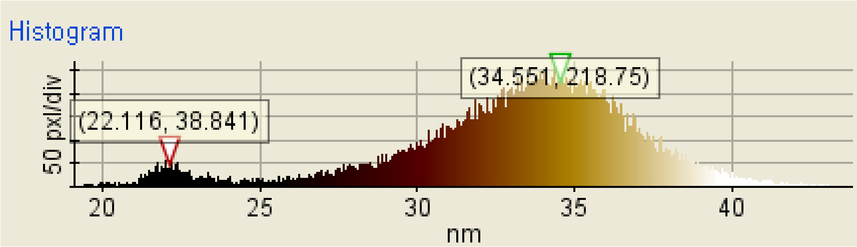


Figure 3-1-12. Cursors on Histogram

■ Delete a Cursor

Deletes a selected cursor, similar to Line Profile panel.

■ Delete all Cursors

Deletes all of the added cursors, similar to Line Profile panel.

■ Insert a Cursor Pair

Inserts a cursor pair, similar to Line Profile panel. Currently, three cursor pairs can be added. Figure 3-1-13 below is shown with one cursor pair inserted in the histogram. The numbers in the rectangle indicates the difference between the cursor pair. The X and Y differences are 113.026nm and 3362pxl respectively.

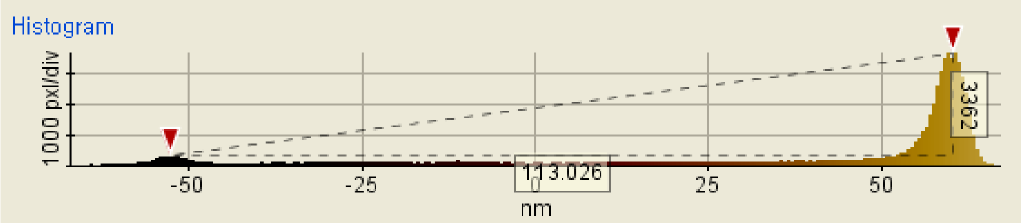


Figure 3-1-13. Cursors on Histogram

■ Delete a Cursor Pair

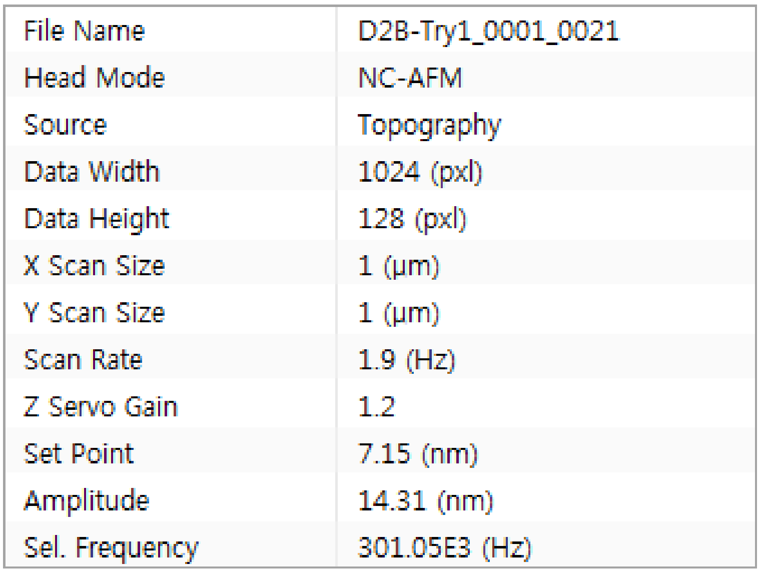
Deletes a selected cursor pair, similar to Line Profile panel.

■ Delete all Cursor Pairs

Deletes all added cursor pairs, similar to Line Profile panel.

3-1-3. Information Table

When scan image file is generated from XEP software, various information and scan parameters used to obtain image is saved along with the image itself. As shown in Figure 3-4-1, these can be viewed through the Information table. Clicking 'Show Details' button will display every information and parameters saved with the image. Click 'Hide Details' button to view only the important information and parameters, summarized. Meaning of the each items found in the Information table is given in the Table 3-1 .



File Name	D2B-Try1_0001_0021
Head Mode	NC-AFM
Source	Topography
Data Width	1024 (pxl)
Data Height	128 (pxl)
X Scan Size	1 (μm)
Y Scan Size	1 (μm)
Scan Rate	1.9 (Hz)
Z Servo Gain	1.2
Set Point	7.15 (nm)
Amplitude	14.31 (nm)
Sel. Frequency	301.05E3 (Hz)

Figure 3-1-14. Information table (Hide Details)

Table 3-2. Items in the detailed Information table

Item	Meaning
File Name	Indicates the file name of the generated image that was saved after scanning.
Version	Indicates the version of Park Systems software that created the image file. XEI 4.3.0 supports tiff file below 1.0.2
Date Time	Shows the time and date at which this file was created.

Comments	Shows the comments you edited in the Image Information dialog of the XEP or SmartScan or XEI.
Head Mode	Indicates the Head mode such as AFM, NC AFM, MFM, LFM, EFM, FMM and so on. It was selected in the XEP or SmartScan Part Selection dialog.
XY Range Mode	Indicates the scan range mode of the XY scanner (Large, Medium or Small) during imaging. This parameter is set in the Part Config dialog box of XEP or SmartScan.
Z Range Mode	Indicates the scan range mode of the Z scanner (Large or Small) during imaging. This parameter is set in the Part Config dialog box of XEP or SmartScan.
Z Scanner Range	Indicates the range of Z scanner (0 to 1 corresponding to 0 to 12um range of the Z scanner) during imaging. This parameter is set from the Part Config dialog box in XEP or SmartScan
Cantilever	Indicates the Type of Cantilever. It was selected in the XEP or SmartScan Part Selection dialog.
Source	Indicates the input signal source that was used to acquire an image. This Source was selected in the Input Configuration dialog of the XEP image acquisition software.
Low Pass Filter	Indicates the time interval used to generate the averaged data pixel so that high frequency noise can be eliminated. The higher value of the LPF means that a longer time interval is permitted to generate each pixel. This parameter was adjusted in the Input Configuration dialog in XEP or SmartScan.

Plain Fit	When turned On, Plain fit keeps the average level of each line of data constant so that the contrast scale does not saturate while an image is being generated. This parameter was selected in the Input Configuration dialog.
Flattening	Shows the type of flattening applied to the image during data acquisition process, if any flattening was selected from the Input Configuration dialog.
Data Width	Indicates the pixel size of an image in the x direction. This parameter was selected in the Scan Configuration dialog.
Data Height	Indicates the pixel size of an image in the y direction. This parameter was selected in the Scan Configuration dialog.
Sine Scan	When it is On, indicates that the sine scan was applied to an image while scanning. This parameter was selected in the Scan Configuration dialog.
Over Scan	Indicates the percentage that an over scan was applied to an image while scanning. This parameter was selected in the Scan Configuration dialog.
XY Servo Mode	
Fast Scan Axis	Indicates the scan direction that was selected to acquire each line of data in compiling the image. This parameter was selected in the X, Y check box in the Scan control window of XEP.
Fast Scan Dir	If the fast scan axis is X, indicates that the fast scan direction is from left to right or from right to left.

Slow Scan Dir	If the fast scan axis is X, indicates that the slow scan direction is from bottom to top or from top to bottom.
X Scan Size	Indicates the scan size of an image in the x direction. This value was set in the Scan control window of XEP or SmartScan.
Y Scan Size	Indicates the scan size of an image in the y direction. This value was set in the Scan control window of XEP or SmartScan.
X Scan Offset	Indicates the X offset coordinate relative to the scanner midpoint (0, 0) that was used to define the scan area. This value was set in the Scan control window of XEP or SmartScan.
Y Scan Offset	Indicates the X offset coordinate relative to the scanner midpoint (0, 0) that was used to define the scan area. This value was set in the Scan control window of XEP SmartScan.
Rotation	Indicates the degree of rotation that the fast scan direction was rotated relative to the X axis or the Y axis while an image was generated. This parameter was adjusted in the Scan control window of XEP or SmartScan.
Scan Rate	Indicates the frequency that the scanner is rastering back and forth across the sample surface. This parameter was adjusted in the Scan control window of XEP or SmartScan.
Z Servo Gain	
Set Point	Indicates the set point value adjusted in the Scan control window or Frequency Sweep dialog. Depending on the scan mode, the meaning of this value may differ for different scan modes.

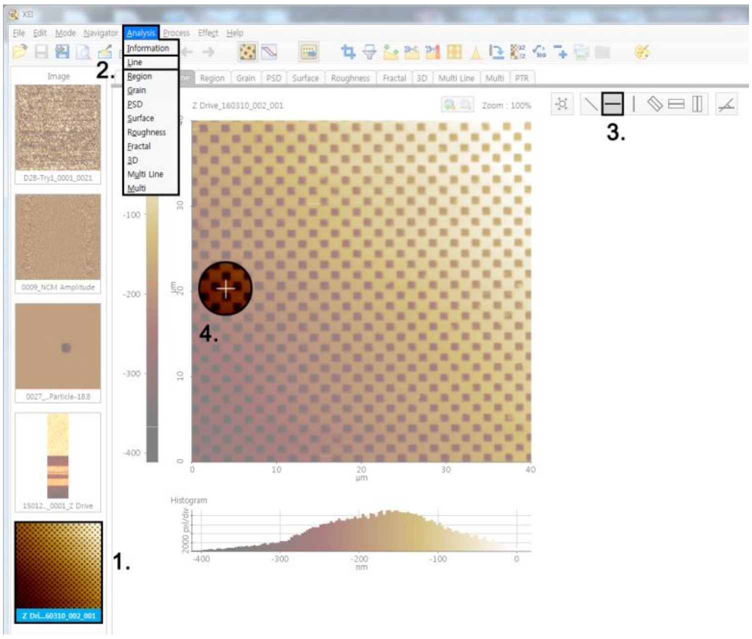
Head Rotation Angle	
Head Tilt Angle	
Tip Bias	Indicates the voltage that was applied to the tip with the sample being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in the Scan control window of XEP or SmartScan.
Sample Bias	Indicates the voltage that was applied to the sample with the tip being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in the Scan control window of XEP or SmartScan.
Data Gain	The real data is obtained by multiplying the raw data and data gain itself.
Z servo NC Gain	Indicates the value of Z servo gain set during the imaging process.
Z servo P Gain	
Z servo I Gain	

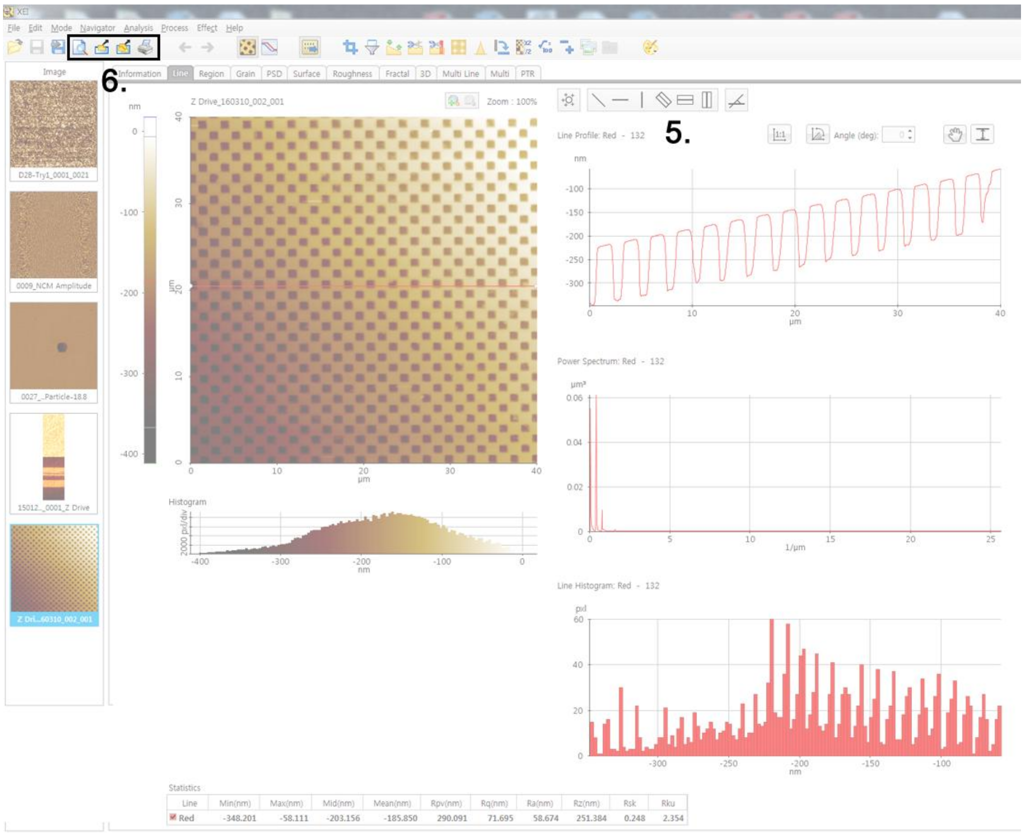
3-2. Line View

In the Line view , you can measure and analyze several characteristics of an image along selected line profiles. Select the line type (for example, vertical, horizontal, or slanted), and generate the line (up to 3 if 'Use Three Lines' is selected in 'File>Preferences') on the image across the profile you want to measure and analyze. You can make quantitative measurements of surface features and collect surface statistical data along the cross section. The Line view provides a Line Profile, a Power Spectrum, and a Histogram of the line profile. In general, you can analyze the selected lines in your image in the Line view through the following steps:

1. Select an image you want to analyze in the Navigator view.
2. Enable the Line view
3. Click the desired line type button on the line selection toolbar that is at the higher right side of the displayed image.
4. To draw a line, drag the mouse across the profile you wish to analyze.
5. The measurement results will appear in several panels and a statistics table.
6. Save and print your Line view results if desired.

Figure 3-2-1 shows the summarized procedure to analyze the selected line in an image.




XEI
File Edit Mode Navigator Analysis Process Effect Help
6.
5.
Image
Information Line Region Grain PSD Surface Roughness Fractal 3D Multi Line Multi PTR
D28-Try1_0001_0021
0009_NCM Amplitude
0027_Particle-18.8
15012_0001_Z Drive
Z Dri...60310_002_001
Z Drive_160310_002_001
Zoom : 100%
Line Profile: Red - 132
Angle (deg):
Power Spectrum: Red - 132
Line Histogram: Red - 132
Histogram

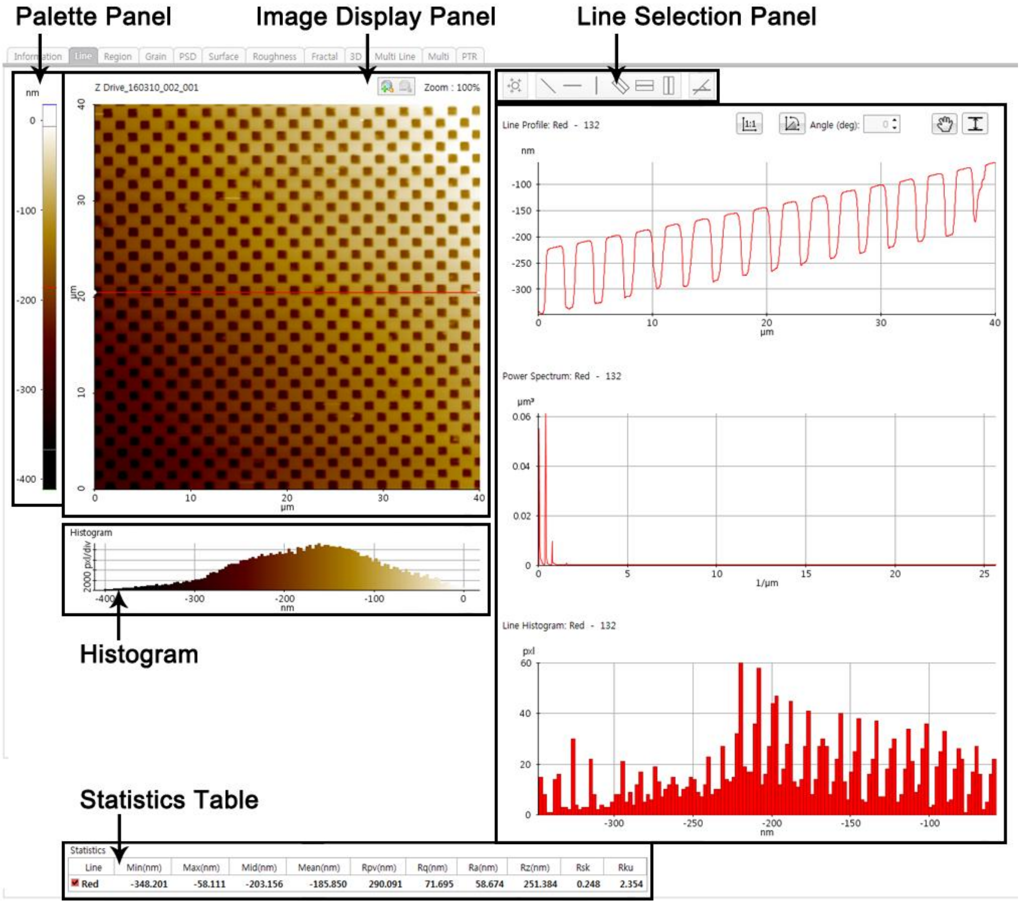
Statistics

Line	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
☑ Red	-348.201	-58.111	-203.156	-185.850	290.091	71.695	58.674	251.384	0.248	2.354

Figure 3-2-1. Procedure for Line view

3-2-1. Line View Layout

To enable the Line view, select ‘Analysis>Line’ from the menu bar or click the Line analysis tab below the Toolbar. The layout of the Line view is divided into three main regions; Image display panel, Analysis plots panel, and Statistics table. Figure 3-2-2 shows the Line view of the horizontal line in the image.



Statistics

Line	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
☑ Red	-348.201	-58.111	-203.156	-185.850	290.091	71.695	58.674	251.384	0.248	2.354

Figure 3-2-2. Line view

3-2-1-1 Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel. It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI.. Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views. Please refer to Section 3-3 for details.

3-2-1-2 Line Selection toolbar

Line selection toolbar, where the Tools for selecting line for the analysis are gathered, is at the right side of the image Display Panel.

3-2-1-3 Line Profile, Power Spectrum and Line Histogram Panel

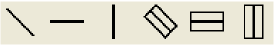
Line Profile, Power Spectrum, and Line Histogram is generated immediately on the separate panel after you create a line across the image for line analysis. These plots are automatically updated whenever you select the line and move the selected line in the image. Detailed features of these three panels are explained in section 4-3, 4 & 6 respectively.

3-2-1-4 Line Statistics Table

In the Line Statistics Table, the statistics table of the quantitative measurements up to three selected lines (classified by different colors: red, green, and blue) is displayed. The related values of the selected lines are changed in accordance with the change in position of the cross section. Detailed features of the Line Statistics Table are explained in section 4-5.

3-2-2. Selecting Lines for Line Analysis

To get reasonable information of line profile of the sample, it is important to select specific lines for analysis. Line selection toolbar contains various tools that help you to select precise lines for line data analysis. The process of selecting line for analysis is done in three steps.

Step 1. Select Type of the Line 

You can create up to three lines for line profile analysis on the image (see Figure 3-2-3): vertical, horizontal and/or arbitrarily sloped lines are possible. Each line you create is indicated by a different color (red, green, and blue in order) in the Image display panel as well as in the analysis plots. The Selected line will display end points of an arrow to easily identify the selected line.

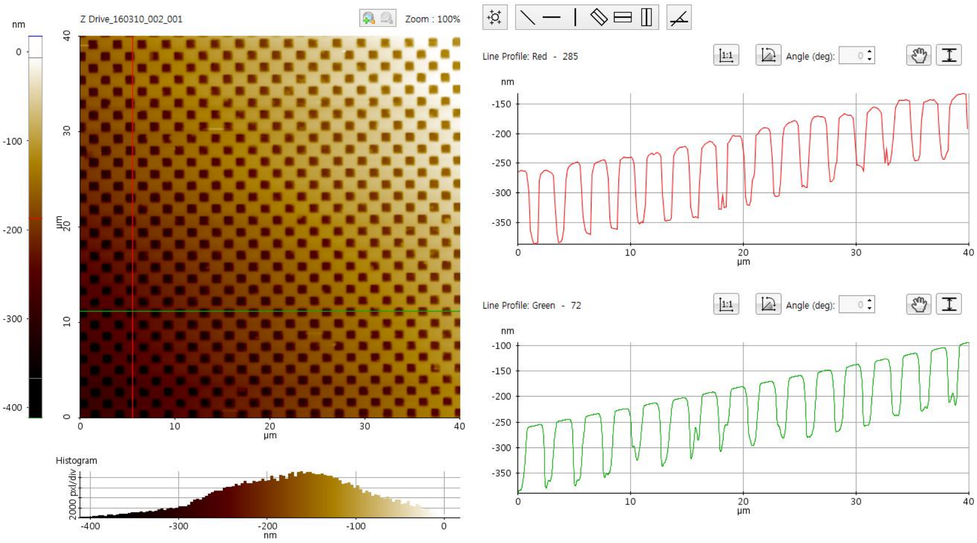


Figure 3-2-3. Line selection toolbar

Step 2. Create the Line ╲ — | ⧄ ⊟ ◫

- **X or Y axis line** — |

Click the X or Y axis line button on the line selection toolbar to generate a horizontal or vertical line to be analyzed as a cross section of the sample surface. Then, click the cursor at any location on the image where you would like to analyze the height profile. The colored horizontal or vertical line will appear in the image. You can easily move the line for analysis anywhere in the image by dragging and dropping the line again and again. Figure 3-2-4 shows an example of moving a X axis line for analyzing different image cross sections.

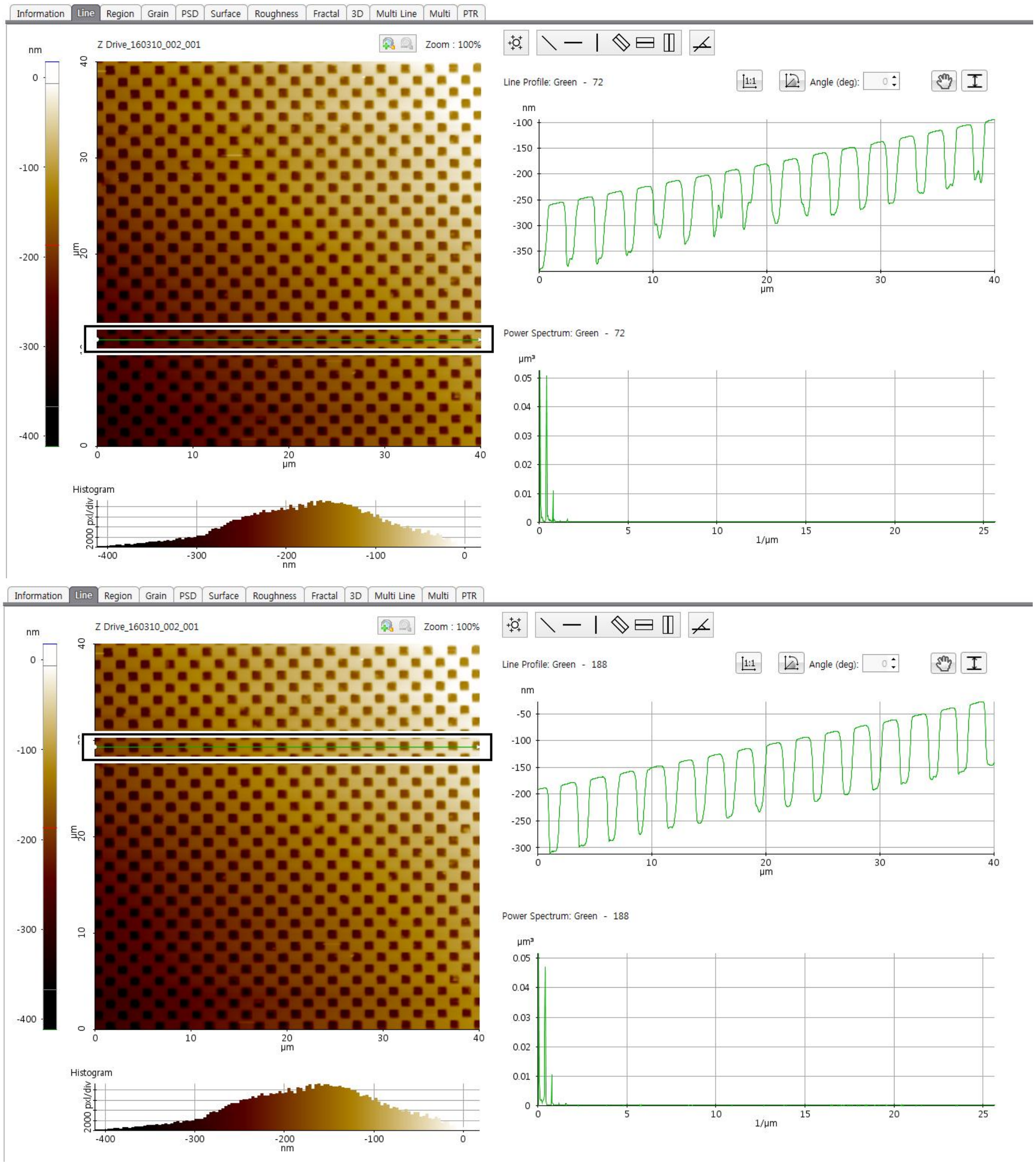
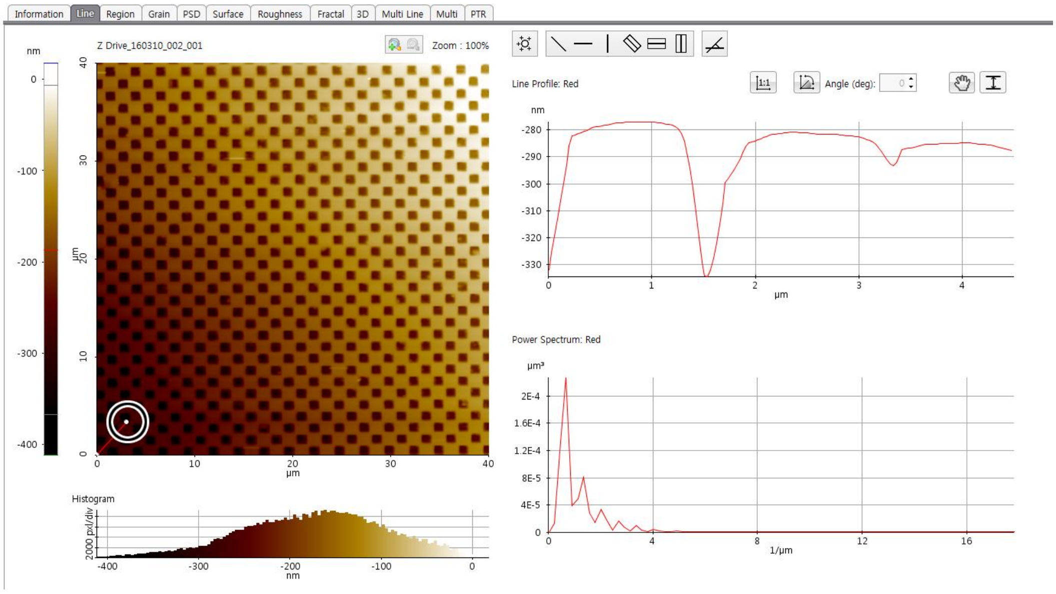


Figure 3-2-4. Move a line for Line view

■ Slanted line ╲

As shown in Figure 3-2-5, after clicking the slanted line button, press the cursor onto any location where you would like to start the arbitrary slanted line. Drag and drop the cursor onto the end point of this line. To change the location of the line, follow the same procedure as for a vertical or horizontal line. Furthermore, you can resize the line by clicking the line to display trackers at the two end points of the line. Then, drag and drop these trackers.



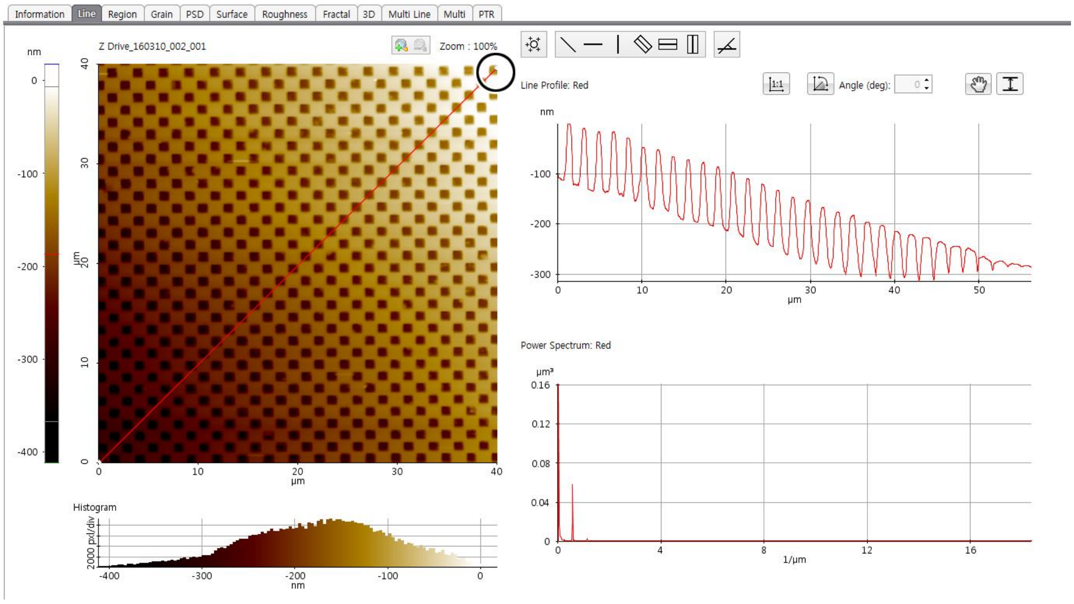


Figure 3-2-5. Create a slanted line

■ Average line

For each X, Y and Slanted lines, there are also Average lines. The process for creating an Average line is the same as creating a single line. When an Average line is created, it is colored from center line towards each side. The selected average area will display in the Line Profile panel as a single Line Profile. Average Lines can be resized by clicking the circular tracker and dragging to desired area. Figure 3-2-6 shows Average X axis Line.

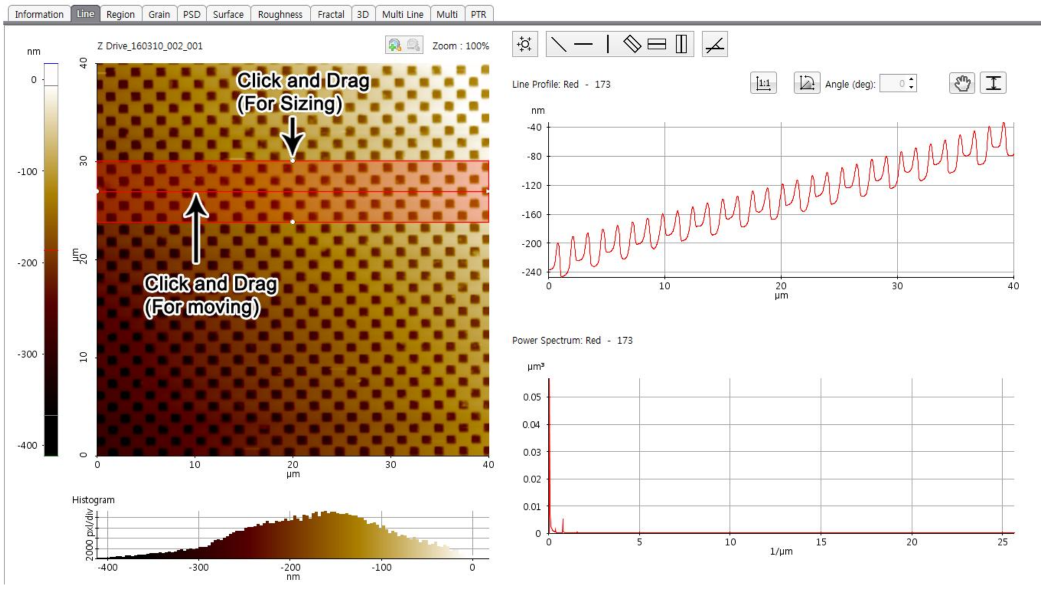
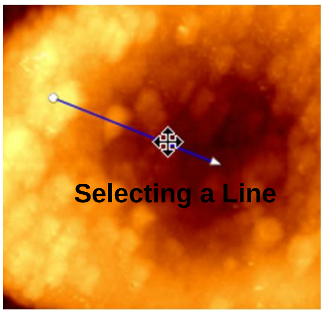


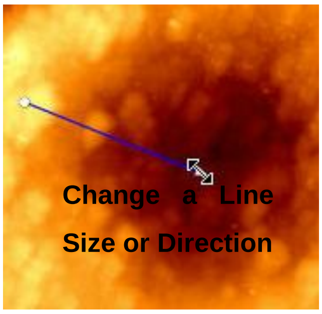
Figure 3-2-6. Control an Average Line Region

Step 3. Edit the created Line

You can move, delete, and resize the line created in step 2 with the help of the 'Move tool'. The Move tool will only appear on the toolbar if you have checked the 'Line' check box in the 'Use Move Tool' option of the 'Preferences Window'.

//When the 'Use Move Tool' option for the 'Line' is checked, the mouse pointer stays in 'line selection' (cross hair mouse pointer) mode so that user can continuously create lines for analysis without reselecting the line button on the toolbar for each line. The mouse pointer will stay in 'line selection' mode unless you deselect the 'Move Tool' button ↖ to exit 'line selection' (cross hair mouse pointer) mode and switch to 'line editing' (arrow mouse pointer) mode.





On the other hand, when the ‘Use Move Tool’ option for the ‘Line’ is not checked, the mouse pointer will automatically switch from ‘line selection’ (cross hair) to ‘line editing’ (arrow) mode each time you create a line.

■ Selecting

First, select the line corresponding to the line shape you would like to edit. Next, click ‘Move tool’ to enable line editing. Click on the line you would like to move to select it. You can also select multiple lines by pressing ‘Ctrl’ key as you click the lines. To select all the lines, press Ctrl+A, or select ‘Select All’ in the context menu.

■ Moving

To move an object, move the mouse cursor over the object until it becomes a four-arrow cursor and the circular tracker appears (circle and arrow at endpoints) on the line. You can move the selected line by dragging it.

■ Deleting

To delete the selected line, right click to bring up the context menu and select the delete command or press delete button on the keyboard.

■ Changing Shape

For slanted lines, you can resize the line by clicking the line to display circular trackers (circle and arrow) at the two end points of the line. Then, drag and drop these trackers.

■ Measuring Angle between Lines ∡

As shown in Figure 3-2-7, when clicking the ‘Show Angle’ ∡ icon, the angle value between two lines will be displayed on Image Display panel. ‘Show Angle’ icon can be selected under the line selection toolbar.

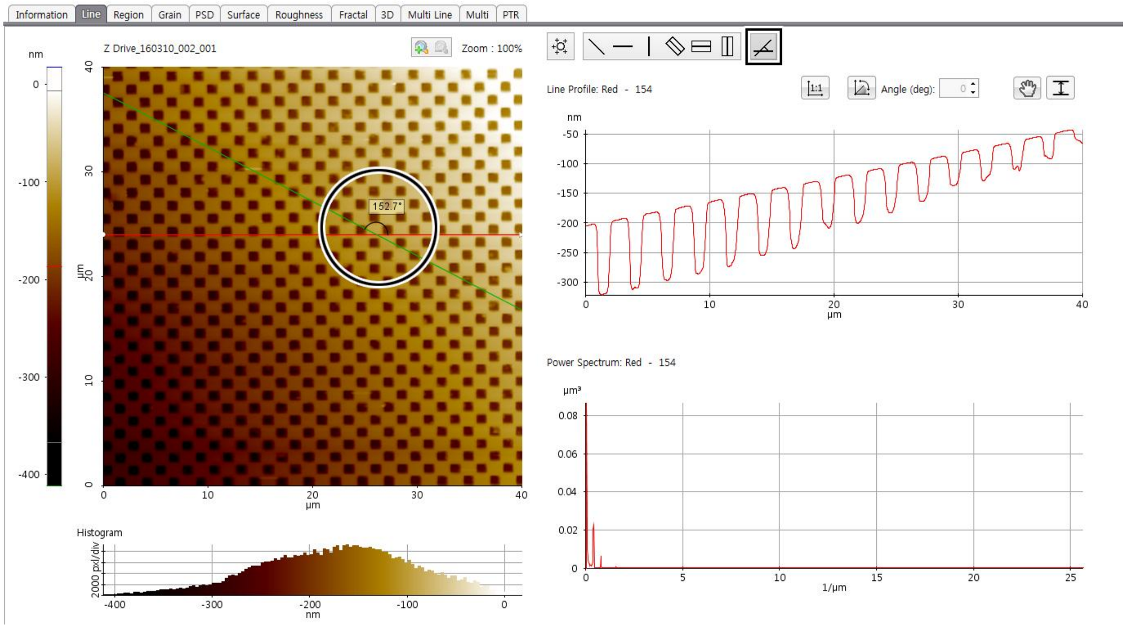


Figure 3-2-7. Show angle between two lines

■ Change Image Color(Use Enhanced Color)

For effective line analysis, enhanced color can be used in the Image Display panel. Clicking the 'Use Enhanced Color' ☼ icon, will activate the feature. Please refer Section 3-2-8 for more detail.

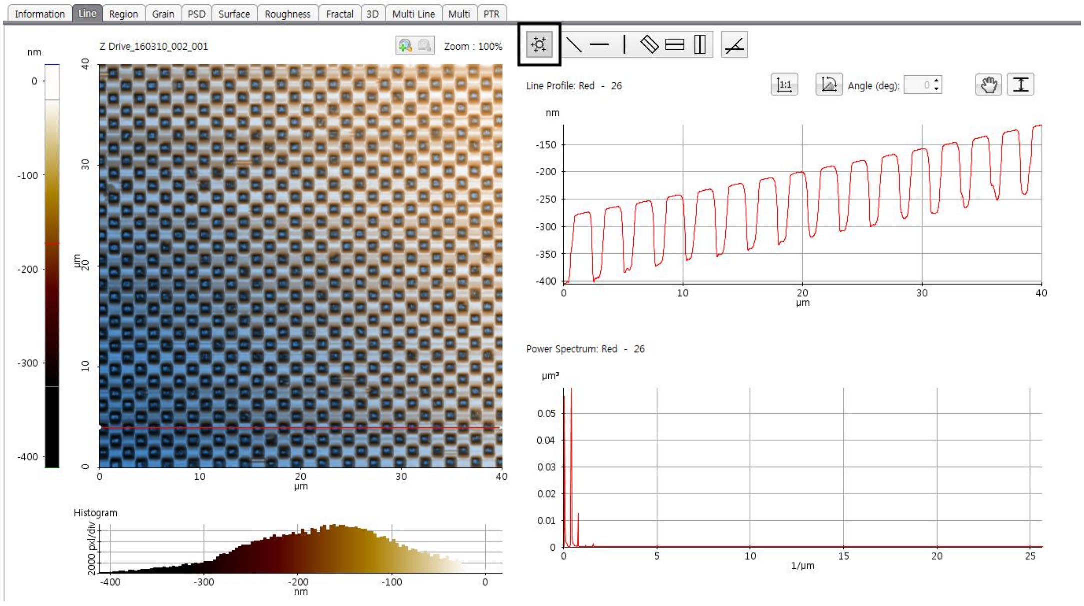


Figure 3-2-8. Use Enhanced Color

3-2-3. Line Profile Panel

The Line Profile panel displays the cross-sectional height profile of the image along the line created by user. The unit of x axis is usually μm or nm and that of y axis is variable depending on the collected signal to generate its image for example, μm, nm, mV, V and so on.

- **1:1 Visual Ratio**

Displays ratio between the X and Y's line profile as 1:1 ratio. This feature can be useful for enlarging the Y axis' line profile.

- **Move**

Selecting this icon ✋ will allow to the user to scroll the viewable area by clicking and dragging the image.

- **Zoom Out**

When selected, the line profile is automatically scaled in the Line Profile panel by clicking ⌶ icon.

A context menu (see the outlined box in Figure 3-2-9) is generated when you right-click the cursor in the Line Profile panel. The items of the context menus are described below.

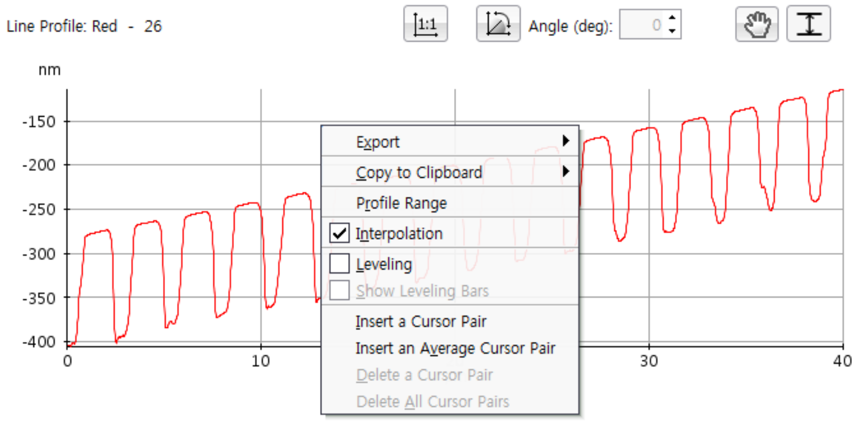


Figure 3-2-9. Context menu in the line profile

3-2-3-1 Export

Through the ‘Export’ command in the context menu of Line view, you can export the data of the Line Profile as a text file and save it individually. This text file can be used for analysis in other software program.

3-2-3-2 Insert (Delete) a Cursor Pair

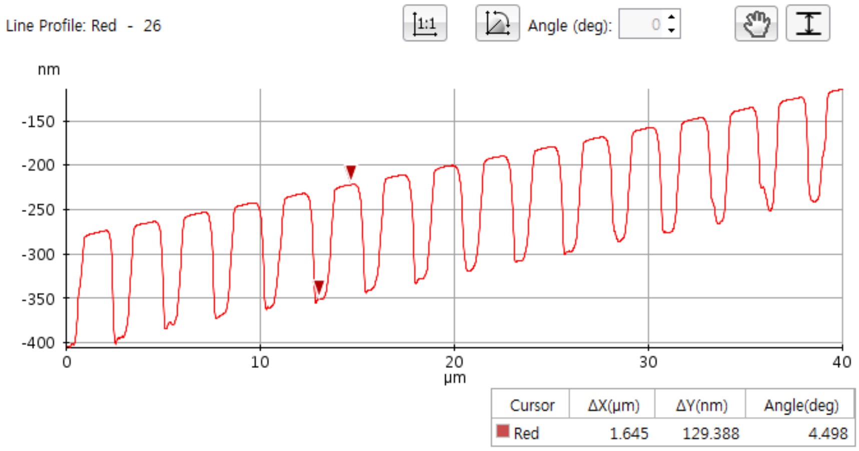
To measure an exact height difference and distance between two data points in the Line profile, you can insert a cursor pair on the Line Profile by selecting ‘Insert a Cursor Pair’ command in the context menu. You can insert up to three cursor pairs per profile.

When the cursor pair is inserted, two triangular shaped cursors appear on two arbitrary points on the Line profile and the corresponding points on the image in the image display panel as well. Along with the cursor pair, ‘∆X’, ‘∆Y’, ‘Angle’ information is displayed in the Cursor Statistics table as default (Figure 3-2-10 and Figure 3-2-11).

Also, you can select the cursor pair parameters to be displayed on the table from the ‘Show Items’ command in the context menu of the Cursor Statistics table as well. The cursor information parameters that can be displayed in the Cursor Statics table are described below.

∆X	The horizontal distance between the two points marked by the cursors
∆Y	The vertical distance between the two points marked by the cursors
Angle	The angle between the points. This is determined by dividing the vertical difference by the horizontal difference.
Left X	The horizontal coordinate for the left cursor.
Left Y	The vertical coordinate for the left cursor.
Right X	The horizontal coordinate for the right cursor.
Right Y	The vertical coordinate for the right cursor.

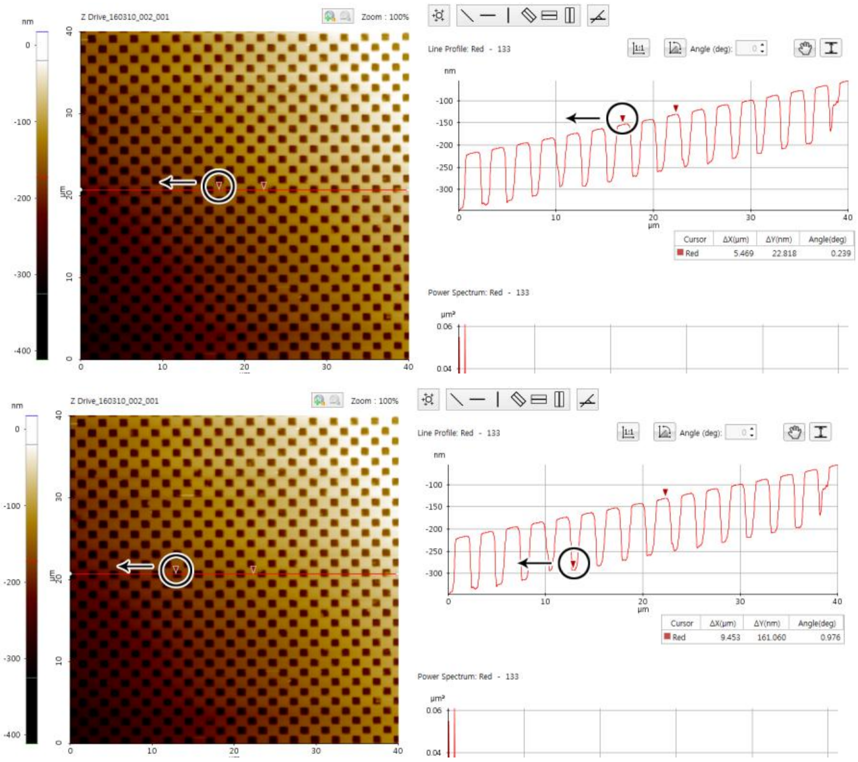
The context menu in the Cursor Statistics table is generated by right clicking on the table. These menu functions are similar to those in region statics table except for the items under the ‘Show Items’ command. Refer to Section 4-3.



Cursor	ΔX(µm)	ΔY(nm)	Angle(deg)
🟥 Red	1.645	129.388	4.498

Figure 3-2-10. Cursor pair and displayed information

You can adjust the location of the cursors by dragging and dropping individual triangular cursors either from the line profile or from the image in the image display panel. You can also move the cursors with pixel precision by clicking on a cursor, then pressing the → and ← keys on your keyboard. The displayed cursor information is automatically updated whenever you change the position of the cursor pair. Figure 3-2-11 shows an example of using the cursor pair.



Cursor	ΔX(µm)	ΔY(nm)	Angle(deg)
🟥 Red	5.469	22.818	0.239

Cursor	ΔX(µm)	ΔY(nm)	Angle(deg)
🟥 Red	9.453	161.060	0.976

Figure 3-2-11. Moving cursors by mouse

To delete the cursor pair from the line profile, click the cursor pair which you want to delete and select ‘Delete a cursor pair’ command from the context menu or use the ‘Delete’ button on your keyboard. This command deletes the selected cursor pair from the Line Profile. To delete all of the cursor pairs from the Line Profile, select ‘Delete all cursor pairs’ command from the context menu.

3-2-3-3 Interpolation

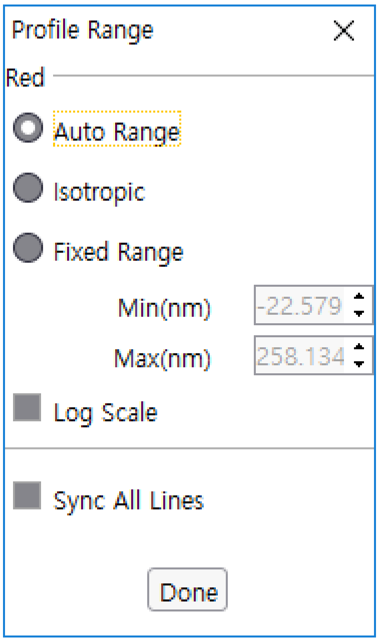
This function allows smooth shifting between pixels by adding another point in between two points. If this function is disabled, it will only move as pixels.

3-2-3-4 Leveling

After you select ‘Leveling’, you will see two white bars in the line profile. You can use these bars to easily subtract the background slope. Point your mouse at each bar and the cursor will change to a left-right arrow. Drag each bar to two different points you believe to be at the same height. The slope of the line profile will change accordingly so that the two different points are brought to the same level. After leveling, the white bars can be disappeared by deselecting ‘Show leveling bars’.

3-2-3-5 Profile Range

Selecting ‘Profile Range’ will appear Profile Range dialog. Line profile range can be adjusted in this dialog.


Profile Range

Red

● Auto Range

○ Isotropic

○ Fixed Range

Min(nm) -22.579

Max(nm) 258.134

☐ Log Scale

☐ Sync All Lines

Figure 3-2-12. Profile Range

- **Color**

  Displays a selected line profile color
- **Auto Range**

  When selected, automatically adjusts the range of the display so that the whole line profile is visible on the graph.
- **Isotropic**

  Fits the Y scale to the maximum scale of X. Consequently, you will see a height that is similar to the real line profile.
- **Fixed Range**

  The vertical scale indicates the height range of the line profile. By default, maximum (minimum) value of the data range corresponds to the maximum (minimum) data of a line profile. This data range can be edited by changing the ‘Max (Min)’ text field in ‘Fixed Range’ of ‘Profile Range’ dialog.

Sync All Lines

When selected, the vertical data range scale of all the lines will be matched.

3-2-3-6 Copy to Clipboard

Through the ‘Copy to Clipboard’ command in the context menu of Line view, you can copy the line profile data to clipboard as text or image file and paste [Ctrl+V] button on the corresponding document file.

3-2-4. Power Spectrum Panel

When you select a line in an image, its power spectrum is displayed in the Power Spectrum panel. Figure 4-4-1 shows the power spectrum of the selected line in the Line view. A power spectrum shows the contribution of each spatial frequency to the line profile versus frequency. It is generally used to examine spatial periodicities in an image and to measure noise characteristics. When you select a line in an image, a power spectrum is automatically displayed.

The Power Spectrum, shown below, is related to the 1-dimensional Fourier transformation of the selected line in the Line Profile. In a Power Spectrum, peaks represent the intensities of frequency components in the selected line. The x axis is the frequency of the selected line and its unit is 1/µm. The y axis is the intensity of the frequency component and its unit can be Å×µm, µm×µm, V×µm and so on. The front unit is varied by on the unit of the selected input signal and z scale within the selected line and the next unit is varied by the length of the line.

A context menu is generated when you right-click the cursor in the Line Power Spectrum panel. Currently, ‘Export’, ‘Copy to Clipboard’ and ‘Show Pair Cursor Pair’ menu are available commands. For more information, refer to Section 4-3.

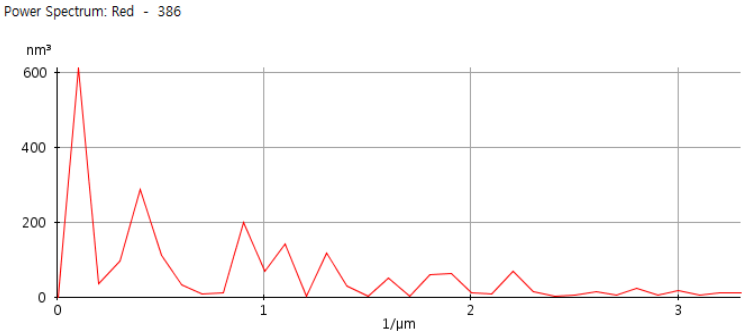
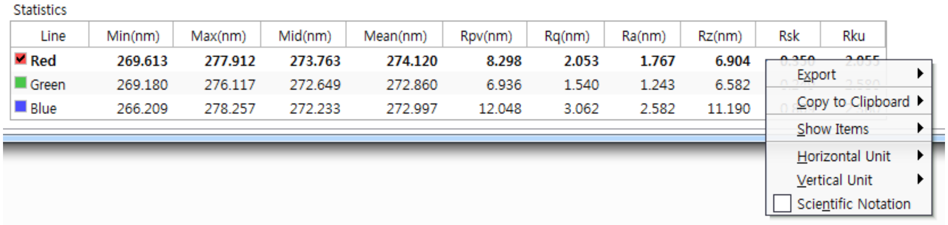


Figure 3-2-13 Power spectrum panel

3-2-5. Line Statistics Table

The Line Statistics table, shown in Figure 3-2-14, shows several statistics of the line profile. Each line is related to one row of the table. The results of the statistics on the selected line are updated automatically when you move the selected line to different locations in an image. The context menu (see the outlined box in Figure 4-5-1) is generated when you right-click the cursor in the Line Profile panel. Through the context menu, the statistics table can be rearranged as desired. These menu items are described as Figure 3-2-14.



Statistics

Line	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
☑ **Red**	**269.613**	**277.912**	**273.763**	**274.120**	**8.298**	**2.053**	**1.767**	**6.904**	[illegible]	[illegible]
🟩 Green	269.180	276.117	272.649	272.860	6.936	1.540	1.243	6.582	[illegible]	[illegible]
🟦 Blue	266.209	278.257	272.233	272.997	12.048	3.062	2.582	11.190	[illegible]	[illegible]

Figure 3-2-14. Line statistics table

■ Export

Export the statistics data as image or text file.

■ Copy to Clipboard

Copy the statistics data as image or text file to clipboard and you can paste the corresponding document file.

- **Show Items**

Select the line profile parameters to be displayed on the statistics table.

- **Horizontal Unit**

In the Statistics table, sets the scale units of the horizontal axis. As default, each parameter scale uses the ‘Auto Unit’ feature. The horizontal (X) axis for all parameters can be manually set to the same single unit (fm, pm, nm, µm, mm, and m).

- **Vertical Unit**

In the Statistics table, sets the scale units of the vertical axis. As default, each parameter scale uses the ‘Auto Unit’ feature. The vertical (Y) axis for all parameters can be manually set to the same single unit (fm, pm, nm, µm, mm, and m).

- **Scientific Notation**

Line profile parameter values in the Statistics table will be displayed in Scientific Notation (Exponential Notation). The values are displayed to three decimal places. Due to limited space in the Statistics table, this feature is useful when displaying multiple parameters.

The meanings of the surface profile parameters displayed in the Line Statistics Table are defined as follows.

Table 4-5-1. Line Profile Parameters

Parameter Name	Meanings
Min	Min is the minimum, or smallest, value in the line profile.
Max	Max is the maximum, or largest, value in the line profile.
Mid	Mid is the arithmetic average between the minimum and maximum values. That is, Mid = (Max + Min) / 2.
Mean	Mean is the arithmetic mean value of the line profile. It is the sum of the height of each point divided by the number of points.
Rpv	Rpv is the peak-to-valley of the line. It is the difference between minimum and maximum, that is, (Max – Min).
Rq	Rq is the root-mean-squared roughness.
Ra	Ra is the roughness average. The average roughness is the area between the roughness profile and its mean line.
Rz	Rz is the ten point average roughness. It is the arithmetic average of the five highest peaks and five lowest valleys in the line.
Rsk	Rsk is the skewness of the line.
Rku	Rku is the kurtosis of the line. It indicates the “spikiness” of the sample surface along that line.

3-2-6. Line Histogram Panel

The Line Histogram panel provides information about the distribution of heights of the pixels within the selected line. Corresponding to the three selectable line groups, up to three Line Histograms (R, G, B) can be generated. Figure 3-2-15 shows the Line Histogram panel. The x axis represents the height of data points in the line. The y axis represents the number of pixels in the selected line. Several features that helps user to perform further analysis of the Line Histogram can be accessed through the context menu. You can see the context menu in the Line Histogram panel right the mouse with the pointer on the table.

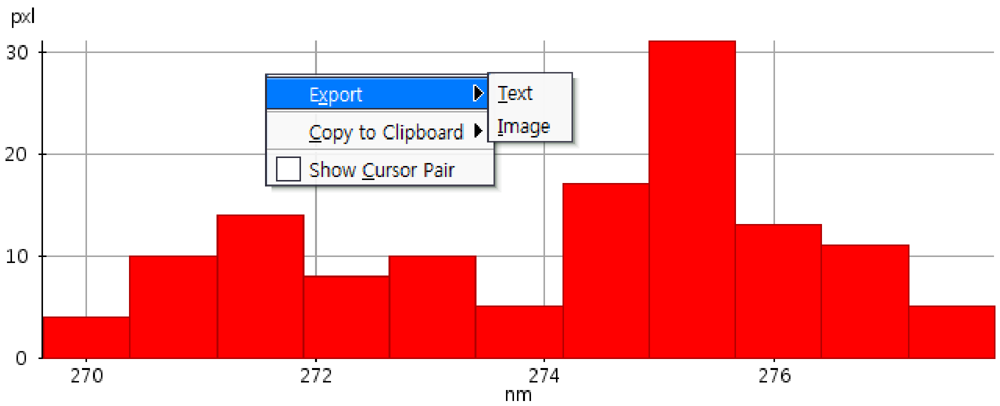


Figure 3-2-15. Line Histogram Panel

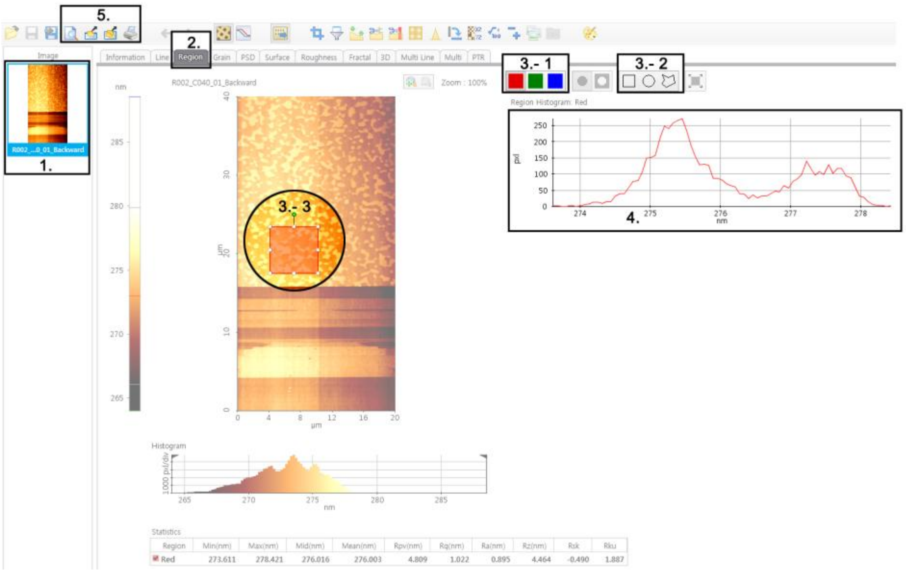
3-3. Region View

In the Region view, you can measure and analyze surface regions of an image. You can make quantitative measurements of surface features in the selected regions and collect surface statistics such as surface roughness, average height. These statistical values are displayed in the table and plotted in the Region Histogram panels. Up to three particular regions can be selected to include regions for analysis. Furthermore, you can select regions to exclude certain features from analysis.

In general, you can go through the following steps in Region view:

1. Load an image you want to analyze into the Analysis view from the Navigator view.
2. Enable the Region view.
3. Select regions of the image to include or exclude for Region view.
4. Once selecting region group, both the region histogram plot and statistics table are generated with results and updated whenever the change of the selected region group occurs.
5. Save and print your Region view results

Figure 3-3 shows the summarized procedure to analyze the region of an image.



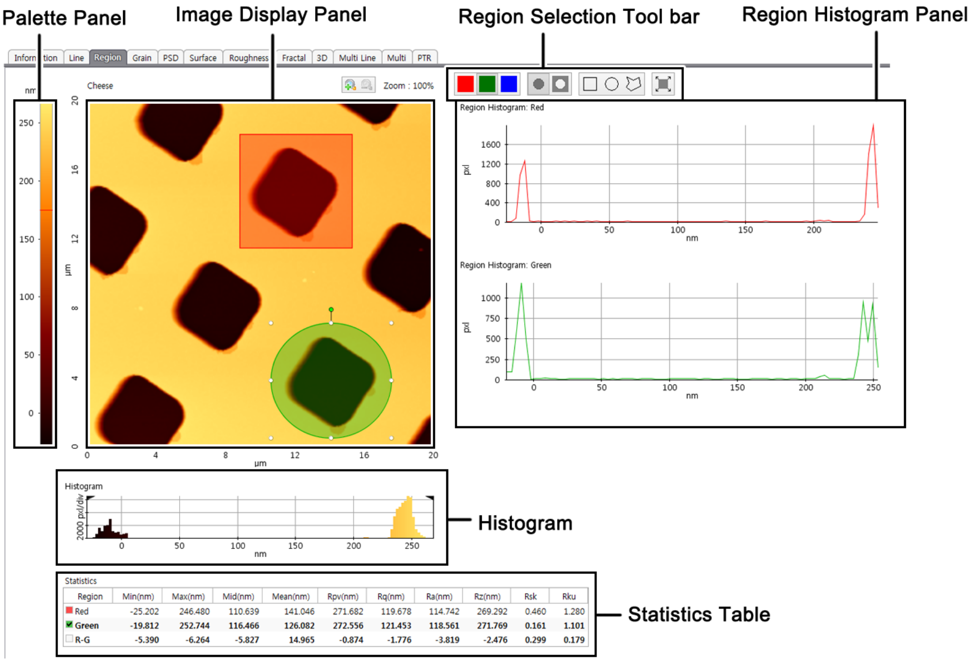
Statistics

Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
☑ Red	273.611	278.421	276.016	276.003	4.809	1.022	0.895	4.464	-0.490	1.887

Figure 3-3. Procedure for Region View

3-3-1. Region View Layout

To enable the Region view, select ‘Analysis>Region’ menu or click the Region analysis tab below the Toolbar. The Region view consists of the Palette Panel, Image Display Panel, Region Selection Toolbar, Region Histogram Panel, Histogram and the Statistics table. Figure 3-3-1 shows the Region view that is divided into several parts.



Statistics

Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
🟥 Red	-25.202	246.480	110.639	141.046	271.682	119.678	114.742	269.292	0.460	1.280
☑ Green	-19.812	252.744	116.466	126.082	272.556	121.453	118.561	271.769	0.161	1.101
☐ R-G	-5.390	-6.264	-5.827	14.965	-0.874	-1.776	-3.819	-2.476	0.299	0.179

Figure 3-3-1. Region view

3-3-1-1 Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel. It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI. Please refer to Chapter 3-2 and 3-3 for details.

Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views. However, Histogram in the Region View has special ‘Height Restriction Markers’ to select pixels within certain height range. Detailed features of the Region Selection Toolbar are explained in section 5-2.

3-3-1-2 Region Selection toolbar

Region selection toolbar, where the Tools for selecting region for the analysis are gathered, is at the right side of the image Display Panel.

3-3-1-3 Region Histogram Panel

Three Region Histograms, corresponding to three different user-selected Region groups (Red, Green and Blue), are generated automatically at the right side of the Image display panel. Detailed features of the Region Histogram Panel are explained in section 5-4.

3-3-1-4 Region Statistics Table

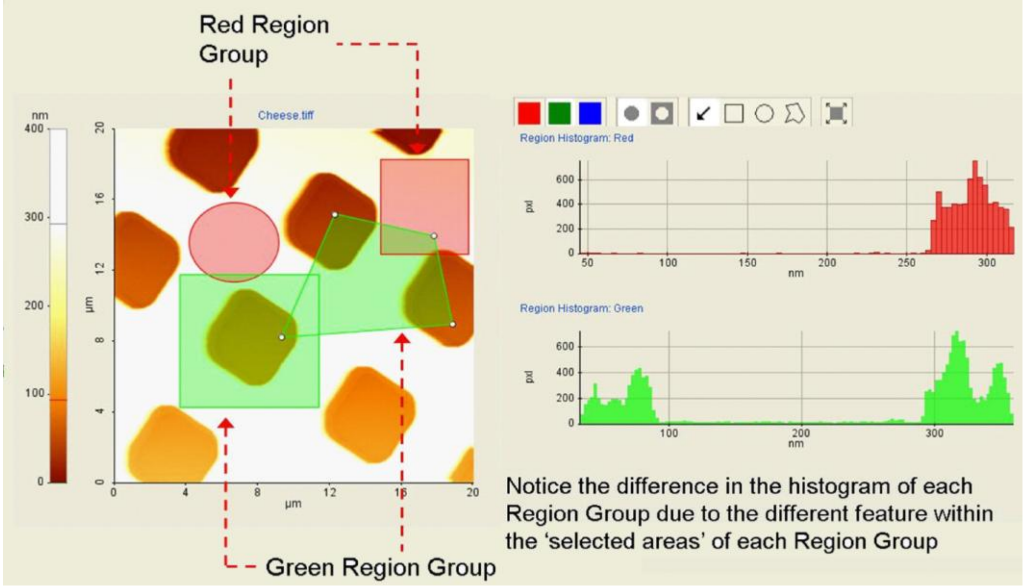
In the Region View, below the Image display panel, the Region Statistics table will be generated. Detailed features of the Region Statistics Table are explained in section 5-5.

3-3-2 Selecting Region for Region Analysis

To get reasonable information of surface statistics, it is important to select specific regions including or excluding the data for analysis. Region selection toolbar contains various tools that help you to select precise region for region data analysis. The process of selecting region for analysis is done in four steps.

Step 1. Select Region Group

Region Group is the grou🟥🟩🟦he ‘selected area’ for the region statistical analysis. Each region group is made of single or multiple ‘selected area’. XEI allows user to create and edit up to three Region Groups, Red, Green and Blue for region analysis. The ‘selected area’ that belong to different Region Groups are discriminated by their color. Before you create or edit ‘selected area’ on the image for the region analysis, you should decide to which region group the ‘selected area’ will belong by clicking one of the Region Group Select button.

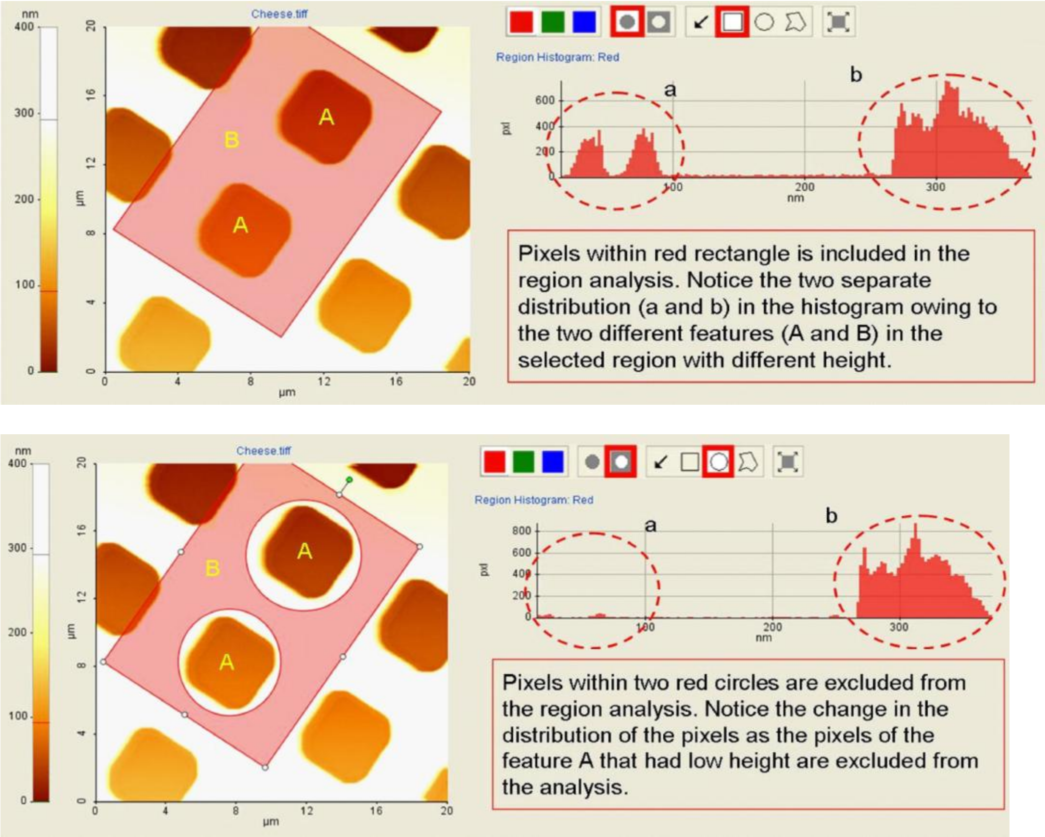


Notice the difference in the histogram of each Region Group due to the different feature within the ‘selected areas’ of each Region Group

Figure 3-3-2. Region Group

Step 2. Select Inclusion or Exclusion ● ◘

You should decide whether the pixels within the ‘selected area’ you create to be included or excluded by clicking either Inclusion or Exclusion before you create a ‘selected area’. Figure 3-3-3 shows effect of selecting Inclusion and Exclusion on region analysis result. Be aware that the selecting area as ‘Exclusion’ is effective only if the area selected as ‘Exclusion’ is part of the area that has been selected as ‘Inclusion’.



Pixels within red rectangle is included in the region analysis. Notice the two separate distribution (a and b) in the histogram owing to the two different features (A and B) in the selected region with different height.

Pixels within two red circles are excluded from the region analysis. Notice the change in the distribution of the pixels as the pixels of the feature A that had low height are excluded from the analysis.

Figure 3-3-3. Region view

Step 3. Create ‘selected area’ ☐ ○

You can create ‘selected area’ of different shapes by using Rectangle, Ellipse and Polygon button. Also you can designate entire image as a ‘selected area’. ‘Selected area’ for Inclusion will be painted in red, green, and blue while the ‘Selected area’ for Exclusion will be only outlined in red, green and blue depending on the color of the region group to which selected area’ belongs to.

- **Rectangle & Ellipse** ☐ ○

To create rectangle or ellipse shaped ‘selected area’, click the ‘Rectangle’ or ‘Ellipse’ button, respectively. Then, press the cursor at the point you want to create the top-left corner of a ‘selected area’, and drag the mouse pointer at the point you want to create bottom-right corner of a ‘selected area’.

■ Polygon

To create polygon shaped ‘selected area’, click the polygon button and click the cursor onto the point you want to create a starting point of a polygon. Move and click the cursor at each point of the polygon region. Double-click at the point you would like to make the end point.

■ Entire Region

To set the entire image as ‘selected area’, click the ‘Entire Region’ button. It is set as default when you select ‘Region View’.

Step 4. Edit the ‘selected area’

You can move, delete and resize the ‘selected area’ created in step 3 with the help of the ‘Move tool’. Move tool only appears on the toolbar only if you have checked ‘region’ check box from the ‘Use Move Tool’ option in the ‘Preferences Window’.

When the ‘Use Move Tool’ option for the ‘region’ is checked, mouse pointer stays in ‘region selection’ (cross hair mouse pointer) mode so that user can continuously create ‘selected area’ for region analysis one after another. Mouse pointer will stay in ‘region selection’ mode unless you click ’Move Tool’ button ↖ to exit ‘region selection’ (cross hair mouse pointer) mode and switch to ‘region edition’ (arrow mouse pointer) mode. On the other hand, when the ‘Use Move Tool’ option for the ‘Region’ is not checked, the mouse pointer will automatically switch from ‘region selection’ (cross hair) to ‘region edition’ (arrow) mode each time you create a line.

■ Selecting

First, select the region group (R, G, B) corresponding to the region shape you would like to edit. Next, click ‘Move tool’ to enable the region shape edit. Click on the region shape you would like to move to select it. You can also select multiple region shape by pressing ‘Ctrl’ key as you click multiple region shape. To select all the region shape of the region group, press Ctrl+A or select ‘Select All’ in the context menu.

■ Moving

The mouse cursor changes to four arrow cursor and selected region shape is marked by circular tracker around it. You can move the selected region by dragging it.

- **Deleting**

To delete the selected region shape, select delete command from the context menu or press delete button.

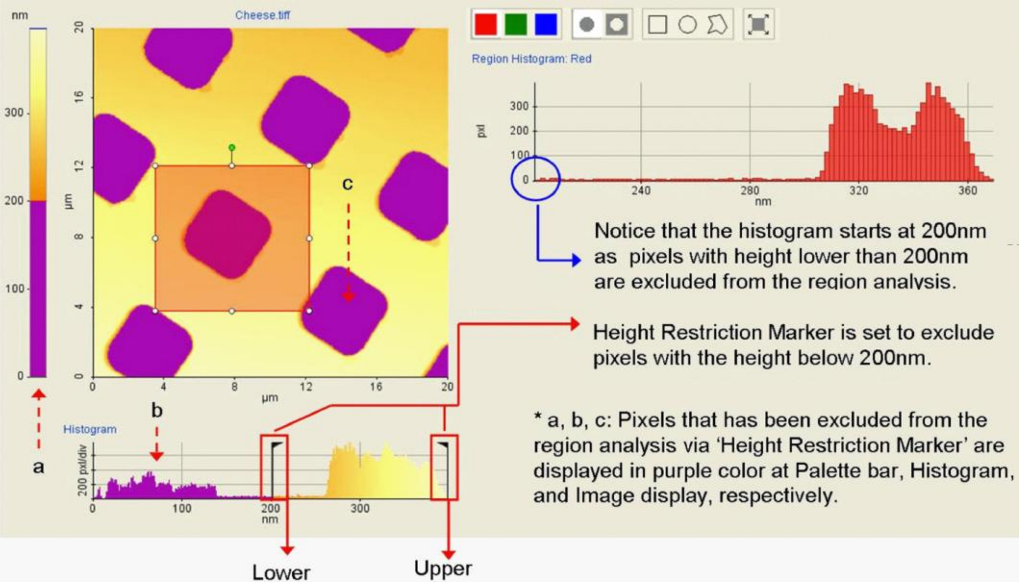
- **Changing Shape**

In case of rectangle and ellipse, you can also extend or shrink the selected region by dragging a small circular tracker that appears when you click the region. You can also rotate a rectangle and ellipse by dragging a green circular tracker. In case of polygon, you can change the shape of the already made polygonal region by dragging each circular tracker of it. However, the number of points cannot be changed.

3-3-3. Height Restriction Markers

Below the Image display panel, histogram of the loaded image is displayed. Height restriction markers are two flags that appear when the Region Histogram is displayed. Height Restriction Markers are used to exclude the pixels within certain height range from the region analysis.

There are two Height Restriction Markers, Lower and Upper. Drag these two ‘Height restriction Markers’ on the each side of the histogram to set the lower and upper value of the pixels to be selected. Pixels with the height lower than the ‘Lower Height restriction Marker’ or higher than the ‘Upper Height restriction Marker’ will be excluded from the region analysis. Pixels that are excluded from the analysis are marked in violet color at Palette bar.



Notice that the histogram starts at 200nm as pixels with height lower than 200nm are excluded from the region analysis.

Height Restriction Marker is set to exclude pixels with the height below 200nm.

* a, b, c: Pixels that has been excluded from the region analysis via ‘Height Restriction Marker’ are displayed in purple color at Palette bar, Histogram, and Image display, respectively.

Figure 3-3-4. Region view

3-3-4. Region Histogram Panel

The Region Histogram panel provides information about the distribution of heights of the pixels within the selected region. Corresponding to the three selectable region groups, up to three Region Histograms (R, G, B) can be generated.

Figure 3-3-5 shows the Region Histogram panel. The x axis represents the height of data points in the sample. The y axis represents the number of pixels (or bearing ratio) in the selected region group. Several features that helps user to perform further analysis of the Region Histogram can be accessed through the context menu.

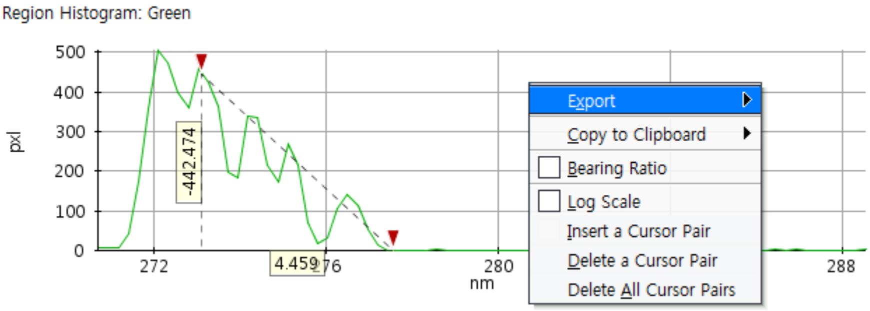


Figure 3-3-5. Region histogram panel

3-3-4-1 Export

Through the ‘Export’ command in the context menu of Line view, you can export the data of the Region Histogram as a text file or an image file and save it individually. This file can be used for analysis in other software program.

3-3-4-2 Bearing Ratio

Bearing ratio at arbitrary representative value in histogram is defined as follows.

Bearing ratio

= 100% - percentage of the pixels whose values are below the current representative value.

In default display, the y axis of the Region Histogram panel represents the number of pixels in the selected region group. User can choose to display ‘Bearing Ratio’ instead of the number of pixels by selecting ‘Bearing Ratio’ command in the context menu.

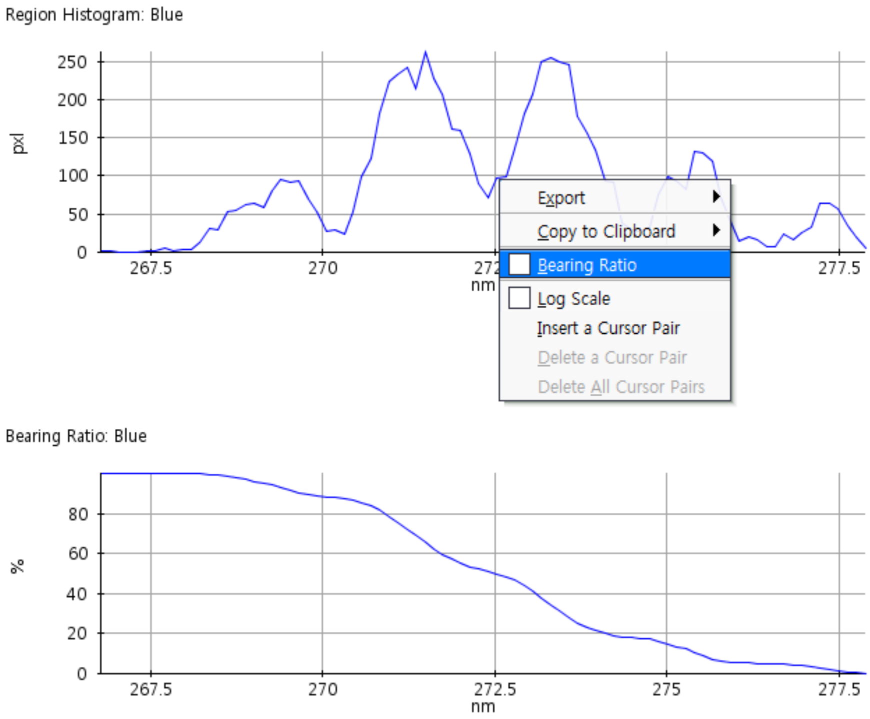


Figure 3-3-6. Bearing Ratio display

3-3-4-3 Insert (Delete) a Cursor Pair

Cursor pair can be inserted into a Region Histogram as it can be done in the Line Profile Panel (See section 4-3-2) to measure a difference between the number of pixels (or bearing ratio) and the representative value of two columns in the histogram. You can insert a cursor pair on the Line Profile by selecting 'Insert a Cursor Pair' command in the context menu. You can insert up to three cursor pairs per profile. Figure 3-3-7 shows a cursor pair inserted in the Region Histogram.

When the cursor pair is inserted, two triangular shaped cursors appear on two arbitrary columns on the Region Histogram. Along with the cursor pair, additional information is displayed (Figure 3-3-7).

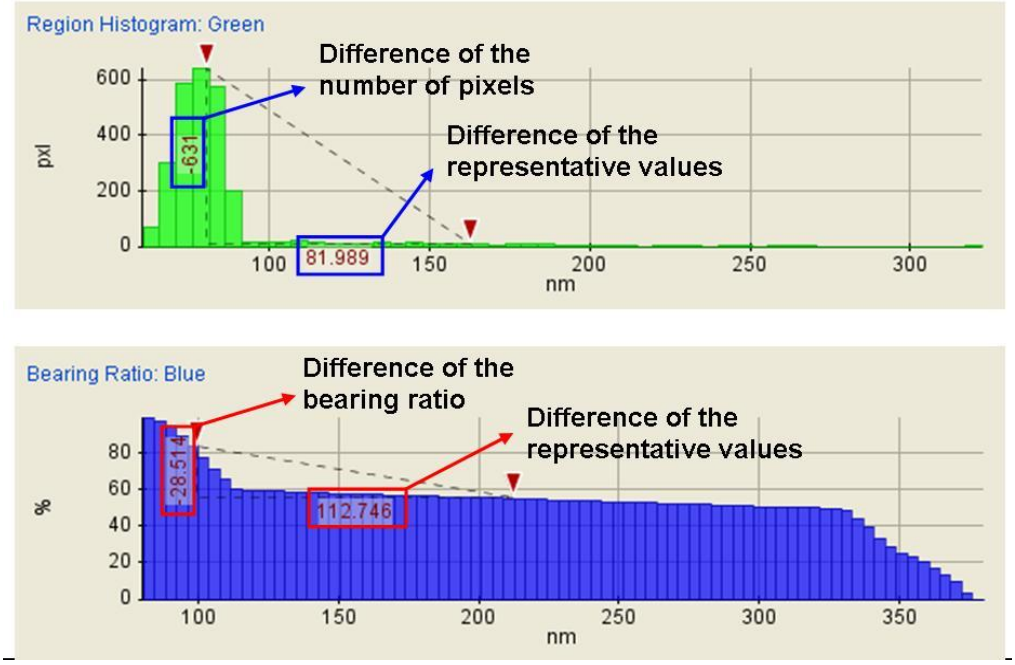


Figure 3-3-7. Cursor pair and displayed information

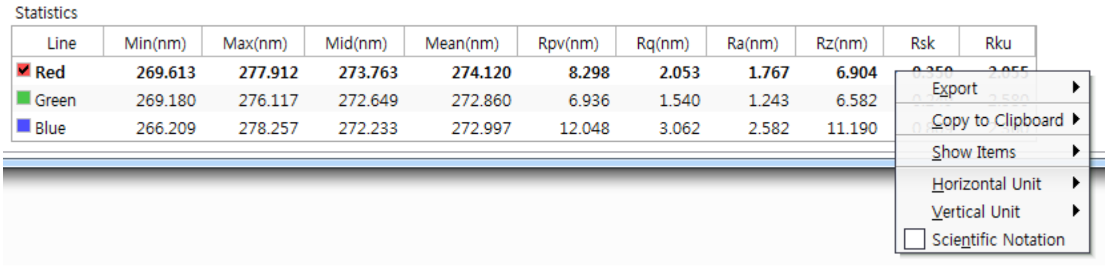
You can adjust the location of the cursors by dragging and dropping individual triangular cursors either from Region Histogram. The information displayed with the cursor are automatically updated whenever you change the position of the cursor pair.

To delete the cursor pair from the Region Histogram, select ‘Delete a cursor pair’ command from the context menu. This command deletes selected cursor pair from the Region Histogram. To delete all the cursor pair from the Region Histogram, select ‘Delete all cursor pairs’ command from the context menu.

3-3-5. Region Statistics Table

The Region Statistics table, shown in Figure 3-3-8, displays the statistics of the all data points in the selected region group. Each region group is related to one row of the table. The results of the statistics on the selected region are updated automatically when you change the selected region group by resizing or moving the region selector.

The context menu (see the outlined box in Figure 3-3-8) is generated when you right-click the cursor in the Region Statics table. The menu items are same as one in Line Profile Statics table. Refer to Section 4-5.



Statistics

Line	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
☑ **Red**	**269.613**	**277.912**	**273.763**	**274.120**	**8.298**	**2.053**	**1.767**	**6.904**	[illegible]	[illegible]
🟩 Green	269.180	276.117	272.649	272.860	6.936	1.540	1.243	6.582	[illegible]	[illegible]
🟦 Blue	266.209	278.257	272.233	272.997	12.048	3.062	2.582	11.190	[illegible]	[illegible]

Figure 3-3-8. Line statistics table

The meanings of the surface profile parameters displayed in the Region Statistics Table are defined as follows:

■ Min

Min is the minimum height value of the region.

■ Max

Max is the maximum height value of the region.

■ Mid

Mid is the arithmetic average between the minimum and maximum height value within the selected region. That is Mid = (Min + Max) / 2.

■ Mean

Mean is the arithmetic mean height value of the region. It is the sum of the height of each point divided by the number of points in the selected region.

■ Rpv

Rpv is the peak-to-valley of the selected region. It is the difference between minimum and maximum, that is, (Max – Min).

- **Rq**

Rq is the root-mean-squared roughness. It is the standard deviation of the height value in the selected region.

- **Ra**

Ra is the average roughness. The average roughness is the area between the roughness and its mean.

- **Rz**

Rz is the ten point average roughness. It is the arithmetic average of the five highest peaks and five lowest valleys in the selected region.

- **Rsk**

Rsk is the skewness of the selected region.

- **Rku**

Rku is the kurtosis of the selected region. It indicates the “spikiness” of the selected sample surface.

3-4. Grain View

In the ‘Grain View’ user can perform grain analysis on the loaded image. System automatically

1. Detects grains in the image
2. Marks each detected grain with different colors and numbers
3. Calculates important surface profile parameters of each detected grain and displays them in table,
4. Displays Distribution of surface parameters among detected grains will be displayed in the histograms.

Basically, you can perform grain analysis on the loaded image through the following procedure.

1. Bring an image file into the Analysis view from the Navigator view.
2. Enable the Grain View and select between two grain detection methods, Threshold or Watershed.
3. Set appropriate parameters for the selected grain detection method (Threshold: Range, Watershed: Filter level). Run the automatic grain detection process.
4. Each detected grain will be marked with different colors and numbers on the loaded image. Surface profile parameter of each detected grain will be displayed in the table. Distribution of surface parameters among detected grains will be displayed in the histograms. Export table, image and histogram as image or text file if desired.

3-4-1. Grain Detection Method

User can select between two different grain detection methods to use for automatic grain detection process. These two detection methods are 'Threshold' and 'Watershed'.

3-4-1-1 Threshold method

- **Algorithm**

In the algorithm of 'Threshold' grain detection method, group of pixels surrounded by the other pixels whose values are larger (or smaller) than the upper (or lower) 'Threshold' value are recognized as grain. Figure 3-4-1 shows a simplified 1D example showing how 'Threshold grain detection algorithm'' works.

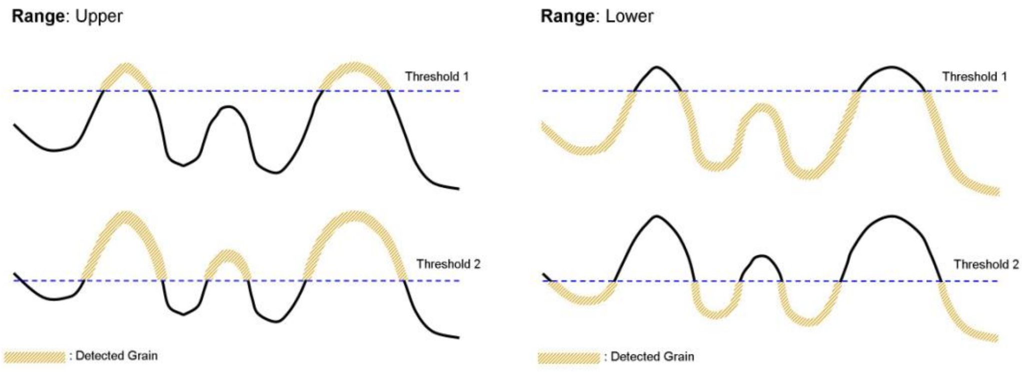


Figure 3-4-1. Threshold Grain detection

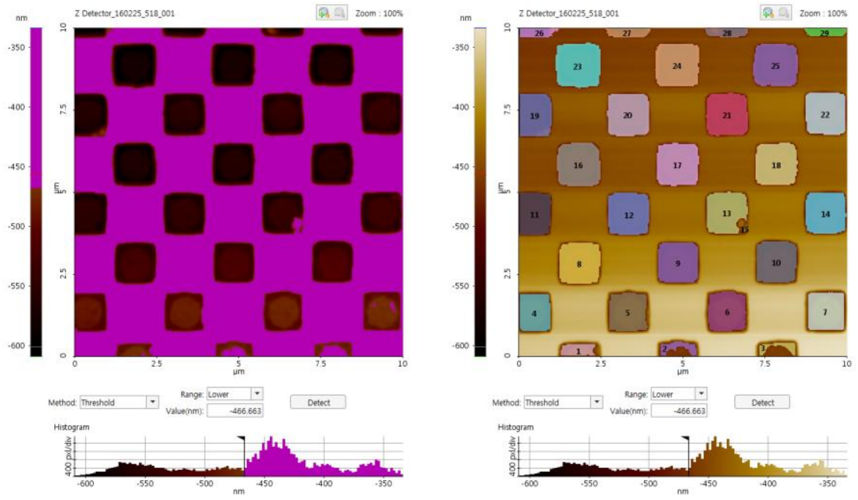
As can be seen from Figure 3-4-1, grain detection result differs according to the range setting and threshold value setting. XEI allows users to select between ‘lower’ and ‘upper’ for range and set the value of threshold by moving ‘Height restriction marker’ in the histogram of loaded image. The area of ‘Height restriction marker’ can be reset by clicking ‘Reset Bounds’ on Histogram Context menu (right clicking histogram will pop-up).

■ Upper

When the range is set to ‘Upper’, the ‘Height restriction marker’ appears on the left side of the histogram. User can set the ‘upper threshold value’ by moving the ‘height restriction marker’. The pixels corresponding to the left side of the upper threshold markers are colored in purple to indicate their values are smaller than the threshold value selected by the marker. Group of pixels surrounded by the other pixels whose values are smaller than the ‘Threshold’ value (i.e. pixels that are not colored in purple) are recognized as grain.

■ Lower

When the range is set to ‘Lower’, the ‘Height restriction marker’ appears on the right side of the histogram. User can set the ‘lower threshold value’ by moving the ‘height restriction marker’. The pixels corresponding to the right side of the lower threshold markers are colored in purple to indicate their values are larger than the threshold value selected by the marker. Group of pixels surrounded by the other pixels whose values are larger than the ‘Threshold’ value (i.e. pixels that are not colored in purple) are recognized as grain. Figure 3-4-2 shows the example of ‘Threshold’ grain detection process.


Method: Threshold
Range: Lower
Value(nm): -466.663

Method: Threshold
Range: Lower
Value(nm): -466.663

Figure 3-4-2. Threshold Grain Detection Process

3-4-1-2 Watershed method

- **Algorithm**

To understand the algorithm of ‘Watershed’ grain detection method, let’s look at the 1D example in the Figure 3-4-3.

Now, let’s imagine that we pour water over this surface. Water will first fill the lowest point of the surface. The region that water starts to fill in is recognized as a single grain. As the level of water increases, water starts to fill more region of the surface and thus more grains are detected. Then when the level of water reaches certain value, water filling one grain will start to overflow to other neighboring grains. Algorithm recognizes this point and sets the grain boundary.

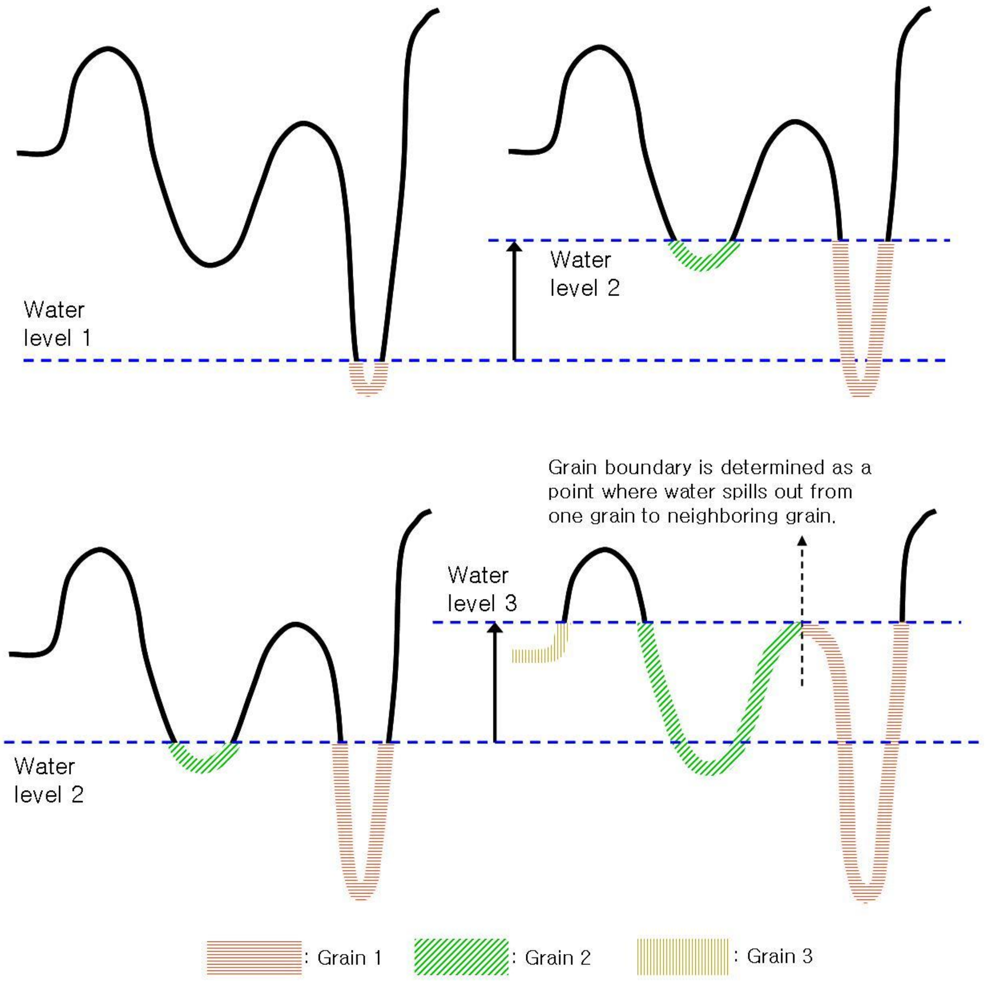

Water
level 1
Water
level 2
Grain boundary is determined as a point where water spills out from one grain to neighboring grain.
Water
level 3
Water
level 2
: Grain 1
: Grain 2
: Grain 3

Figure 3-4-3. Watershed Grain Detection Process

■ Parameter settings in 'Watershed' grain detection

As it can be expected from the algorithm of the 'Watershed' grain detection method, surface roughness affects the number of detected grains, or the 'sensitivity' in the watershed grain detection method. See Figure 3-4-4. In some cases, ripples in the images can be detected as a grain via watershed algorithm, resulting in a single grain to be divided in to many 'unwanted' grains.

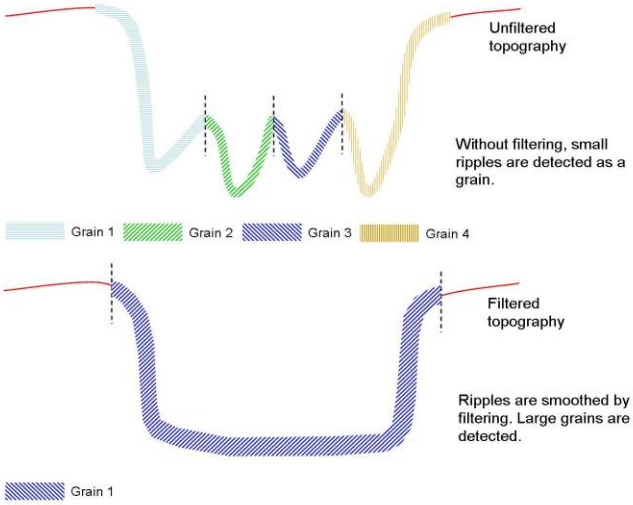
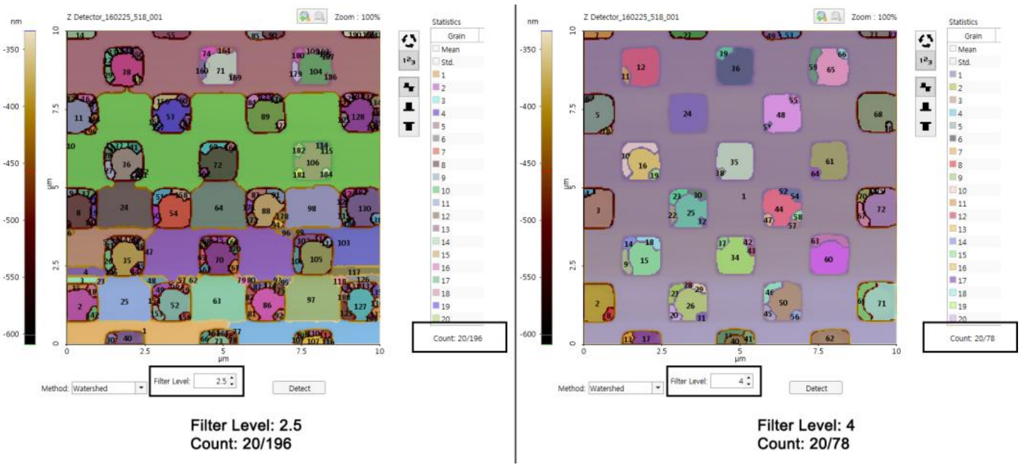

Unfiltered
topography
Without filtering, small ripples are detected as a grain.
Grain 1
Grain 2
Grain 3
Grain 4
Filtered
topography
Ripples are smoothed by filtering. Large grains are detected.
Grain 1

Figure 3-4-4. Effect of filtering on 'Watershed' grain detection

To control the surface roughness and thus the detection sensitivity of the method, it is desirable to apply 'smoothing' filter to the image before the detection algorithm starts. 'Filter level' parameter is the level of filter that is applied to the image before the 'Watershed' grain detection starts. The higher the filter level, the more the image will be smoothed before grain detection to remove 'grains' created by noise. Filter level acts to control the sensitivity of the grain detection as shown in Figure 3-4-5. Notice the difference in the number of total detected grain displayed in right corner and how the grains circled in dotted line differ according to the filter level.


Method: Watershed
Filter Level: 2.5
Count: 20/196

Method: Watershed
Filter Level: 4
Count: 20/78

Filter Level: 2.5
Count: 20/196

Filter Level: 4
Count: 20/78

Figure 3-4-5. Effect of filter level on grain detection. Grain detection results with Filter level 4 (left) and filter level 2.5 (right).

3-4-2. Grain Display Panel

When the grain detection process is complete, XEI will mark each detected grain with a different color and number. The number for each grain is allocated in the order that it was detected. The color of each grain is randomly generated from XEI in order to prevent any grains being marked with same color. (Each colored grain is best seen if you view the original image in 'Gray scale'.)

3-4-2-1 Selecting and deleting the detected grains

Each detected grain can be selected and deleted. This function is useful for picking out the 'unwanted' grains. Just click on any detected grain to select it. Then the boundaries of selected grains will be dotted with white circles. To delete the selected grains press 'Delete' button. You can also select multiple grains. There are two ways.

1. Hold down 'Ctrl' button of your keyboard as you click multiple grains.
2. Click and drag to select grains in the region of your interest (Figure 3-4-6).

To select all the detected grains in the loaded image, click any where on the image and then press 'Ctrl+A' or select 'Select All' from the context menu which appears when you right click on the image (Figure 3-4-6).

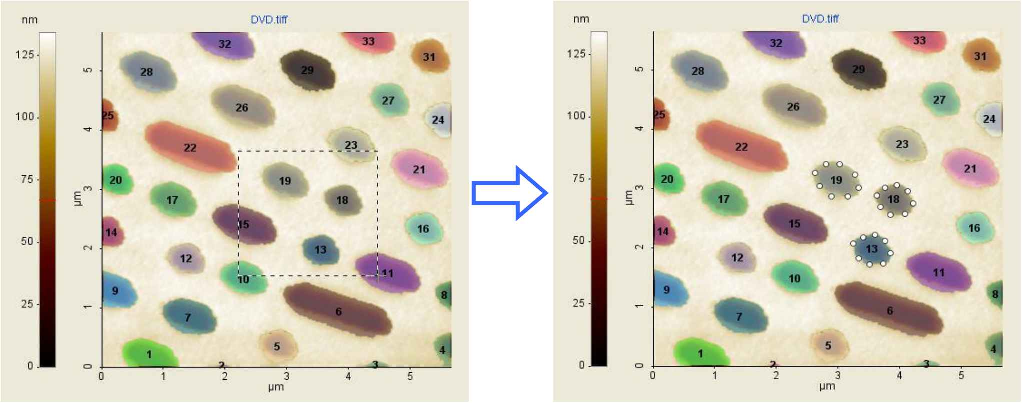


Figure 3-4-6. Multiple grain selection

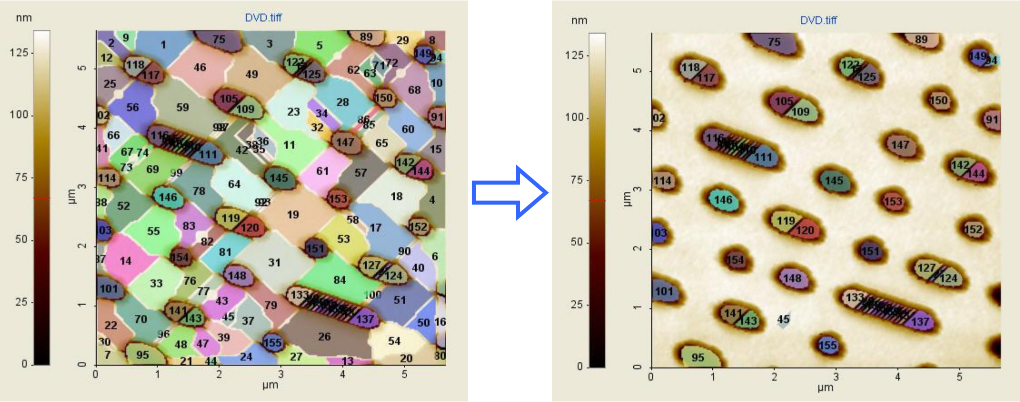
3-4-2-2. Show Number and Restore Grain Button

■ Restore Grain Button

Click this button to restore the deleted grains by reloading the initially detected grains.

■ Show Number Button

Click this button to display or hide the numbered label on each detected grains.



Show All

Show Valley

Figure 3-4-7. Show All and Show Valley

■ Show All (only in watershed mode)

Clicking this button displays all the grains detected by 'watershed' grain detection method.

■ Show Hills Only (only in watershed mode)

Clicking this button displays only the 'hills' among the grains detected by 'watershed' grain detection method. In the algorithm of the 'watershed' grain detection, hills are defined as a grain whose average value of the pixels within exceeds the average of the pixels on the boundary.

■ Show Valleys Only (only in watershed mode)

Clicking this button displays only the 'valleys' among the grains detected by 'watershed' grain detection method. In the algorithm of the 'watershed' grain detection, valleys are defined as a grain whose average value of the pixels within does not exceed the average of the pixels on the boundary.

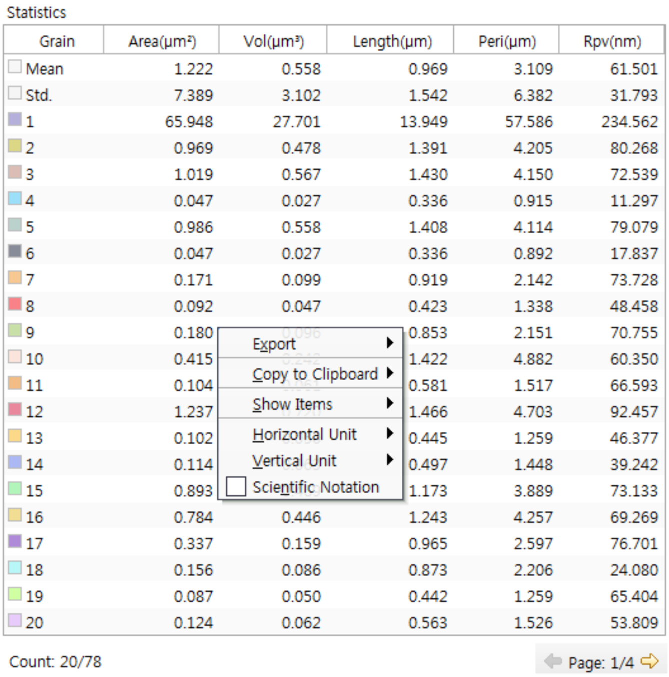
3-4-3. Statistics Table

After automatic grain detection, XEI calculates important surface profile parameters of each detected grain. These parameters are displayed in the statistic table. The meanings of the parameters are given in the table below.

Area	Area is the projected area of the detected grain.
Volume	Volume is the volume of the detected grain.
Length	Length is the distance between the two farthest points within the projected area of the grain.
Peri	Peri is the perimeter of the projected area.
Rpv	Rpv is the peak-to-valley of the line. It is the difference between minimum and maximum, that is, (Max-Min).

Table 6-3-1. Grain statistics parameters

In the ‘Statistic Table’, the surface profile parameters of the detected grains are arranged in numerical order. If more than 20 grains are detected system will display 20 grains at each page. You can jump from pages to pages through the arrow at the bottom right of the table. When the user selects grains from the image, surface profile parameters of the selected grains are displayed in the top of the table in bold letter. Moreover, when multiple grains are selected, mean value and standard deviation of each parameter are displayed in Mean and Std row. Table can be exported as a table or text file from the context menu which is shown when you right click the mouse with the pointer on the table. Currently, the context menu has ‘Export’, ‘Copy to Clipboard’, ‘Show Items’, ‘Horizontal Unit’, ‘Vertical Unit’ and ‘Scientific Notation’ items. For the information, please refer to the Section 4-5.



Statistics

Grain	Area(µm²)	Vol(µm³)	Length(µm)	Peri(µm)	Rpv(nm)
Mean	1.222	0.558	0.969	3.109	61.501
Std.	7.389	3.102	1.542	6.382	31.793
1	65.948	27.701	13.949	57.586	234.562
2	0.969	0.478	1.391	4.205	80.268
3	1.019	0.567	1.430	4.150	72.539
4	0.047	0.027	0.336	0.915	11.297
5	0.986	0.558	1.408	4.114	79.079
6	0.047	0.027	0.336	0.892	17.837
7	0.171	0.099	0.919	2.142	73.728
8	0.092	0.047	0.423	1.338	48.458
9	0.180	0.096	0.853	2.151	70.755
10	0.415	0.242	1.422	4.882	60.350
11	0.104	[illegible]	0.581	1.517	66.593
12	1.237	[illegible]	1.466	4.703	92.457
13	0.102	[illegible]	0.445	1.259	46.377
14	0.114	[illegible]	0.497	1.448	39.242
15	0.893	[illegible]	1.173	3.889	73.133
16	0.784	0.446	1.243	4.257	69.269
17	0.337	0.159	0.965	2.597	76.701
18	0.156	0.086	0.873	2.206	24.080
19	0.087	0.050	0.442	1.259	65.404
20	0.124	0.062	0.563	1.526	53.809

Count: 20/78

Figure 3-4-8. Statistics Table

3-4-4. Histogram Panel

The distribution of the certain surface profile parameters related to the grain size analysis, (i.e. area, volume, surface, perimeter) is plotted as a histogram in the histogram panel.

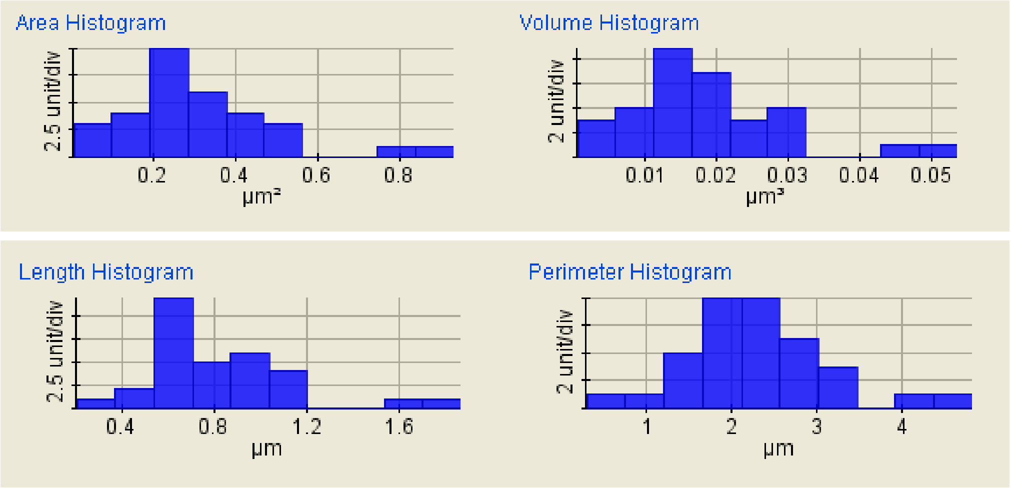


Figure 3-4-9. Statistics Table

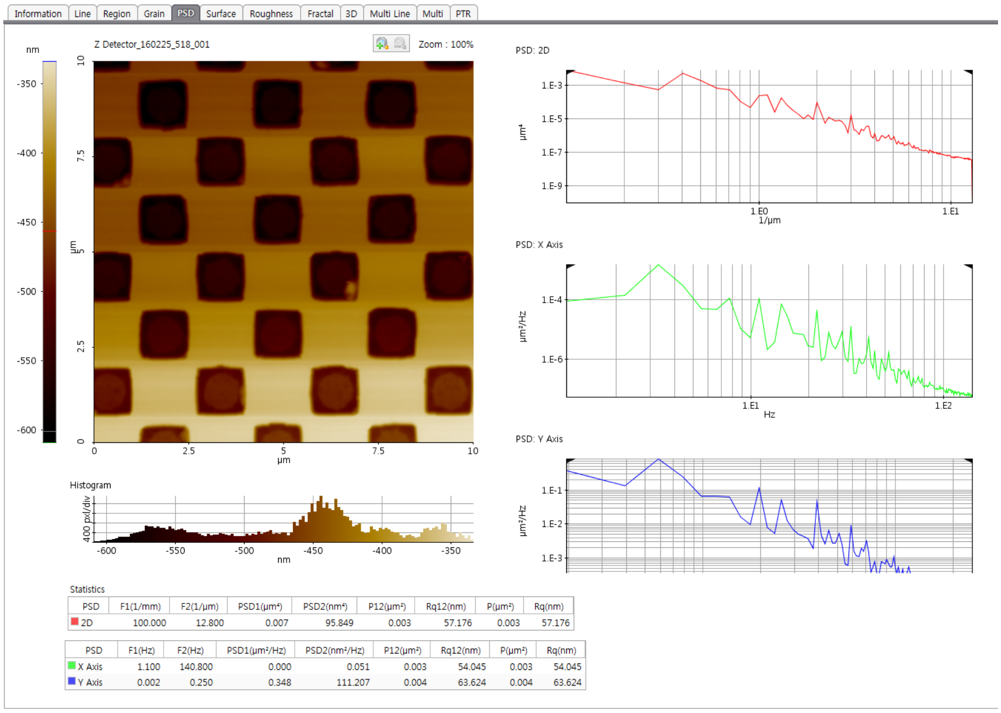
3-5. PSD View

PSD is an abbreviation of "Power Spectrum Density." PSD of the loaded image is obtained from Fourier Transform (FT) of the image and reflects the RMS roughness of the sample surface. PSD, FT, and RMS roughness are related as follows.

$$\mathbf{PSD = FT^2 = RMS^2}$$

The power spectral density (PSD) of a surface is equal to square of its Fourier Transform (FT) and RMS roughness value squared.

In the 'PSD View' user can view PSD graph of the loaded image and obtain relevant data. PSD view is useful for surface roughness analysis.



Statistics

PSD	F1(1/mm)	F2(1/µm)	PSD1(µm⁴)	PSD2(nm⁴)	P12(µm²)	Rq12(nm)	P(µm²)	Rq(nm)
🟥 2D	100.000	12.800	0.007	95.849	0.003	57.176	0.003	57.176

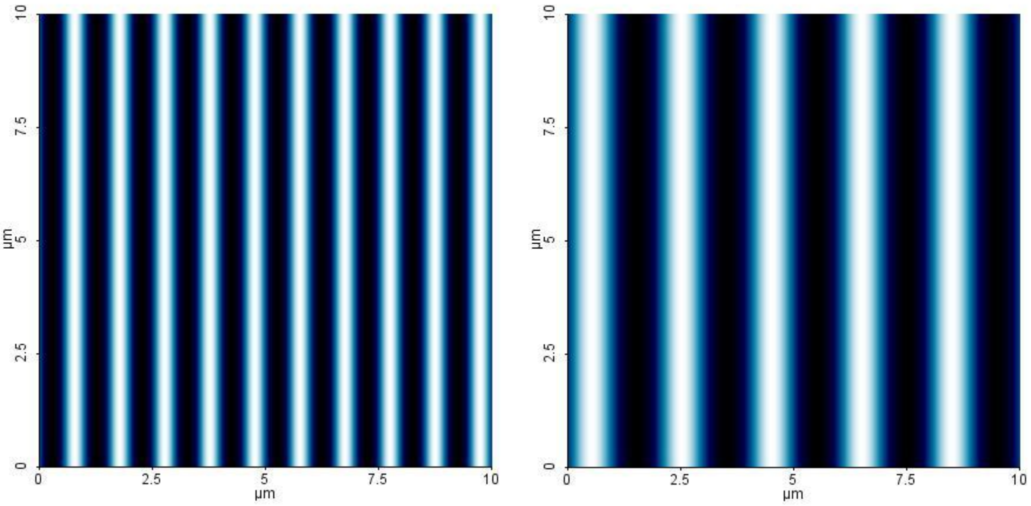
PSD	F1(Hz)	F2(Hz)	PSD1(µm²/Hz)	PSD2(nm²/Hz)	P12(µm²)	Rq12(nm)	P(µm²)	Rq(nm)
🟩 X Axis	1.100	140.800	0.000	0.051	0.003	54.045	0.003	54.045
🟦 Y Axis	0.002	0.250	0.348	111.207	0.004	63.624	0.004	63.624

Figure 3-5. PSD View

3-5-1 Meaning of PSD

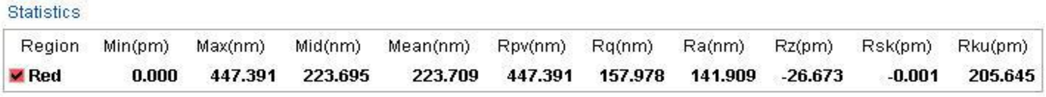
PSD is one of many parameters that are used to represent the surface roughness of the sample. PSD has advantages over the other surface roughness parameters such as RMS roughness because PSD contains the information how each frequency components contributes to the total roughness of the surface.

The example below shows the advantage of PSD as a surface roughness parameter. The images 'sinepi.tiff' and 'sine2pi.tiff' in Figure 3-5-1a are synthetic images generated from two sine functions with same amplitude but different frequency.



sinepi.tiff **sine2pi.tiff**

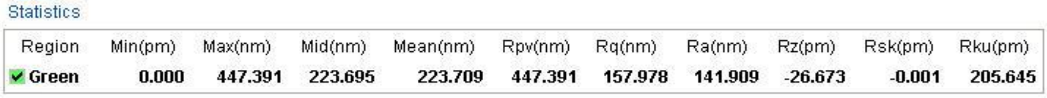
Roughness parameters of 'sinepi.tiff'



Statistics

Region	Min(pm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(pm)	Rsk(pm)	Rku(pm)
☑ Red	0.000	447.391	223.695	223.709	447.391	157.978	141.909	-26.673	-0.001	205.645

Roughness parameters of 'sine2pi.tiff'



Statistics

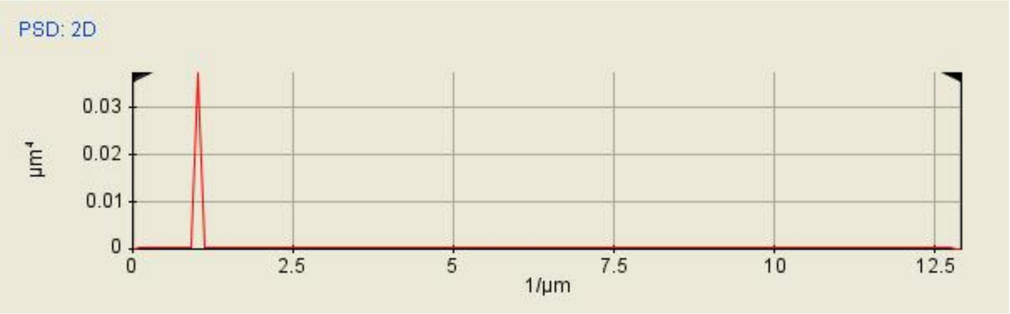
Region	Min(pm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(pm)	Rsk(pm)	Rku(pm)
☑ Green	0.000	447.391	223.695	223.709	447.391	157.978	141.909	-26.673	-0.001	205.645

Figure 3-5-1a. Two synthetic images of same roughness

As a result, their roughness parameters (Rpv, Rq, Ra, Rz, Rsk, Rku) are same despite eminent differences between their surface profile. These images are also included in sample image folder of XEI (C:\Park Systems\XEI\Samples). You can verify that they have the same roughness.

However, PSD graph which contains not only roughness information but also the contribution of each frequency components to the roughness can discriminate the difference of roughness between two images.

2D PSD of 'sinepi.tiff'



2D PSD of 'sine2pi.tiff'

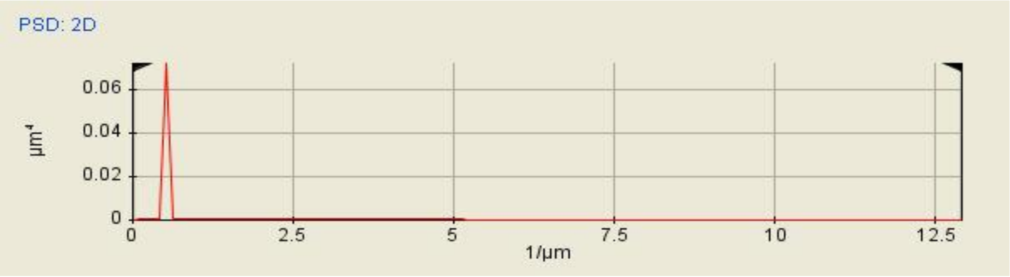


Figure 3-5-1b. PSD of two synthetic images of same roughness

3-5-2. PSD Graphs

XEI calculates and plots three different types of PSD for the loaded image; PSD X, PSD Y and PSD 2D. The X axis of the PSD X and PSD Y graph is the 'spatial frequency (cycle/μm)' of the image. For PSD 2D graph, the unit of the 'spatial frequency' is different (cycle/μm^2) as the range of power spectrum is 2 dimensional area.

The Y axis of the PSD graph is 'Power Spectrum Density', which is Power spectrum (μm^2) corresponding to each spatial spectrum (cycle/μm) value. Thus the unit for the Power Spectrum Density is μm^2 / (cycle/μm) = μm^3.

For each PSD graphs, there are two cursor(F1, F2) that slides along the X axis to mark point of interest on the PSD graph.

3-5-2-1 PSD 2D

PSD 2D graph is generated from 2 dimensional Power spectrum of the image. Power corresponding to the area of same ‘spatial frequency’ (represented as concentric circle in 2D power spectrum of the image)

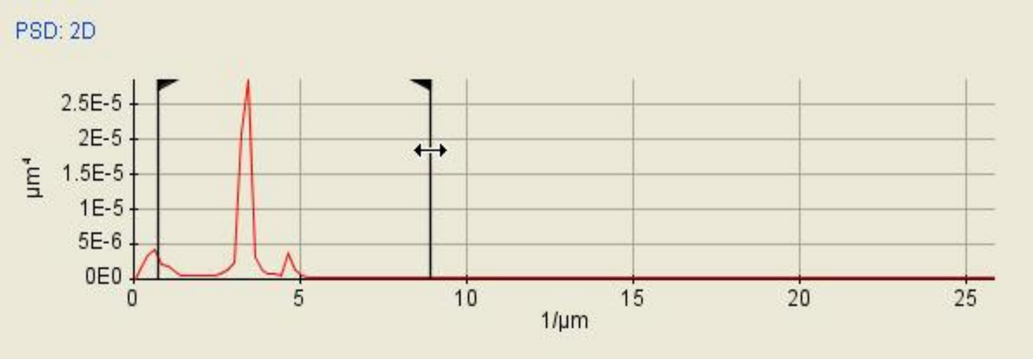


Figure 3-5-2a. PSD 2D

3-5-2-2 PSD X(Y)

PSD X(Y) is an average of the power spectrums for each line of the image parallel to X(Y) axis

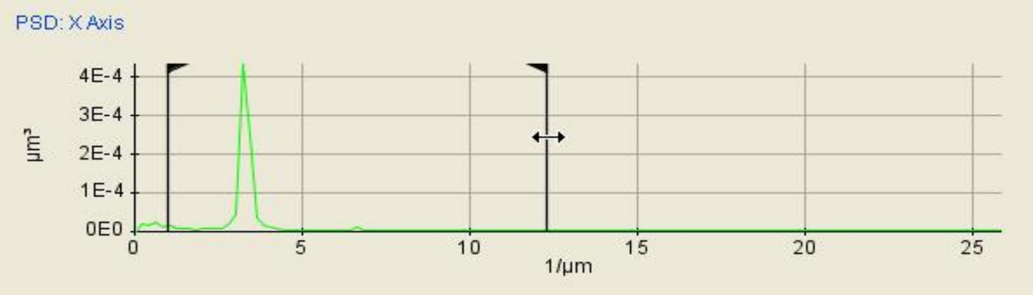


Figure 3-5-2b. PSD X axis

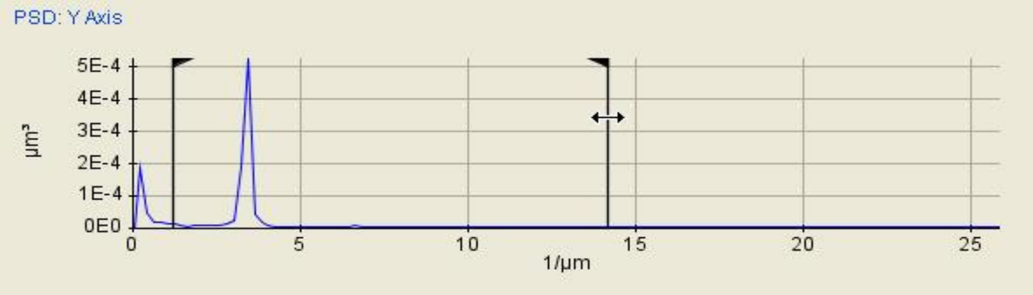


Figure 3-5-2c. PSD Y axis

3-5-2-3 PSD Context Menu

Right clicking on the graph will appear menu window as Figure 3-5-2d.

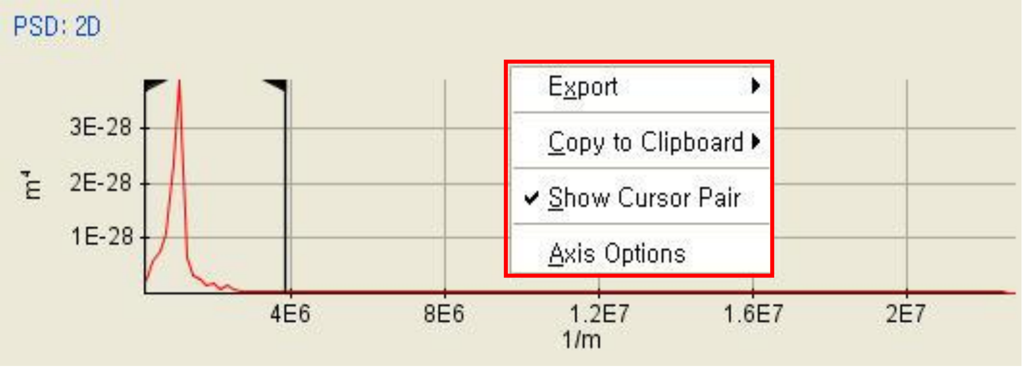


Figure 3-5-2d. PSD Context Menu

- **Export**

PSD graphs can be exported to ‘text’ or ‘image’ file for further analysis through other data processing software.

- **Copy to Clipboard**

PSD graphs can be copied to clipboard and pasted to the corresponding document program.

- **Show Cursor Pair**

For each PSD graphs, you can show two cursors that slide along the X axis to mark point of interest on the PSD graph.

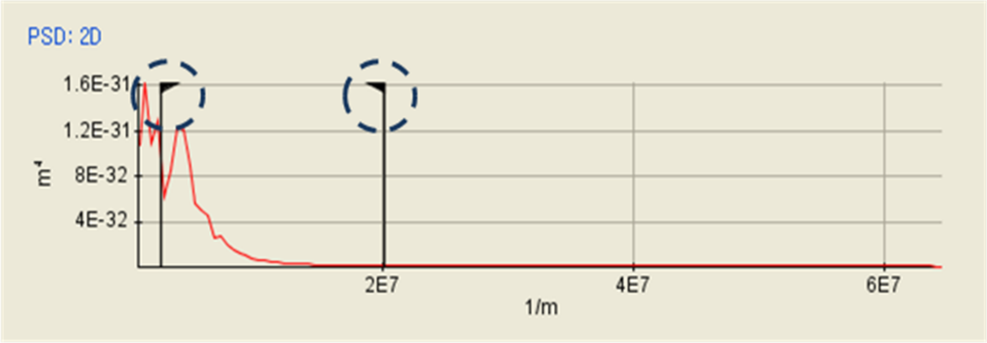


Figure 3-5-2e. PSD Show Cursor Pair

- **Axis Options**

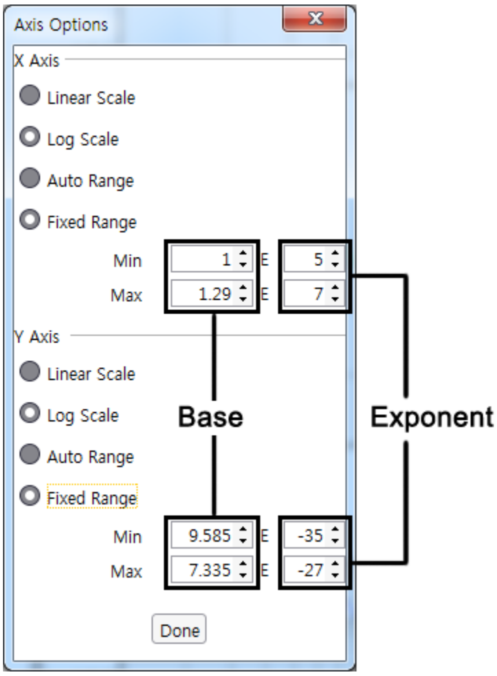
Graph scale and range can be adjusted in ‘Axis Options’ dialog which is popped up when choosing ‘Axis Options’ menu. Data Range/Scale can be appointed on each axis.

Linear Scale: Display selected axis’ data range as linear scale.

Log Scale: Display selected axis’ data range as log scale.

Auto Range: Display full data range in a selected axis.

Fixed Range: Display selected axis’ inserted Min/Max values. To select big or small value, base and exponent are separated.



Axis Options

X Axis

● Linear Scale
○ Log Scale
● Auto Range
○ Fixed Range

Min 1 E 5
Max 1.29 E 7

Y Axis

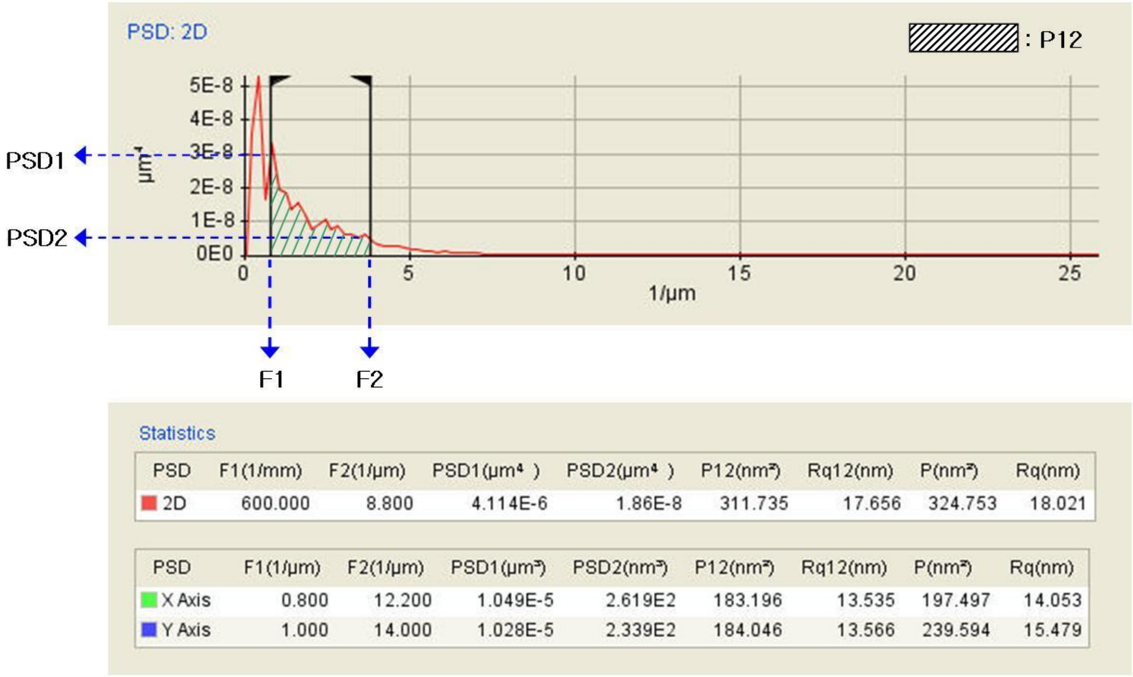
● Linear Scale
○ Log Scale
● Auto Range
○ Fixed Range

Min 9.585 E -35
Max 7.335 E -27

Figure 3-5-2f. PSD Axis Options

3-5-3 PSD Statistics Histogram

Various statistical analysis results of the PSD graph is displayed in this Histogram Panel. Below the Histogram panel, PSD Statistics table is shown at the same time. When you right click the mouse with the pointer on the table, you can see the context menu. Currently, the context menu has ‘Export’, ‘Copy to Clipboard’, ‘Show Items’, ‘Horizontal Unit’, ‘Vertical Unit’ and ‘Scientific Notation’ items. For the information, please refer to the Section 4-5.



Statistics

PSD	F1(1/mm)	F2(1/µm)	PSD1(μm^4)	PSD2(μm^4)	P12(nm^2)	Rq12(nm)	P(nm^2)	Rq(nm)
🟥 2D	600.000	8.800	4.114E-6	1.86E-8	311.735	17.656	324.753	18.021

PSD	F1(1/µm)	F2(1/µm)	PSD1(μm^3)	PSD2(nm^3)	P12(nm^2)	Rq12(nm)	P(nm^2)	Rq(nm)
🟩 X Axis	0.800	12.200	1.049E-5	2.619E2	183.196	13.535	197.497	14.053
🟦 Y Axis	1.000	14.000	1.028E-5	2.339E2	184.046	13.566	239.594	15.479

Figure 3-5-3. PSD Statistics & Histogram

- **F1(2)**

  Spatial frequency of the cursor 1(2)'s position.

- **PSD1(2)**

  Power Spectrum Density at the cursor 1(2)'s position.

- **P12**

  Area under the graph bounded by the cursor 1 and 2.

- **Rq12**

  RMS roughness between the cursor 1 and 2. Square root of the P12.

- **P**

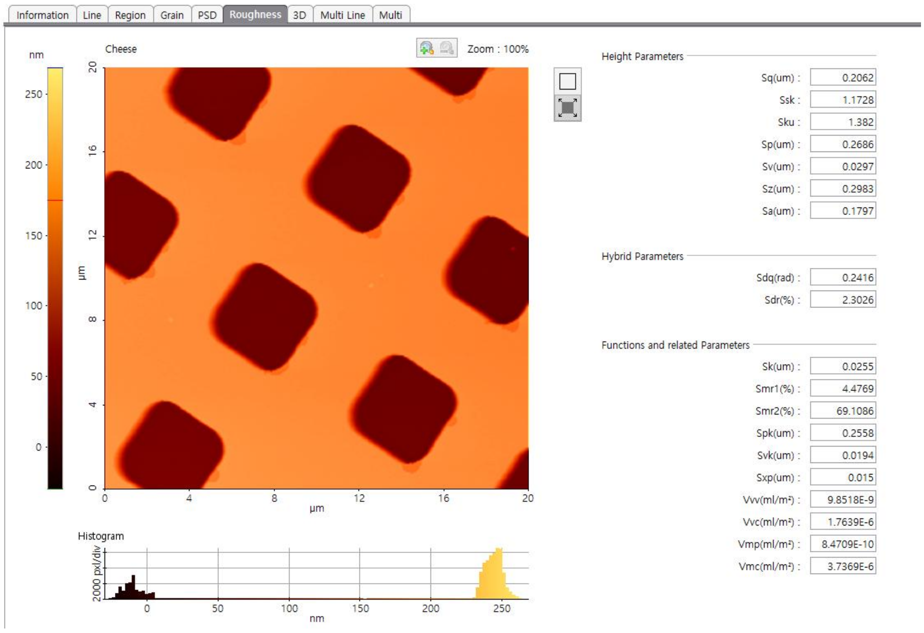
  Total area under the graph.

- **Rq**

  Total RMS roughness of the image. Square root of the P.

3-6. Roughness View

As a Roughness analysis, Region View and usage are the same. Selecting an entire area or part of the image via the Toolbar will update the Roughness on the right side of the screen.



Height Parameters

Sq(um) : 0.2062
Ssk : 1.1728
Sku : 1.382
Sp(um) : 0.2686
Sv(um) : 0.0297
Sz(um) : 0.2983
Sa(um) : 0.1797

Hybrid Parameters

Sdq(rad) : 0.2416
Sdr(%) : 2.3026

Functions and related Parameters

Sk(um) : 0.0255
Smr1(%) : 4.4769
Smr2(%) : 69.1086
Spk(um) : 0.2558
Svk(um) : 0.0194
Sxp(um) : 0.015
Vvv(ml/m²) : 9.8518E-9
Vvc(ml/m²) : 1.7639E-6
Vmp(ml/m²) : 8.4709E-10
Vmc(ml/m²) : 3.7369E-6

Figure 3-6. Roughness View

3-6-1 Height Parameter

All height parameters are defined over the definition area.

- **Sq (um)**

$$S_{\mathrm{q}} = \sqrt{\frac{1}{A}\iint_A z^2(x,y)\mathrm{d}x\mathrm{d}y}$$

Root mean square height.

- **Ssk**

$$S_{\mathrm{sk}} = \frac{1}{S_{\mathrm{q}}^3}\left[\frac{1}{A}\iint_A z^3(x,y)\mathrm{d}x\mathrm{d}y\right]$$

Skewness of height distribution.

- **Sku**

$$S_{\mathrm{ku}} = \frac{1}{S_{\mathrm{q}}^4}\left[\frac{1}{A}\iint_A z^4(x,y)\,\mathrm{d}x\mathrm{d}y\right]$$

Kurtosis of height distribution

- **Sp**

Maximum height of peaks.

- **Sv**

Maximum height of valleys.

- **Sz**

Sum of the maximum peak height value and the maximum pit height value within a definition area.

- **Sa**

$$S_{\mathrm{a}} = \frac{1}{A}\iint_A \left|z(x,y)\right|\,\mathrm{d}x\mathrm{d}y$$

Arithmetic mean height.

3-6-2 Hybrid Parameter.

- **Sdq**

$$S_{\mathrm{dq}} = \sqrt{\frac{1}{A}\iint_A\left[\left(\frac{\partial z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial z(x,y)}{\partial y}\right)^2\right]\mathrm{d}x\mathrm{d}y}$$

Root mean square of the surface gradient within the definition area of a scale-limited surface.

- **Sdr**

$$S_{\mathrm{dr}} = \frac{1}{A}\left[\iint_A\left(\sqrt{\left[1+\left(\frac{\partial z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial z(x,y)}{\partial y}\right)^2\right]} - 1\right)\mathrm{d}x\mathrm{d}y\right]$$

Developed area ratio.

3-6-3 Functions and related Parameter

Function representing the areal material ratio of the scale-limited surface as a function of height.

- **Sk**

Core height.

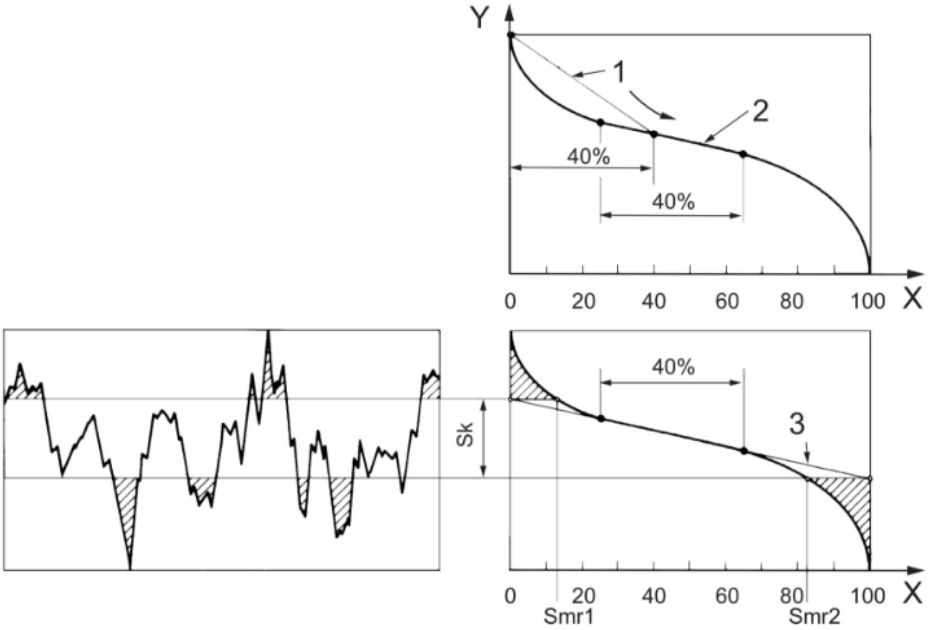
- **Smr1(%)**

Ratio of the increment of the interfacial area of the scale-limited surface within the definition area over the definition area.

- **Smr2(%)**

Ratio of the increment of the interfacial area of the scale-limited surface within the definition area over the definition area.

Figure 3-6-1 shows a profile instead of a surface area for ease of illustration. The principle is the same for a surface area.



Key

X	areal material ratio
Y	intersection line position
1	secant
2	secant with smallest gradient
3	equivalent straight line
Sk	core height
Smr1, Smr2	material ratios

Figure 3-6-1. Calculation of Sk, Smr1 and Smr2

- **Spk**

Reduced peak height.

- **Svk**

Reduced dale height.

- **Sxp**

Peak extreme height.

- **Vvv(ml/m^2)**

$$V_{\mathrm{vv}} = V_{\mathrm{v}}(p)$$

Dale void volume of the scale-limited surface.

- **Vvc(ml/m^2)**

$$V_{\mathrm{vc}} = V_{\mathrm{v}}(p) - V_{\mathrm{v}}(q)$$

Core void volume of the scale-limited surface.

- **Vmp(ml/m^2)**

Peak material volume of the scale-limited surface.

- **Vmc(ml/m^2)**

$$V_{\mathrm{mc}} = V_{\mathrm{m}}(q) - V_{\mathrm{m}}(p)$$

Core material volume of the scale-limited surface.

Some of the Roughness related parameters defined in ISO 25178 have been implemented. Please contact Park Systems for a detailed formula for those values.

3-7. Fractal View

In fractal geometry, objects can have non-integer (fractional) dimensions. Fractal analysis allows calculation of the dimension of sample topographies using the triangulation, cube counting, and partitioning methods.

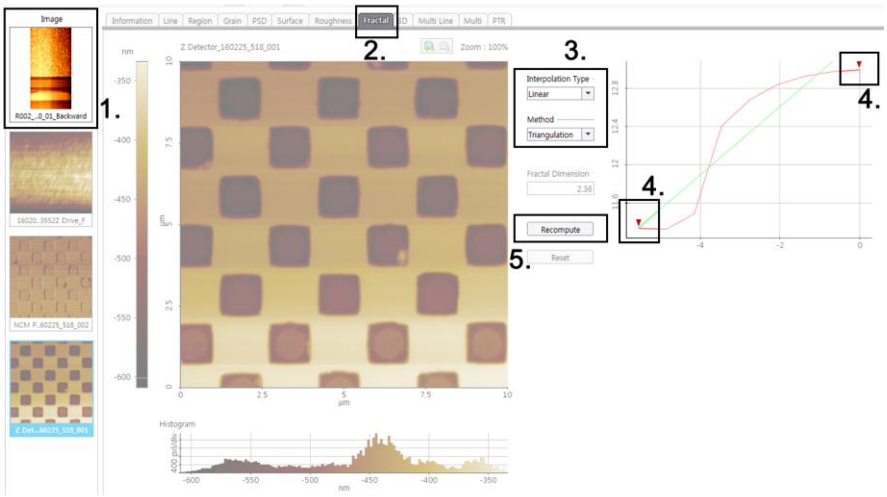
To see how an object can have a non-integer dimension, consider a continental coastline. If one measures the coastline with a 100km-length ruler, a certain measurement will result. Then, if one took multiple 10km-length rulers, a larger measurement will result, as more of the curves will be counted. As the length of the rulers used approaches 0, the measured coastline length approaches infinity. The slope of this length-of-ruler to length-of-coast curve can be said to be the dimension of the coastline. For a topographic image, one counts area or volume instead of length.

As shown in Figure 3-7, the Fractal Analysis View consists of Image Display Panel, the Fractal Analysis Control Panel, and the Fractal Graph.

The following procedure can be used for estimating D:

1. Bring an image file into the Analysis view from the Navigator view.
2. Select Fractal View.
3. Adjust the parameters in the Fractal Control Panel.
4. Adjust the cursors in the Fractal Graph.
5. Click the Recalculate button.

Figure 3-7 shows some of these steps.



Interpolation Type: Linear

Method: Triangulation

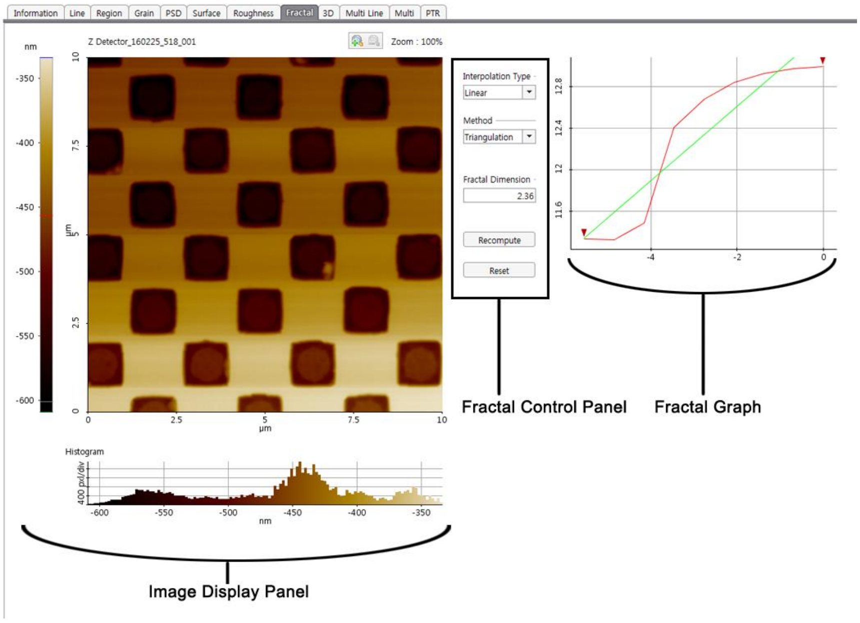
Fractal Dimension: 2.36

Figure 3-7. Procedure for Fractal view

3-7-1. Fractal View Layout

To open the Fractal view, select the 'Analysis>Fractal' menu or click the Fractal view tab below the Menu bar.

The Fractal view consists of three main regions (see Figure 3-7-1): On the left is the Image Display Panel, which shows the image being analyzed. In the center is the Fractal Control Panel, which accepts parameters from the user and displays the analysis results. On the right is the Fractal Graph, which displays the curve relevant to the selected analysis method, and allows the user to select the region to be used in fractal analysis.



Interpolation Type: Linear

Method: Triangulation

Fractal Dimension: 2.36

Figure 3-7-1. Layout of Fractal View

3-7-2. Fractal Control Panel

There are several items in the control panel that can be controlled for estimating D, the fractal dimension value, and for displaying the results of the estimation.

3-7-2-1. Interpolation Type

When computing the fractal dimension, it is useful to increase the effective resolution by estimating, or interpolating, values in between pixels. Currently, only linear interpolation is available.

Linear interpolation simply takes the arithmetic mean of the two pixels.

3-7-2-2. Method

There are several methods by which to calculate D.

- **Triangulation**

In the Triangulation method, the surface of the image is “coated” with triangular plates. As the triangles become more numerous and smaller, their collective surface area increases. This relationship is the basis of the triangulation method.

- **Box Counting**

In the Box Counting method, the image is imagined to be enclosed in a cubic area. As the cube is increasingly split into smaller pieces, some of the resulting cubes are no longer required to completely overlap the sample, and thus the collective volume of the cubes decreases as their size decreases.

- **Partitioning**

Similar to the Box Counting method, the image is separated into prisms. However, the value measured is not the combined volume of these prisms, but rather the difference in height between the prism and the sample surface. As these prisms become smaller, the sum of these differences, or variance, can be expected to decrease. When the slope between the number of cubes and the variance is β, the fractal dimension is equal to 3 – β/2.

3-7-2-3. Fractional Dimension

This label displays the estimated value for D with the current parameters.

3-7-2-4. Control Buttons

The Recompute button causes a new estimation to be performed with the current settings.

The Reset button reverts all of the parameters to the default values.

3-7-3. Fractal Graph Panel

The Graph Panel plots the number of subdivisions to the relevant value, depending on the method described in 8-2-2. Two cursors are used to select the domain to be used in estimating the fractal dimension. Simply click and drag the cursors to move them, or select one and use the right and left keys to move them with pixel precision.

3-8. 3D View

In the 3D view, you can see both the features of the image and the relationships between those features in a 3D rendered view. Different from other microscopic techniques such as SEM or TEM, the 3D view is unique to SPM. The scanning probe microscope scans the sample surface horizontally (x, y) line by line while collecting the vertical (z) direction profile of the sample surface. As a result, the scanning probe microscope collects truly 3-dimensional (x, y, z) information from the surface and this 3-dimensional data represents true surface topography.

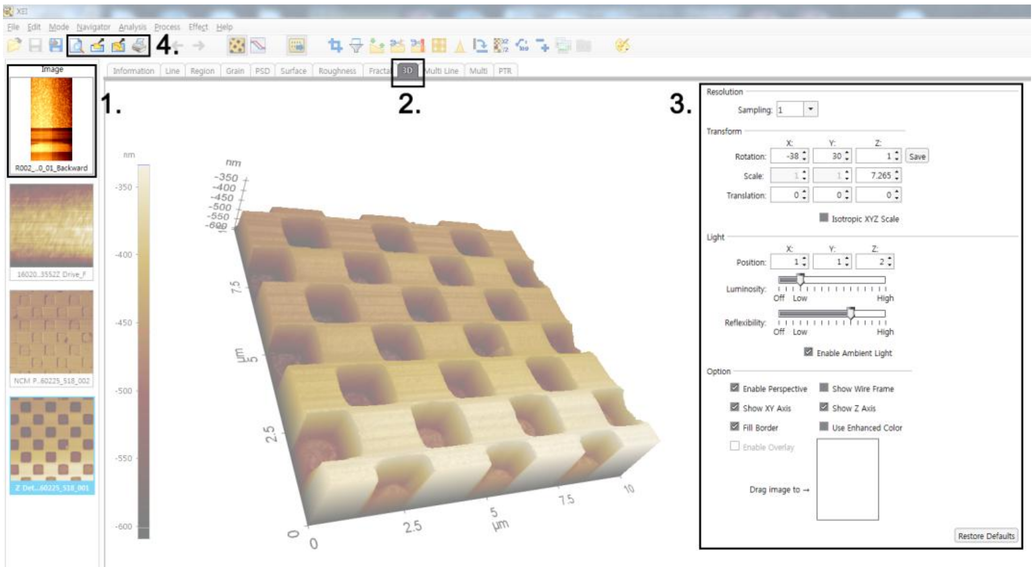
Basically, you can create the 3-diemnsional perspective of an image through the following procedure.

1. Bring an image file into the Analysis view from the Navigator view.
2. Enable the 3D view to generate an initial 3D rendering of the image.
3. Adjust several 3D rendering parameters to obtain the best 3D view.
4. Export and print out the 3D image if desired.

NOTE!

The original image will be distorted in 3D view when the type of 3D Renderer(OpenGL, Direct3D) is unsuitable for your system. Otherwise, the XEI program will be closed immediately after the 3D view opens. In this case, change the type of 3D Renderer, selected in ‘File>Preferences’.

Figure 3-8 shows the summarized procedure for 3D rendering of an image.



Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	-38	30	1
Scale:	1	1	7.265
Translation:	0	0	0

▨ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

☑ Enable Ambient Light

Option

☑ Enable Perspective
▨ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
▨ Use Enhanced Color
☐ Enable Overlay

Figure 3-8. Procedure for 3D view

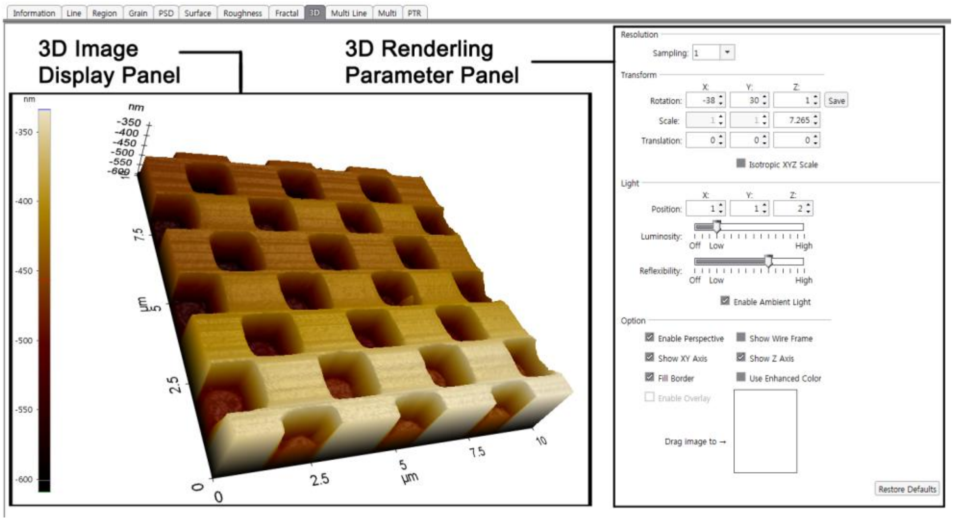
3-8-1. 3D View Layout

To open the 3D view, select the 'Analysis>3D' menu or click the 3D view tab below the Menu bar.

The 3D view consists of two main regions (see Figure 3-8-1): One is the 3D Image display panel that is placed to the left side in the Analysis view. The other is the 3D rendering parameters panel to the right side. These are going to be described in detail in the next section.

In the 3D view, you can change the following characteristics of the image:

- The presented resolution of the image
- The rotation angle of the image
- The size of the image
- The height magnification
- The position of the simulated light source
- The color and intensity of the simulated light source
- The color of the image and background



Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	-38	30	1
Scale:	1	1	7.265
Translation:	0	0	0

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity:

Reflexibility:

☑ Enable Ambient Light

Option

☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Figure 3-8-1. Layout of 3D View

3-8-2. 3D Image Display Panel

In the 3D Image display panel, the 3-dimensional perspective of an image is displayed and updated immediately after you adjust anything of the available 3D rendering parameters. The 3D image is held within a frame and presented on a virtual plane. Dragging the cursor within the frame allows you to rotate the image in the 3D Image display panel.

Using the 3-dimensional (x, y, z) data set, the individual lines will be stacked to generate the 3-dimensional perspective and then this view may be adjusted by simulating the reflection of light from the surface. Surface features that would be illuminated from above appear bright, and features that would be illuminated from an oblique view appear dark. You can vary the direction of illumination by changing the position of an artificial light source. You can also rotate the image to vary your viewing angle. Figure 3-8-2 shows the general 3D Image display panel

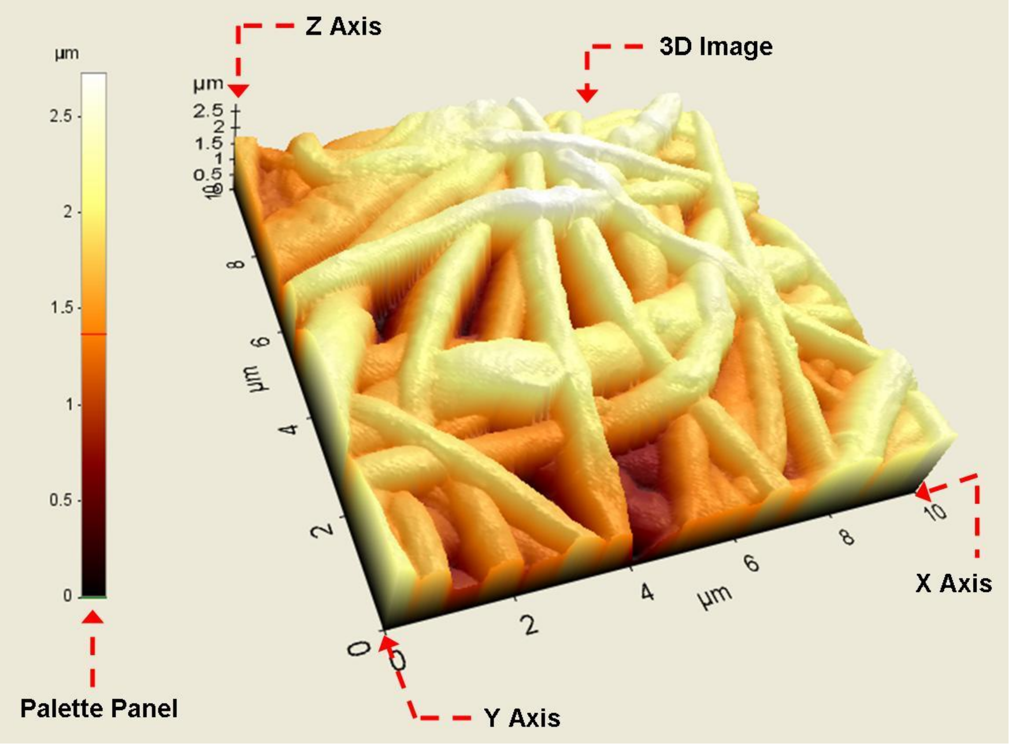
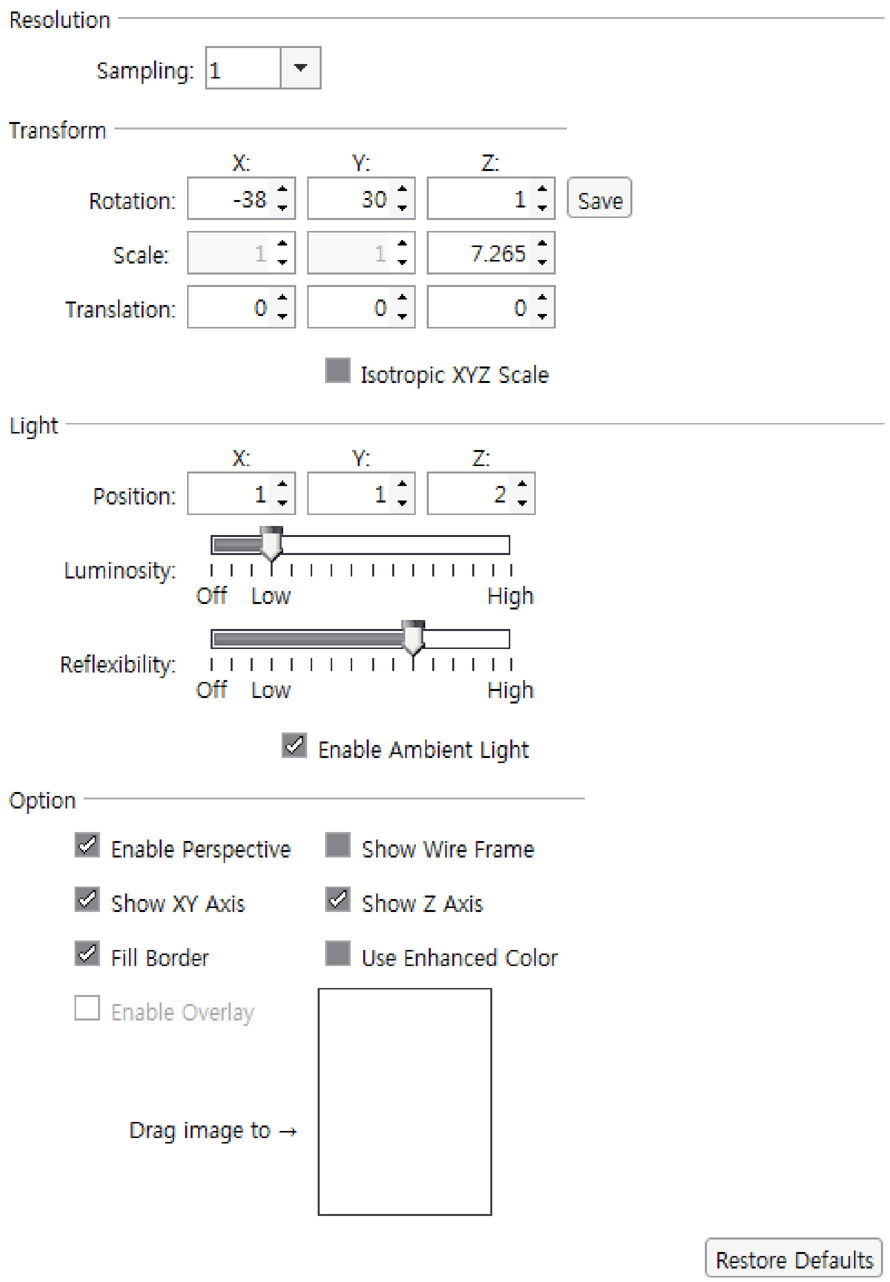


Figure 3-8-2. 3D Image display panel

3-8-3. 3D Rendering Parameters

The 3D rendering parameters can be adjusted to get the best 3-dimmensional view of the sample surface. Whenever you adjust these parameters, they are automatically applied to the 3-dimensional image in the 3D Image display panel. These 3D rendering parameters, as shown in Figure 3-8-3, are described further below.



Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	-38	30	1
Scale:	1	1	7.265
Translation:	0	0	0

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

☑ Enable Ambient Light

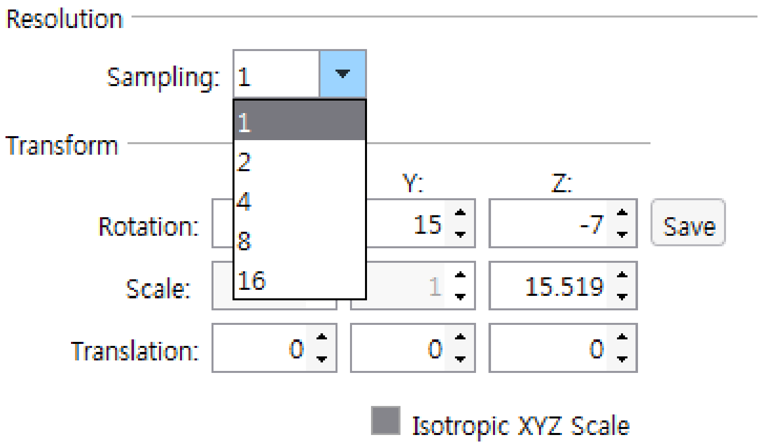
Option

☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Figure 3-8-3. 3D rendering parameters

3-8-3-1. Resolution

Allows you to vary the resolution of the displayed 3D image. You can select the number of sampling data points in the Sampling combo box. By default, the image pixel size is set to be 256×256. So the number of sampling data points is automatically changed to be displayed at this default resolution. However, when the pixel size of the original image is more than 256×256 (512, 1024, 2048, and 4096), you can enhance the resolution of the 3D view by selecting the appropriate sampling number (1, 2, 4, 8, or 16; see Figure 3-8-4). However, increment of the image pixel size is less effective since this may need larger memory but cannot show remarkable enhancement of the image's resolution.



Sampling: 1

Rotation: Y: 15 Z: -7

Scale: 1 15.519

Translation: 0 0 0

Figure 3-8-4. Sampling numbers

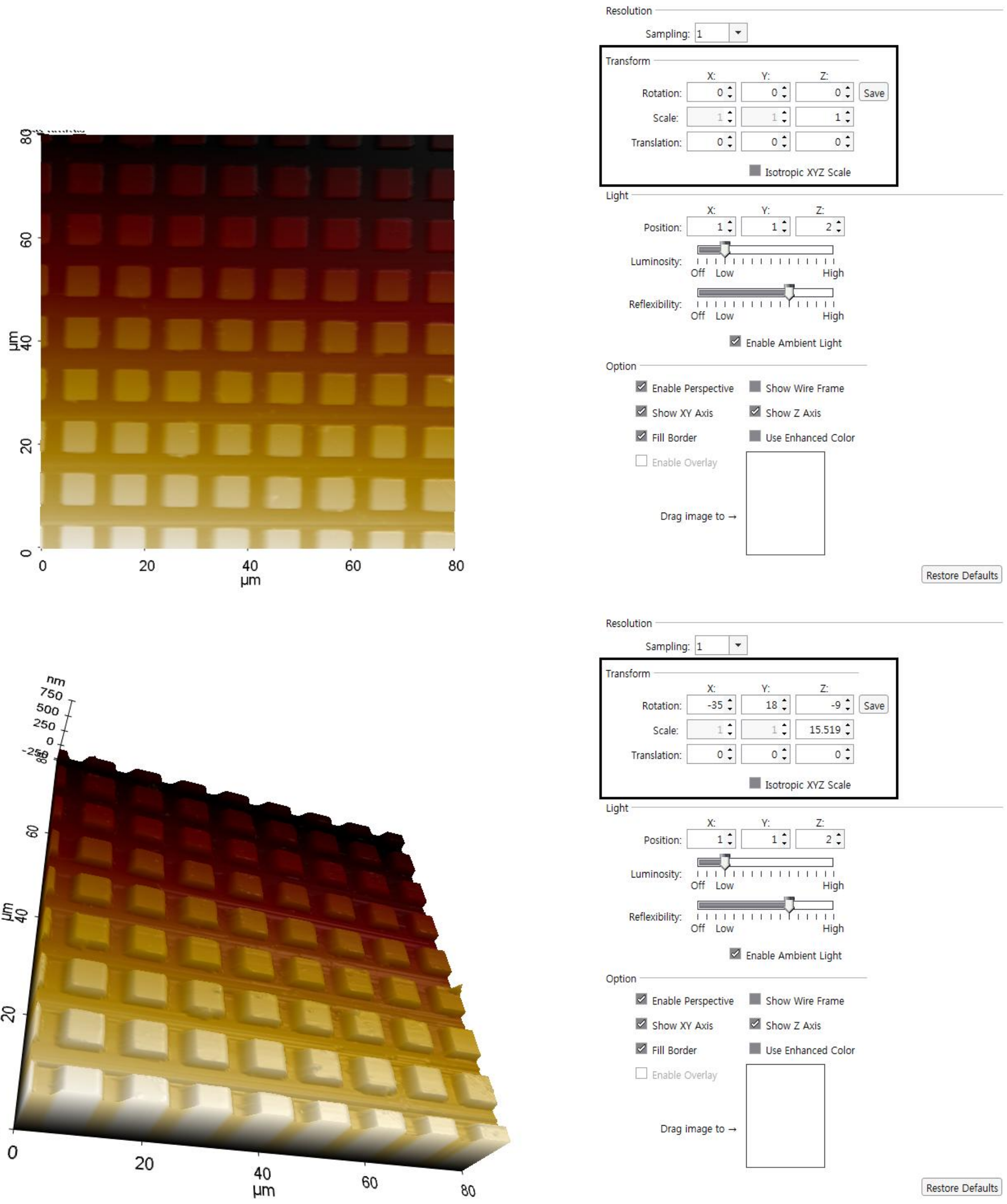
■ **Sampling Number**

Changes the number of sampling data points in the line. Sampling number is automatically set to as follows: the number of data points ÷ sampling number =256.

Sometimes the number of data points collected for a line exceeds the number of pixels on the 3D Image display panel. In this case, you should select the reasonable sampling number (see Figure 3-8-4) to enhance the resolution of the 3D displayed image. When you open a new image, the sampling is selected automatically to display 256 data points for a line. To adjust the display for higher resolution images, you should set the sampling numbers manually. For example, when the pixel size of the original image is 1024, the sampling number is automatically converted to 4 (in order to reduce its pixel size to 256×256 1024 should be divided by 4), but you can enhance the resolution of the 3D image by selecting a smaller number for sampling the data (when the number is 1 or 2, the image pixel size is 1024 or 512).

3-8-3-2. Transform

Allows you to alter the viewing angle and the scale of the 3D image. Also, you can translate the 3D rendered image in the z direction. Figure 3-8-5 shows the 3D image view that the Transform functions are applied to the 3D rendition of an image.



Resolution
Sampling: 1
Transform
Rotation: X: 0 Y: 0 Z: 0
Scale: X: 1 Y: 1 Z: 1
Translation: X: 0 Y: 0 Z: 0
☐ Isotropic XYZ Scale
Light
Position: X: 1 Y: 1 Z: 2
☑ Enable Ambient Light
Option
☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Resolution
Sampling: 1
Transform
Rotation: X: -35 Y: 18 Z: -9
Scale: X: 1 Y: 1 Z: 15.519
Translation: X: 0 Y: 0 Z: 0
☐ Isotropic XYZ Scale
Light
Position: X: 1 Y: 1 Z: 2
☑ Enable Ambient Light
Option
☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Figure 3-8-5. Transformed 3D image

■ Rotation

Changes the viewing angle of the image by rotating the 3D image. You can rotate the image plane around the x, y and z axis by entering the rotation degrees or by using the spin buttons next to the Rotation text fields for X, Y and Z respectively. You can change the viewing angle from -180 to 180 in x, y and z direction. The Rotation angle can be saved by clicking 'Save' button in Transform Panel. After save, all the images that opens in 3D Analysis View will be based on previous saved value. When clicking 'Restore Defaults' button, all the values will be set as default value. You must click 'Save' button if these values need to be saved.

- X: changes the viewing angle of the image in the x direction
- Y: changes the viewing angle of the image in the y direction
- Z: changes the viewing angle of the image in the z direction

■ Scale

You can alter the scale of the 3D rendered image in the horizontal (x, y) and the vertical (z) directions. Also, you can manipulate the scale by rolling the mouse wheel. When adjusting the scale using the mouse wheel, the ratio between X, Y, and Z axis on the image will be preserved. The 'Isotropic Z scale' check box fits the z scale to the maximum scale of x, y. Consequently, you will see an image that is similar to the real surface.

- X: alters the scale of the 3D image in the x direction
- Y: alters the scale of the 3D image in the y direction
- Z: alters the scale of the 3D image in the z direction

■ Translation

You can change the position of the 3D image in XYZ direction. Also, you can change in XY direction with dragging mouse and control key on keyboard.

3-8-3-3. Light

Changes the position of the simulated light source. By default, an ‘Ambient Light’ is turned on when you enable the 3D view. The ‘Ambient Light’ is the default light that commonly exists everywhere, similar to sunlight. It is used to minimize the variation of light effects among various shaped images.

In addition to an ambient light, there is another light source that may be adjusted by the user. You can change the position of the light source by specifying the position in x, y, and z direction.

■ Position

- X: moves the position of the simulated light source in the x direction
- Y: moves the position of the simulated light source in the y direction
- Z: moves the position of the simulated light source in the z direction

■ Luminosity

You can increase or decrease the luminosity of a 3D rendered image by adjusting the slider from Low to High.

■ Reflexibility

You can increase or decrease the reflexibility of a 3D rendered image by adjusting the slider from Low to High.

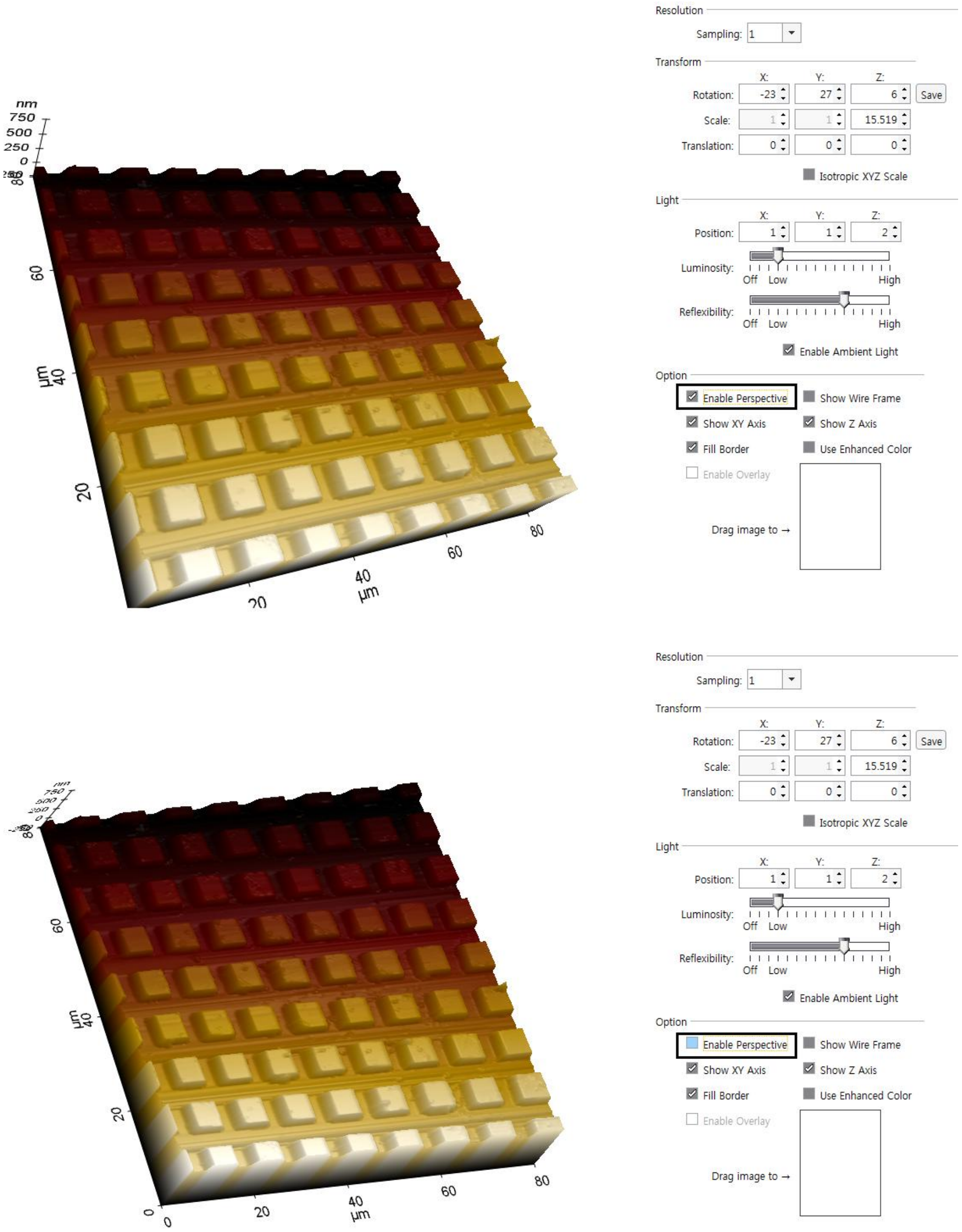
■ Enable Ambient Light

You can turn on or off the ’Ambient light’ by selecting or deselecting it in the ‘Ambient light’ check box, respectively.

3-8-3-4. Option

■ Enable Perspective

Enables the perspective 3D display. Figure 9-3-4 shows two images selected (above) and deselected (below) the ‘Enable Perspective’ option in the 3D view.



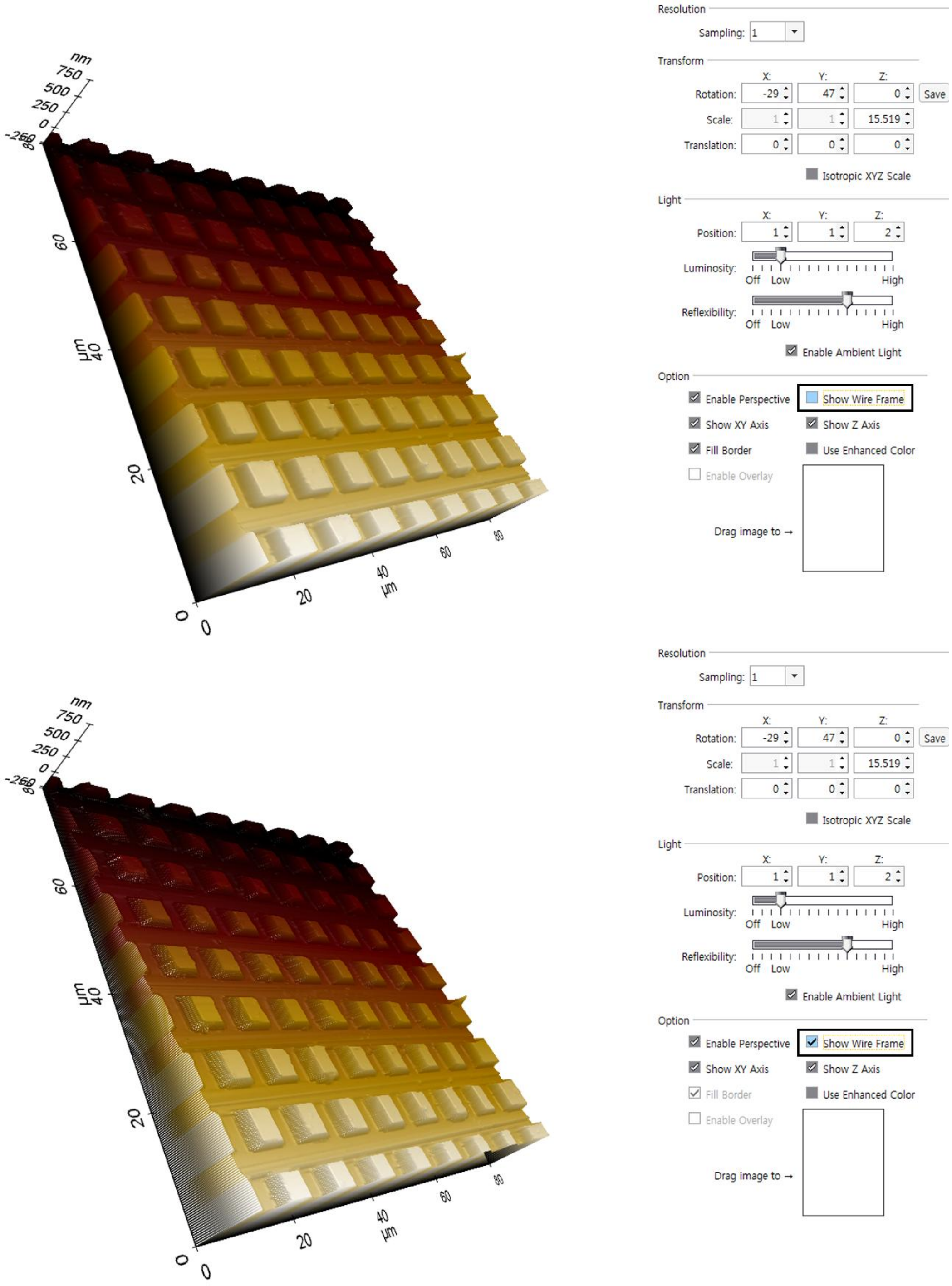
Resolution
Sampling: 1
Transform
X: Y: Z:
Rotation: -23 27 6 Save
Scale: 1 1 15.519
Translation: 0 0 0
■ Isotropic XYZ Scale
Light
X: Y: Z:
Position: 1 1 2
Luminosity: Off Low High
Reflexibility: Off Low High
☑ Enable Ambient Light
Option
☑ Enable Perspective ■ Show Wire Frame
☑ Show XY Axis ☑ Show Z Axis
☑ Fill Border ■ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Resolution
Sampling: 1
Transform
X: Y: Z:
Rotation: -23 27 6 Save
Scale: 1 1 15.519
Translation: 0 0 0
■ Isotropic XYZ Scale
Light
X: Y: Z:
Position: 1 1 2
Luminosity: Off Low High
Reflexibility: Off Low High
☑ Enable Ambient Light
Option
☐ Enable Perspective ■ Show Wire Frame
☑ Show XY Axis ☑ Show Z Axis
☑ Fill Border ■ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Figure 3-8-6. Enable Perspective

■ Show Wire Frame

Shows the wire frame display of the image. Figure 9-3-5 shows two images deselected (above) and selected (below) the 'Show Wire Frame' option in the 3D view.



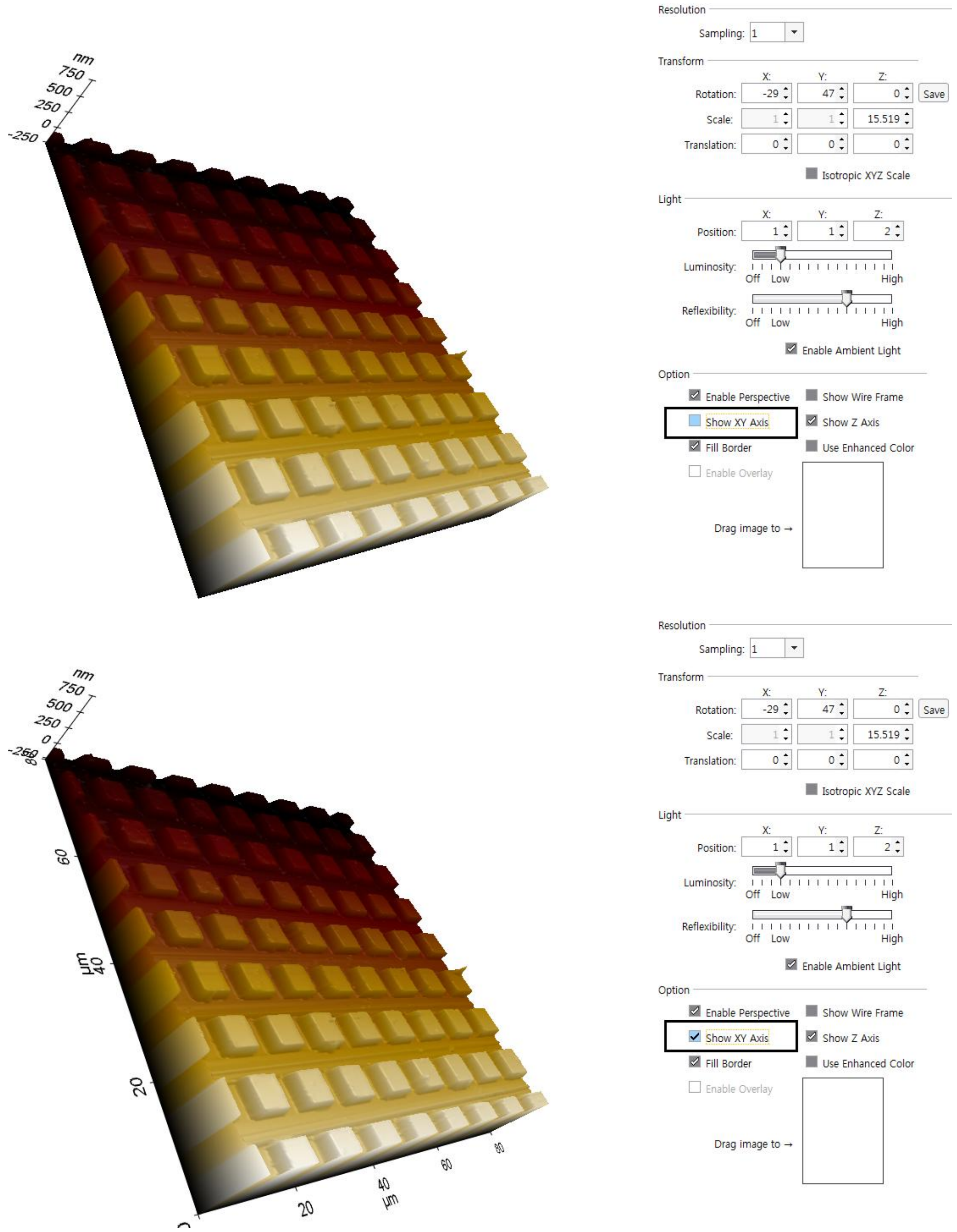
Resolution
Sampling: 1
Transform
X: Y: Z:
Rotation: -29 47 0 Save
Scale: 1 1 15.519
Translation: 0 0 0
■ Isotropic XYZ Scale
Light
X: Y: Z:
Position: 1 1 2
Luminosity: Off Low High
Reflexibility: Off Low High
☑ Enable Ambient Light
Option
☑ Enable Perspective ☐ Show Wire Frame
☑ Show XY Axis ☑ Show Z Axis
☑ Fill Border ■ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Resolution
Sampling: 1
Transform
X: Y: Z:
Rotation: -29 47 0 Save
Scale: 1 1 15.519
Translation: 0 0 0
■ Isotropic XYZ Scale
Light
X: Y: Z:
Position: 1 1 2
Luminosity: Off Low High
Reflexibility: Off Low High
☑ Enable Ambient Light
Option
☑ Enable Perspective ☑ Show Wire Frame
☑ Show XY Axis ☑ Show Z Axis
☑ Fill Border ■ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Figure 3-8-7. Show Wire Frame

■ Show XY Axis

Shows the X and Y axes. Figure 3-8-8 shows two images selected (above) and deselected (below) the ‘Show XY Axis’ option in the 3D view.



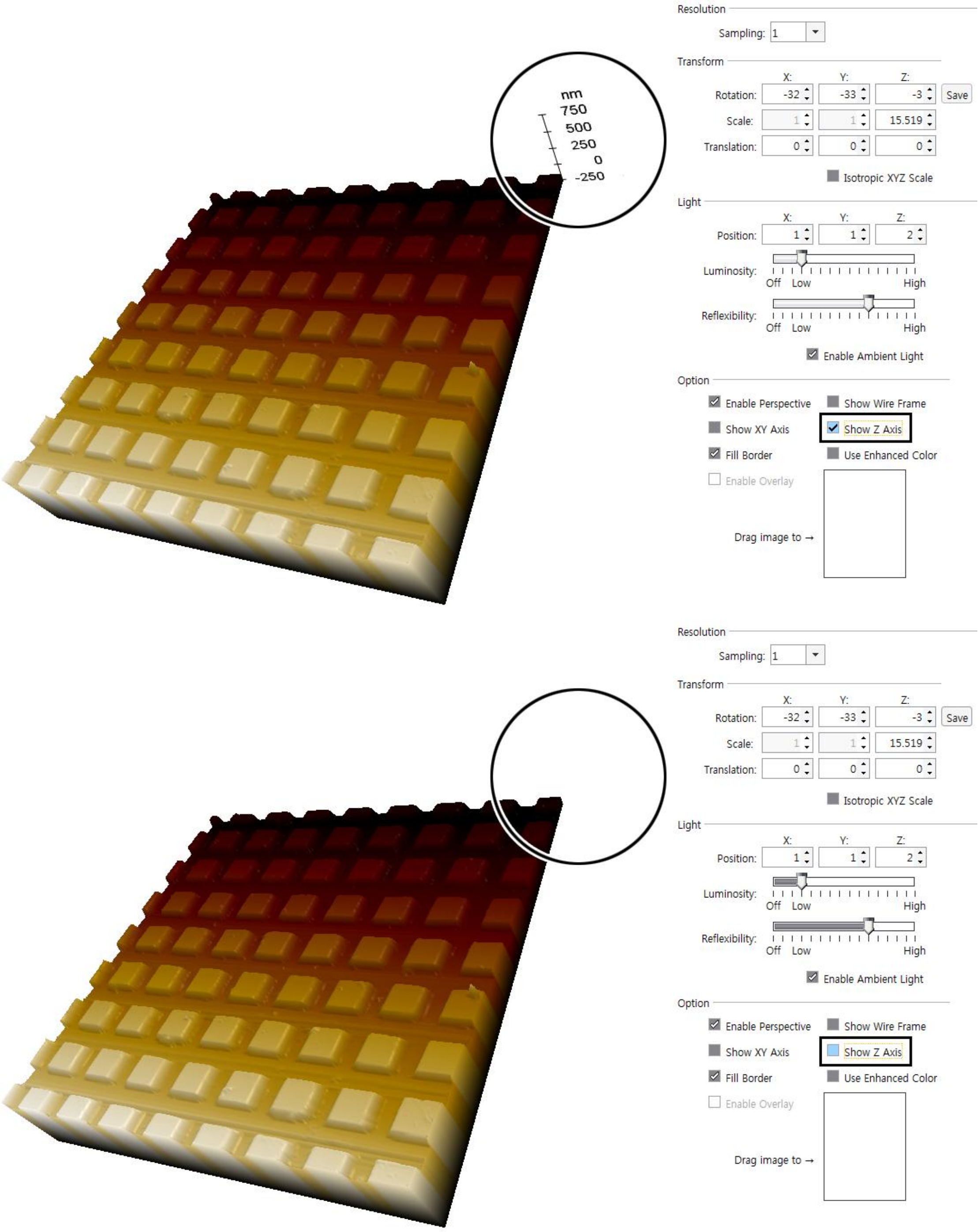
Resolution
Sampling: 1
Transform
Rotation: X: -29 Y: 47 Z: 0
Scale: X: 1 Y: 1 Z: 15.519
Translation: X: 0 Y: 0 Z: 0
☐ Isotropic XYZ Scale
Light
Position: X: 1 Y: 1 Z: 2
Luminosity:
Reflexibility:
☑ Enable Ambient Light
Option
☑ Enable Perspective
☐ Show Wire Frame
☐ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Resolution
Sampling: 1
Transform
Rotation: X: -29 Y: 47 Z: 0
Scale: X: 1 Y: 1 Z: 15.519
Translation: X: 0 Y: 0 Z: 0
☐ Isotropic XYZ Scale
Light
Position: X: 1 Y: 1 Z: 2
Luminosity:
Reflexibility:
☑ Enable Ambient Light
Option
☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay
Drag image to →

Figure 3-8-8. Show XY Axis

■ Show Z Axis

Shows the Z axis. Figure 3-8-9 shows two images selected (above) and deselected (below) the ‘Show Z Axis’ option in the 3D view.



Resolution

Sampling: 1

Transform

	X:	Y:	Z:	
Rotation:	-32	-33	-3	Save
Scale:	1	1	15.519	
Translation:	0	0	0	

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity: Off Low High

Reflexibility: Off Low High

☑ Enable Ambient Light

Option

☑ Enable Perspective
☐ Show Wire Frame
☐ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Drag image to →

Resolution

Sampling: 1

Transform

	X:	Y:	Z:	
Rotation:	-32	-33	-3	Save
Scale:	1	1	15.519	
Translation:	0	0	0	

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity: Off Low High

Reflexibility: Off Low High

☑ Enable Ambient Light

Option

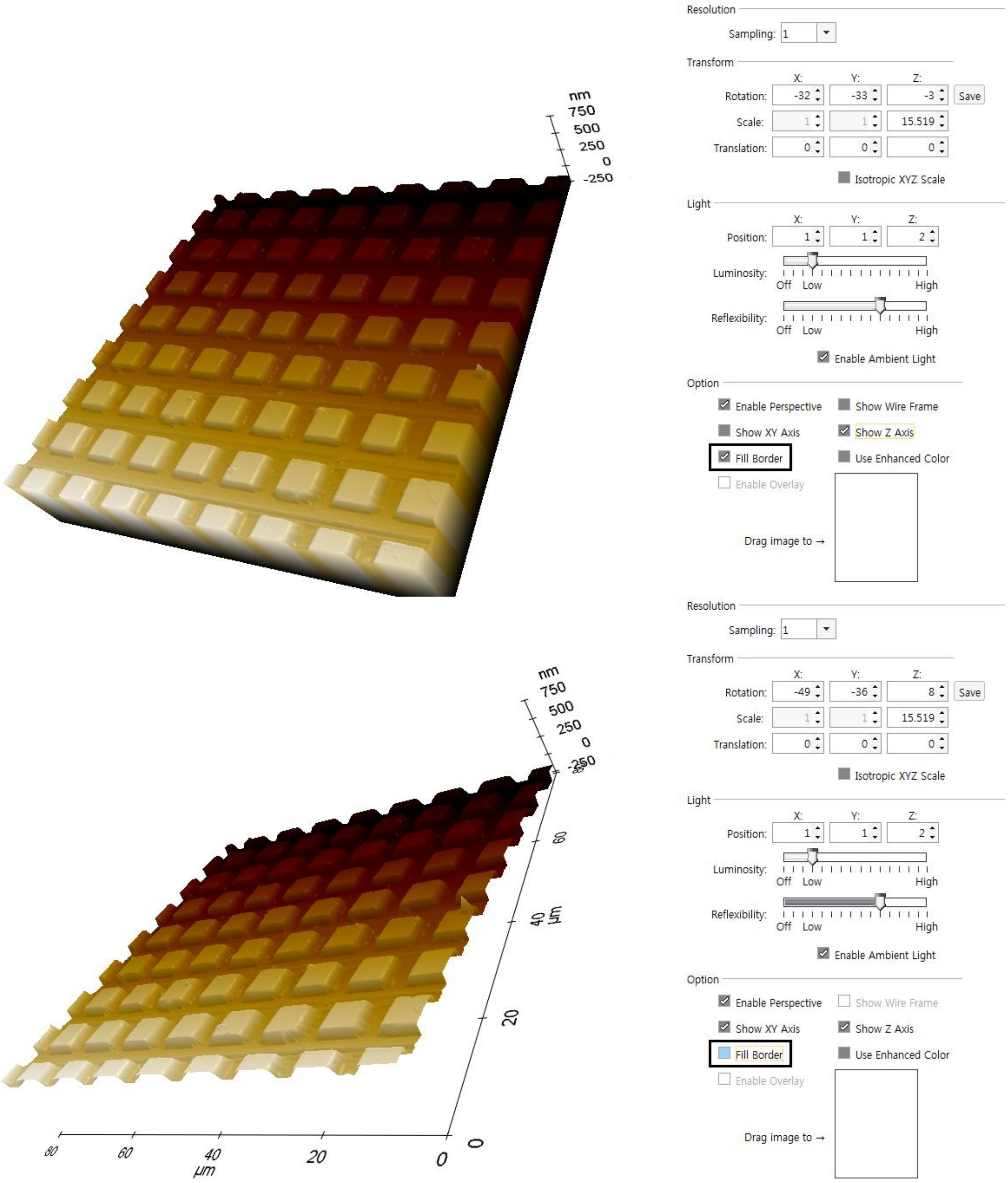
☑ Enable Perspective
☐ Show Wire Frame
☐ Show XY Axis
☐ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☐ Enable Overlay

Drag image to →

Figure 3-8-9. Show Z Axis

■ Fill Border

Fills the border of the image. Figure 3-8-10 shows two images selected (above) and deselected (below) the ‘Fill Border’ option in the 3D view.



Resolution
Sampling: 1

Transform
Rotation: X: -32 Y: -33 Z: -3
Scale: X: 1 Y: 1 Z: 15.519
Translation: X: 0 Y: 0 Z: 0
■ Isotropic XYZ Scale

Light
Position: X: 1 Y: 1 Z: 2
Luminosity:
Reflexibility:
☑ Enable Ambient Light

Option
☑ Enable Perspective
■ Show Wire Frame
■ Show XY Axis
☑ Show Z Axis
☑ Fill Border
■ Use Enhanced Color
☐ Enable Overlay

Resolution
Sampling: 1

Transform
Rotation: X: -49 Y: -36 Z: 8
Scale: X: 1 Y: 1 Z: 15.519
Translation: X: 0 Y: 0 Z: 0
■ Isotropic XYZ Scale

Light
Position: X: 1 Y: 1 Z: 2
Luminosity:
Reflexibility:
☑ Enable Ambient Light

Option
☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☐ Fill Border
■ Use Enhanced Color
☐ Enable Overlay

Figure 3-8-10. Fill Border

■ Use Enhanced Color

Changes the coloring scheme to Enhanced Color. Enhanced color uses the change of a pixel relative to its neighbors instead of its absolute value. Figure 3-8-11 shows an image with enhanced color on.

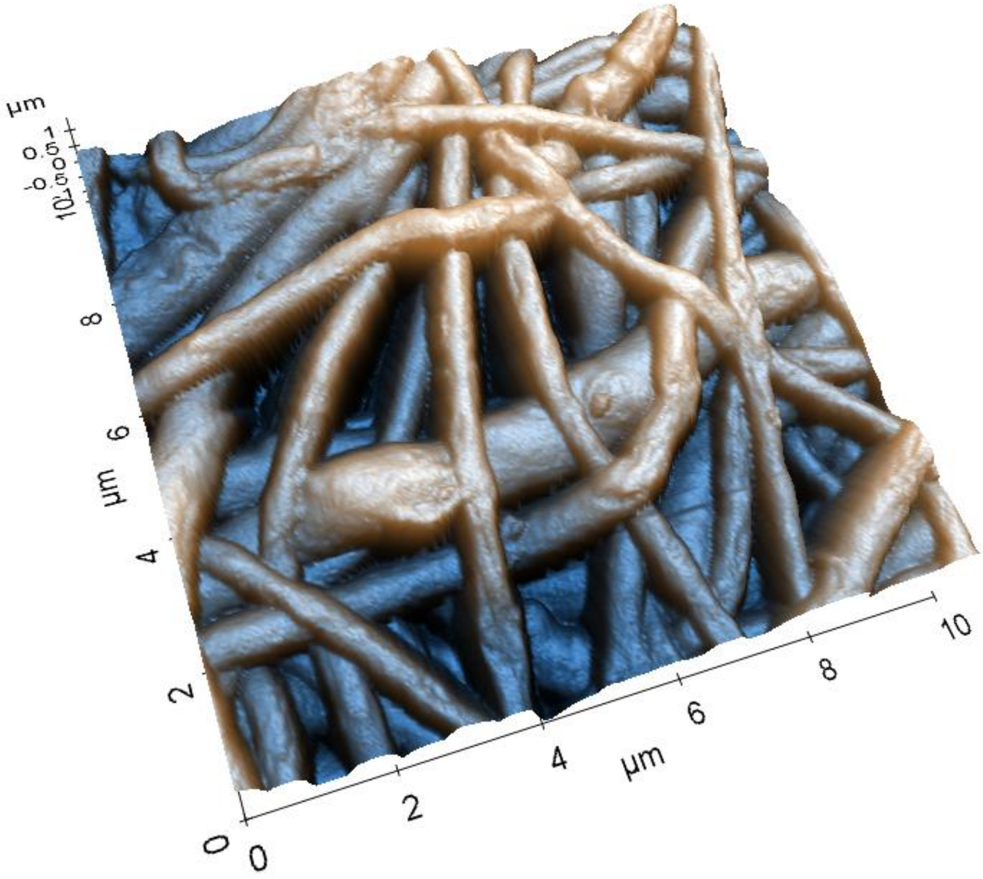
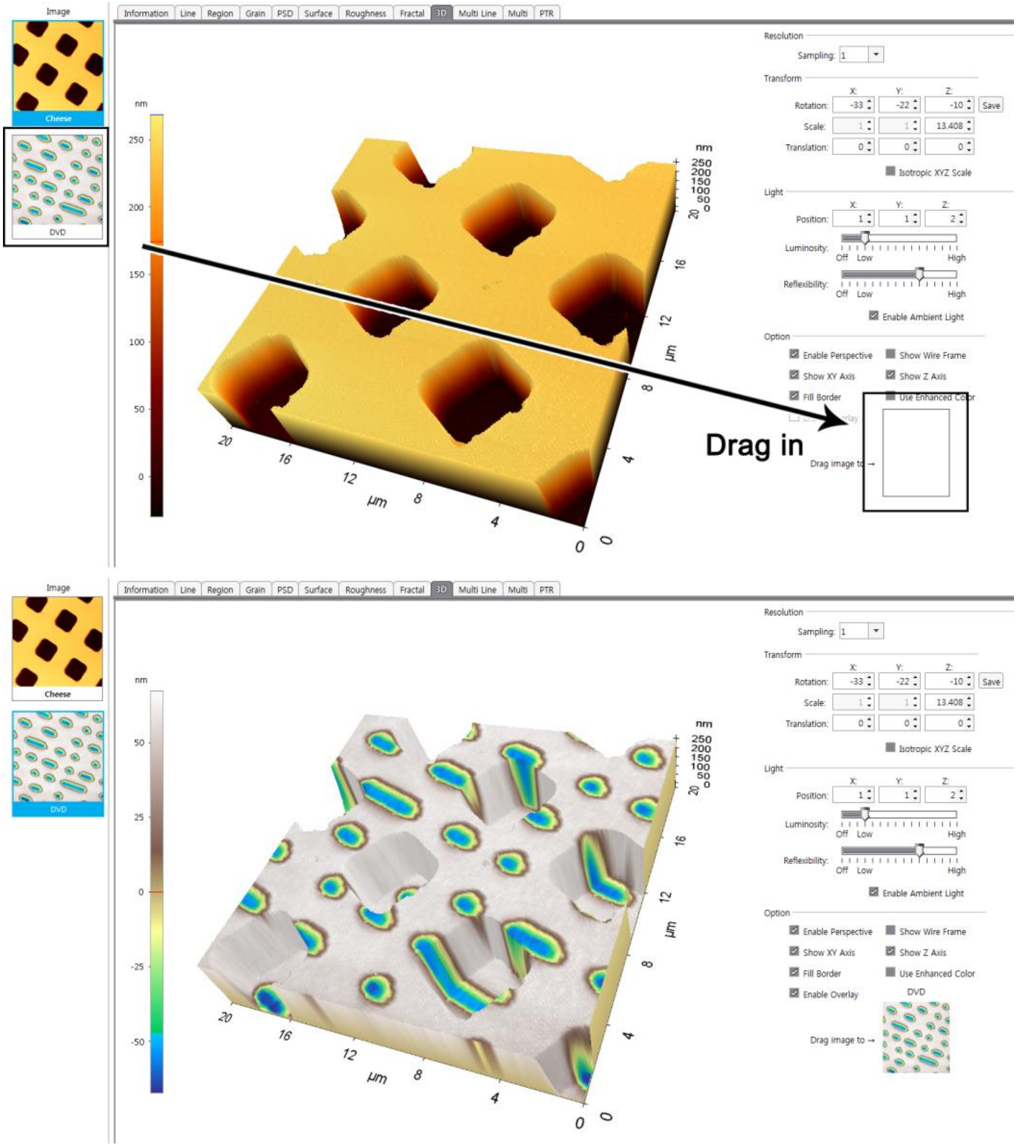


Figure 3-8-11. Use Enhanced Color

■ Enable Overlay

You can overlay another image on to the currently opened one. Click and drag an image from the navigator to the box indicated in Figure 3-8-12. This will change the coloring of the rendered image to reflect the overlaid image.

The images must be of matching sizes for this feature to work properly.

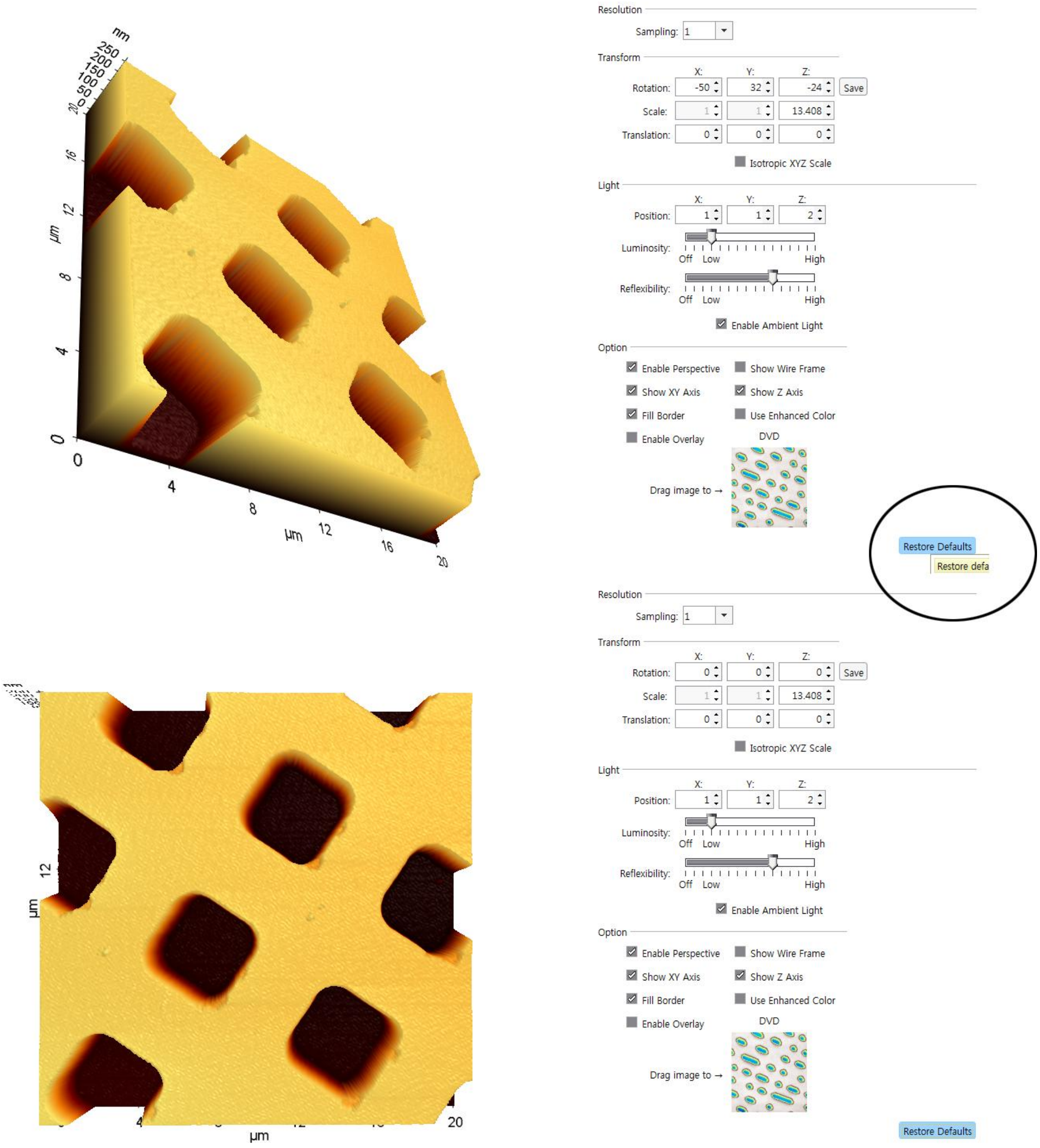


Sampling: 1
Rotation: X: -33 Y: -22 Z: -10 Save
Scale: 1 1 13.408
Translation: 0 0 0
☐ Isotropic XYZ Scale
Position: X: 1 Y: 1 Z: 2
Luminosity: Off Low High
Reflexibility: Off Low High
☑ Enable Ambient Light
☑ Enable Perspective
☐ Show Wire Frame
☑ Show XY Axis
☑ Show Z Axis
☑ Fill Border
☐ Use Enhanced Color
☑ Enable Overlay
DVD

Figure 3-8-12. Image Overlay

3-8-3-5. Restore Defaults

Restores parameter values to the original default settings provided with the software. Figure 3-8-13 shows two images before (above) and after (below) click the 'Restore Defaults' button in the 3D view.



Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	-50	32	-24
Scale:	1	1	13.408
Translation:	0	0	0

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity: Off Low High

Reflexibility: Off Low High

☑ Enable Ambient Light

Option

☑ Enable Perspective ☐ Show Wire Frame

☑ Show XY Axis ☑ Show Z Axis

☑ Fill Border ☐ Use Enhanced Color

☐ Enable Overlay

DVD

Drag image to →

Resolution

Sampling: 1

Transform

	X:	Y:	Z:
Rotation:	0	0	0
Scale:	1	1	13.408
Translation:	0	0	0

☐ Isotropic XYZ Scale

Light

	X:	Y:	Z:
Position:	1	1	2

Luminosity: Off Low High

Reflexibility: Off Low High

☑ Enable Ambient Light

Option

☑ Enable Perspective ☐ Show Wire Frame

☑ Show XY Axis ☑ Show Z Axis

☑ Fill Border ☐ Use Enhanced Color

☐ Enable Overlay

DVD

Drag image to →

Figure 3-8-13. Restore Defaults

3-9. Multi Line View

Multi-Line View can compare the same locations of different images simultaneously. Drag and drop the images to the Multi-Line View on the left side of the Image Navigation View to use them in the same way as the existing line analysis view. The images to be compared need to have the same scan size (X, Y) to be compared, and the Pixel Size is irrelevant. Toolbar on the top, Image to be compared in the middle, and Line profile and Cursor data on the bottom.

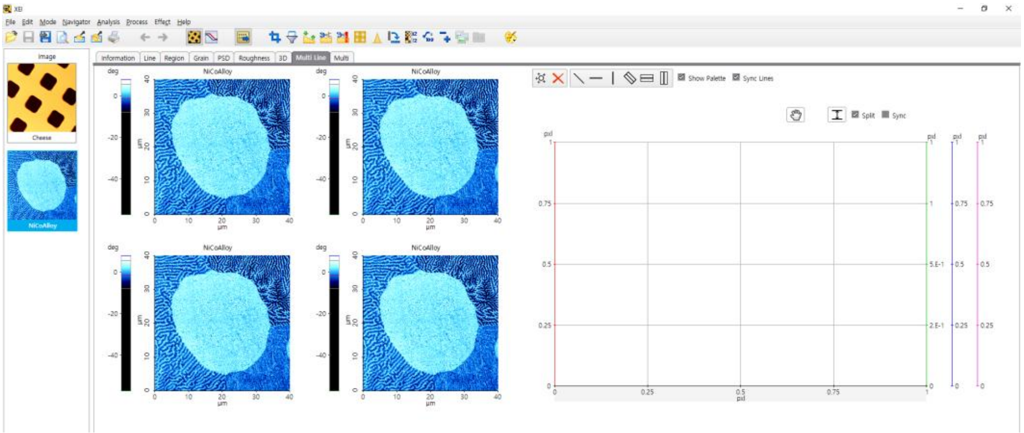

File Edit Mode Navigator Analysis Process Effect Help
Information Line Region Grain PSD Roughness 3D Multi Line Multi
Image
Cheese
NiCoAlloy
Show Palette
Sync Lines
Split
Sync

Figure 3-9. Layout of Multi Line View

The top Toolbar functions as follows :

1. Enhanced color applied on, off (applies to all images.)
2. Remove all images from the MultI-Line View.
3. Line tool. (The ability to create a line to compare over an image the same as the one in the line analysis view. Only one line is supported.Only one line is supported.)
4. You can show or hide the palettes next to each image in a screen break.

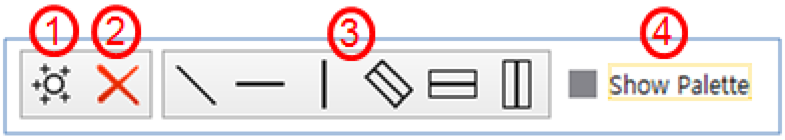
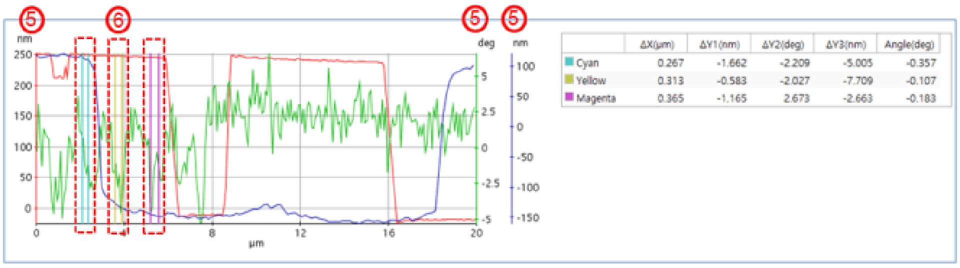


Figure 3-9-1.Top of Toolbar



	ΔX(µm)	ΔY1(nm)	ΔY2(deg)	ΔY3(nm)	Angle(deg)
Cyan	0.267	-1.662	-2.209	-5.005	-0.357
Yellow	0.313	-0.583	-2.027	-7.709	-0.107
Magenta	0.365	-1.165	2.673	-2.663	-0.183

5. Indicates the Y-axis of each image profile. It can be distinguished by color.
6. Unlike traditional line views, the cursor is displayed as Y axis lines in a multI-line view.

3-10. Multi View

In the Multi view, you can display and export or print out several images simultaneously. All images will include a file name and a palette panel indicating the contrast level and data range. Up to 6 images can be displayed at once for a multi image report. You can arrange several images in the Multi view using the following procedure:

1. Load multiple images into the Navigator view from your image directory.
2. Enable the Multi view.
3. Drag and drop images from the Navigator view to the Multi view.
4. Individually adjust the contrast level and range using the palette panel of the selected image.
5. Print and Export the multi images if desired

Figure 10-1 shows the procedure to generate multi images report in the Multi view.

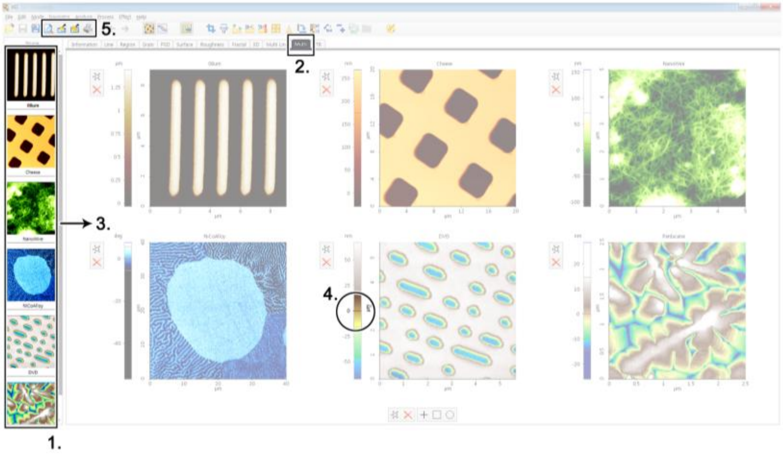


Figure 3-10. Procedure to generate multi images

3-10-1. Multi View Layout

To enable the Multi view, select the ‘Analysis>Multi’ in the Menu or click the Multi tab below the menu bar. You can display up to 6 images at once in the Multi view. When you want to eliminate displayed images from the Multi view, click the ‘Delete All ✕’ button that is positioned at the bottom of Multi View.

Figure 10-1-1 shows the Multi view which shows the initial screen, two images loaded view, four imaged loaded view and six images loaded view. You can see that as the images are added into the multi view, their size become smaller.

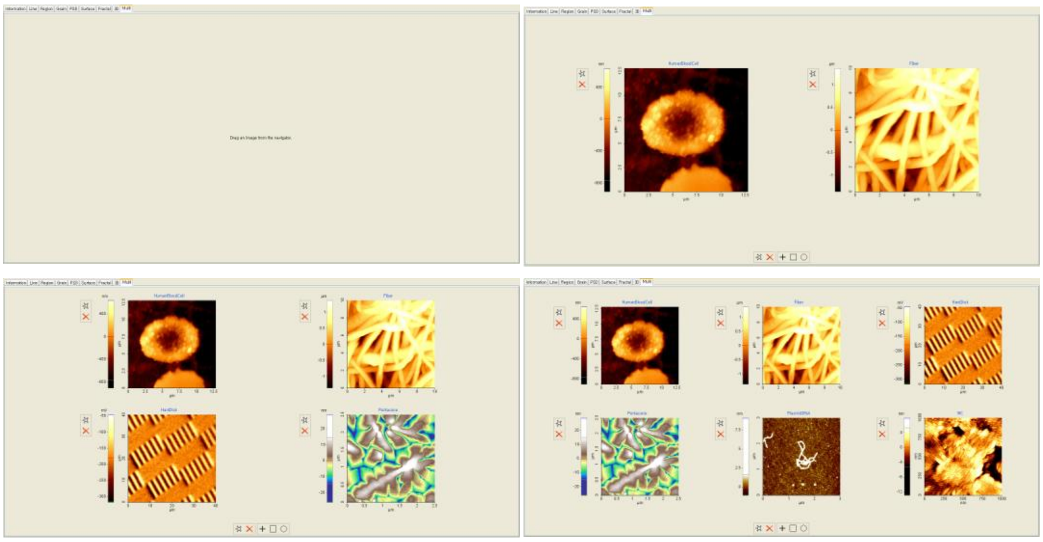


Figure 3-10-1. Multi View with different numbers of images loaded.

3-10-2. Bring Images into the Multi View

It is simple for you to bring images for Multi view. Only you have to do is to drag and drop images from the Navigator view into the Multi view (see Figure 10-1). One image can be loaded into the Multi view at one time. Up to 6 images can be loaded into the Multi view. The more images in the Multi view, the smaller size of the images. If you want to delete an image, click the ‘Delete Selected One ✕’ button on the left top of the individual image. If you want to delete all images, click the ‘Delete All ✕’ button on the bottom of Multi view.

3-10-3. Adjust the Contrast Level and Range

You can adjust the contrast range and level using the individual palette pane or ‘Use Enhanced Color☼’ for each image in the Multi view. How to adjust the contrast level or range is like that of other analysis views. Please refer Section 3-2. Palette Panel, for more information about changing the contrast range and level. Also, if you want to use enhanced color for all displayed images, click the ‘Use Enhanced Color All☼’ button on the bottom of the Multi view.

3-10-4. Compare Images

A figure such as a Cross ＋, Rectangle□, or Ellipse○, can be inserted in an image to help analyze the image in Multi View. On the bottom of the Multi View Image display panel, click the desired figure icon, and then click the desired location of the image and drag the figure to the appropriate size.

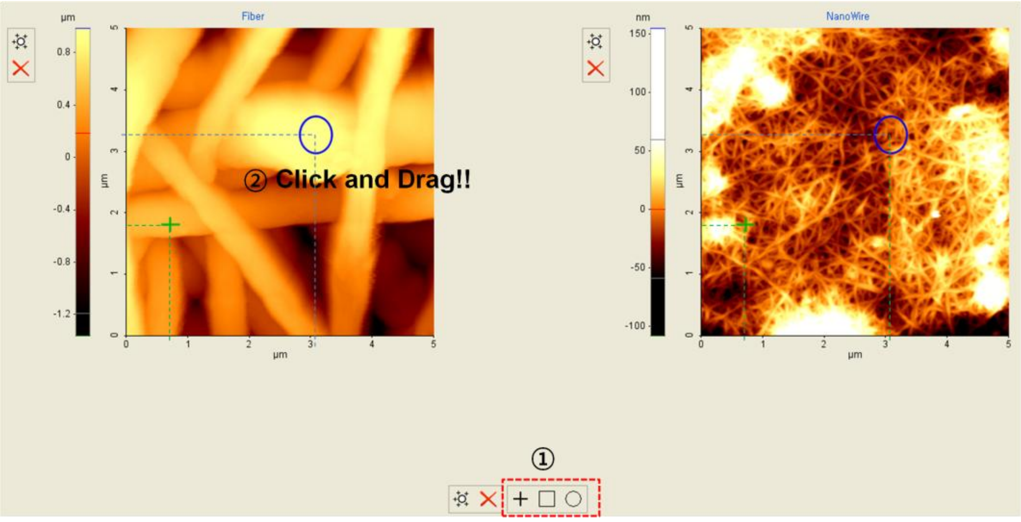


Figure 3-10-2. Compare Images using figures

■ Changing Shape

When the figure’s size needs adjustment, click the figure on image, then click the circular tracker and drag the figure to the appropriate size. When the figure’s angle needs adjustment, click the figure on image then click the green rotation handle and drag it to the appropriate direction.

■ Deleting

Select the desired figure to delete then press the [Delete] key on the keyboard.

■ Moving

Select the desired figure to move then click and drag.

Chapter 4. Crop

In the Crop process, you can select several parts of an image that you are interested in. The Crop processing tool allows you to eliminate “bad data” from an image file, thus making it easier to selectively process the true or reliable data in the same file.

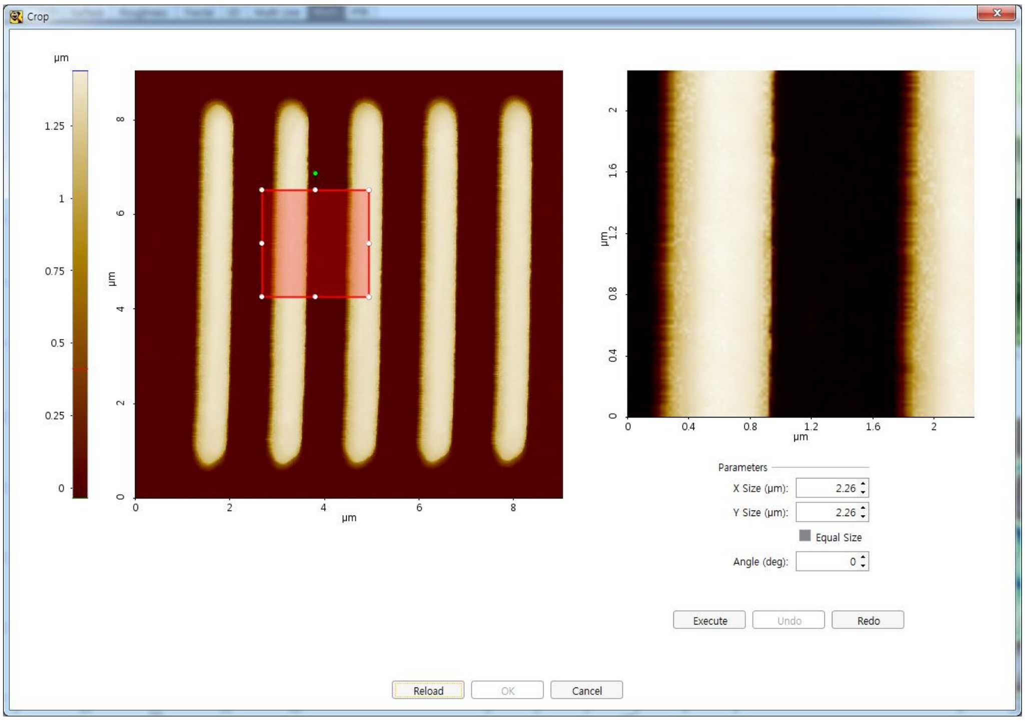
4-1. Crop Process Dialog

To open the Crop process dialog, select ‘Process>Crop’ in the Menu or click the ‘Crop’ icon in the Toolbar. As shown in Figure 11-1-1, the Crop process dialog is composed of two panels, the Image display panel and the Zoom Image display panel.

In the Image display panel, on the left side of the Crop Process dialog, you will see a red outlined rectangle. You can use this rectangle to select the region you want to crop. You can control the size of the region to be cropped and move it to the desired area. To magnify and reduce the selected region, drag and drop the cursor which is generated at any of the rectangle’s four corners. When the selected region needs to be rotated, click the green rotation handle and drag it to the desired rotation direction. Alternatively, you can enter numbers into the X/Y Size and angle fields.

Too move the rectangle, drag and drop the four-arrow cursor that appears when the cursor is positioned within it.

The Zoomed Image display panel to the right of the Image Display Panel shows the enlarged image of the selected region (red bordered box in the image). You can preview a newly cropped region in this Image display panel.



X Size (µm): 2.26

Y Size (µm): 2.26

☐ Equal Size

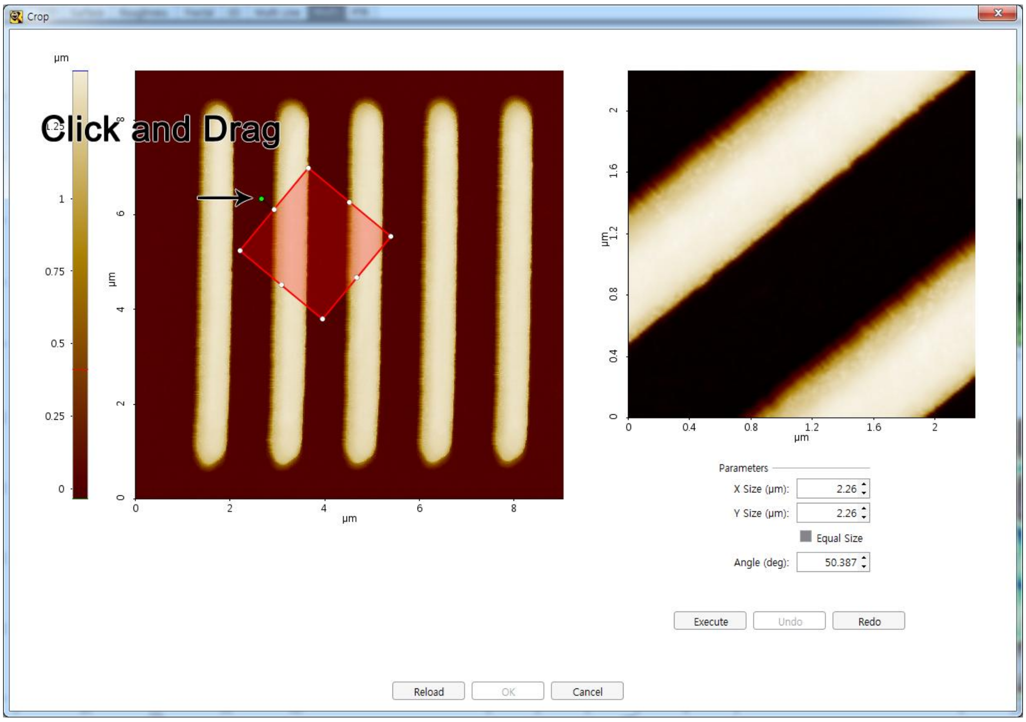
Angle (deg): 0

Figure 4-1-1. Crop process dialog

4-2. Crop an Image

In general, follow these steps to crop an image (see Figure 4-1-2):

1. Load an image file into the Analysis view from the Navigator view.
2. Select 'Process>Crop' or click the 'Crop' icon in the Toolbar to display the Crop process dialog.
3. Move the crop rectangle over the region to be cropped. Increase or decrease the size of the selected region and/or rotate the region as desired.
4. Once you are satisfied with the new area displayed in Zoom Image Display panel, click the 'Execute' and 'OK' button to create a newly cropped image in the Navigator view. The image will be generated with a default name of 'original name+cropped.tiff'. The image will be automatically displayed in the image display panel.
5. Save the cropped image as another file name for further image processing and analysis.



X Size (µm): 2.26

Y Size (µm): 2.26

Angle (deg): 50.387

Figure 4-1-2. Rotation

NOTE!

Cropping a local region of an image produces a new, processed image that can be saved to your hard disk or printed. Cropping an image does not affect the original data unless you press the Save button.

NOTE!

The Cropping procedure is only possible with image in the Image Display panel.

NOTE!

After rotation, the image is produced with a 2D Bi-linear interpolation algorithm.

- **X/Y Size**

Crops Rectangle’s X/Y size

- **Equal Size Check Box**

When this box is checked, X/Y Size input text-field will be one. Any input in this text-field will adjust both X/Y size.

- **Angle**

Rotates the Crop Rectangle. Crop rectangle will rotate counter-clockwise as the Angle increases in the positive direction. Values between 0 ~ 359.9° can be used in the input box.

- **Execute**

Crops the selected region and displays the new image in the Image Display panel.

- **Undo/Redo**

Undo/Redo previous action.

- **OK**

Saves cropped image in Image Display panel and closes Crop process dialog.

- **Cancel**

Cancels Crop process and closes Crop process dialog.

- **Reload**

Loads the original image in Crop process dialog.

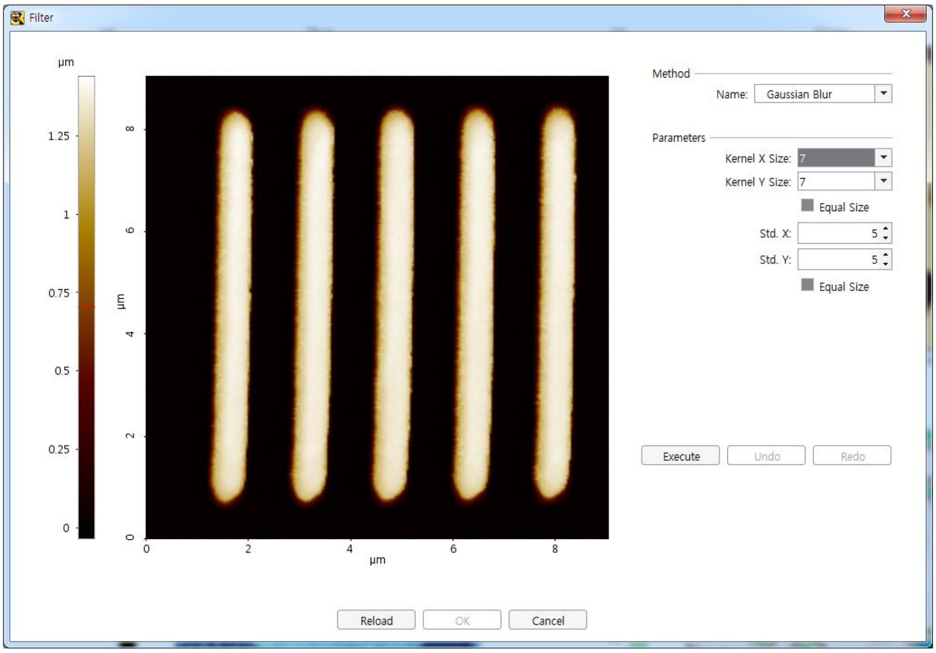
Chapter 5. Arithmetic Filter

In order to get better presentations and the best measurement results, the Arithmetic Filters are used to reduce various noisy features in the image. The Arithmetic Filter processing techniques in XEI are divided into four classes: Smoothing, Sharpening, Edge Enhancement, and Custom. This chapter describes the functions under each of these four classes.

Most of the filters use an *n x m* filtering kernel matrix, where *n* and *m* are odd integers so that there is a unique center of the kernel matrix. A filter places this kernel on a matrix of image pixels and uses the values of neighboring pixels to determine the new value for the center pixel.

5-1. Filter Process Dialog

To open the Filter process dialog, select the ‘Process>Filter’ menu or click the ‘Filter’ icon in the Toolbar. As shown in Figure 5-1, the Filter list box has four groups of filters. Those groups are ‘Smoothing’, ‘Sharpening’, ‘Edge Enhancement’, and ‘Custom’. Each filter group has several different types of filters. After you select the desired filter, set the kernel width and height. The meaning of each item in the Filter process dialog is described in detail below.



Method

Name: Gaussian Blur

Parameters

Kernel X Size: 7

Kernel Y Size: 7

☐ Equal Size

Std. X: 5

Std. Y: 5

☐ Equal Size

Figure 5-1. Filter process dialog

5-2. Smoothing

The smoothing processes reduce sharp edges and small variations. This effectively removes glitches and is useful therefore.

5-2-1 Mean

The Mean Filter’s characteristics are determined by the kernel height and width. A larger kernel size results in more blurring. Therefore, an excessive kernel size may produce unexpected effects on your data.

After the filter calculates the average of the pixels bounded in the kernel matrix, the average is set to be a new pixel value located at the center of the kernel. If you use a 3 by 5 kernel, for example, this filter places this kernel on an image and then calculates the average of 15 (= 3 × 5) image pixels bounded in the kernel to substitute each pixel value to the average.

5-2-2 Gaussian Blur

The Gaussian Blur Filter’s characteristics are determined by the kernel height and width, and the standard deviation. These can be varied with separate values for the X and Y dimensions. The pixel is set to the center value of the Gaussian curve that best fits the data points.

5-2-3 Median

The Median filter is an effective method for removing outliers or shot noise in an image. At first, the Median filter sorts the pixel data to find the median of the pixels bounded in the kernel matrix. Then, the median value is used to replace the value of a pixel that is over the acceptable range. If you use a 3 by 5 kernel, for example, this filter places this kernel on an image and calculates the median of 15 (= 3 × 5) image pixels bounded in the kernel. The calculated median is set as a new pixel value located at the center of the kernel.

The median filtering is more reliable than the average filtering in the cases such as the one in the following example:

When one value deviates extremely from the others and shifts the mean as in this set “1, 3, 4, 5, 9, **10**, 200, 14, 15, 17, 19”, the median is 10 and the average of this set is 297/11=27. If the out of range value is considered to be a bad data point and is then excluded from the calculation of the average, the more accurate average would now be closer to the median: (297-200)/10=9.7.

5-2-4 Low Pass

The Low Pass filter has a fixed kernel size of 3x3. The value “Weighting Factor” is represented in the kernel by n. The term $1/(n+2)^2$ can be factored out, so the kernel can also be represented as the product of $(n+2)^{-2}$ and the values in the following table.

$1/(n+2)^2$	$n/(n+2)^2$	$1/(n+2)^2$
$n/(n+2)^2$	$n^2/(n+2)^2$	$n/(n+2)^2$
$1/(n+2)^2$	$n/(n+2)^2$	$1/(n+2)^2$

1	n	1
n	n^2	n
1	n	1

5-2-5 Conservative

The Conservative filter removes extreme points. For a given pixel, the surrounding pixels are considered. The number of neighboring pixels is determined by the Kernel Size parameter.

If the pixel is the highest point within the kernel, its value is lowered to the next-highest value within the kernel. If it is the lowest point, then its value is increased to the second-lowest value within the kernel.

This operation is performed simultaneously on all of the pixels, with the effect of removing extreme points and maintaining the same median value.

5-3. Sharpening

Sharpening filters are used to make smaller features more noticeable. They increase the difference between neighboring pixels.

5-3-1 High Pass

High Pass is the first of the Sharpening filters. Its kernel size is variable but must be a square. The center pixel is multiplied by the square of the length of the square; all other pixels are given a weight of -1.

5-3-2 Laplacian of Gaussian

The Laplacian of Gaussian allows the user to perform both the Gaussian Blur, then the Laplacian Edge Enhancement on an image in one go. However, the X and Y kernel size and standard deviation values for the Gaussian blur are equal.

5-4. Edge Enhancement

Edge Enhancement function create images of the gradient between pixels. This allows the user to better distinguish edges of sample features.

5-4-1 Roberts

The Roberts filter can be applied in the four cardinal directions, denoted as “East,” “West,” “North,” and “South.” This filter sets the value of each point as the difference between the point and the point adjacent to it in the direction of application. For example, if one chose East, pixel (5,5,10) with a neighbor (4,5,8) would now have the value of (5,5,11-8). One can also say that the value of a pixel is set to be the sum of itself and its neighbors when they are multiplied by the following kernel (for the East direction):

0	0	0
-1	1	0
0	0	0

5-4-2 Sobel

The Sobel filter differs from the Roberts filter in that it weighs the neighboring pixels differently. Instead of finding the difference between the actual pixel and one neighbor, it finds the difference between pixels on opposing sides:

-1	0	1
-2	0	2
-1	0	1

5-4-3 Laplacian

A Laplacian filter is different from a Roberts or Sobel filter in that it finds the differential between a pixel and its neighbors in the four cardinal directions. Its kernel is as follows:

0	-1	0
-1	4	-1
0	-1	0

5-5. Custom

Custom filters can be applied to images. User-defined kernels are limited to a size of 3x3.

5-5-1 3x3 Convolution

The user may decide what weight is given to each pixel in the kernel which has a 3x3 size.

<u>NOTE!</u>

Applying the Arithmetic Filter process to an image produces a new, processed image that can be saved or printed as a new file. Filtering does not change the original data unless you click the Save button.

Chapter 6. Flatten

The Flattening processing tool removes artifacts that result from the slope and curvature produced by the scanning process. These artifacts can affect the height data of the image and make the image difficult to interpret.

Slope results from the fact that the sample surface will always be tilted to some extent relative to the plane of the XY scanner. Also slope can be caused by the XY scanner not moving in a plane perpendicular to the Z scanning direction. Curvature is mainly caused by the out-of-plane motion of the XY scanner while scanning the sample.

During the flattening process, XEI first obtains the ‘fitting curve’ for each scan lines in the image. ‘Fitting curve’ is an estimation of the ‘slope’ or ‘curvature’ introduced in the image. Then, from each scan line in the image, XEI ‘subtracts’ the corresponding fitting curve. As a result, the ‘offset’ between the each point on the scan line and the each corresponding point on the fitting curve is obtained. This ‘offset’ is assigned as a new data for the each point. Figure 6-1 shows short example showing flattening applied to a single line.

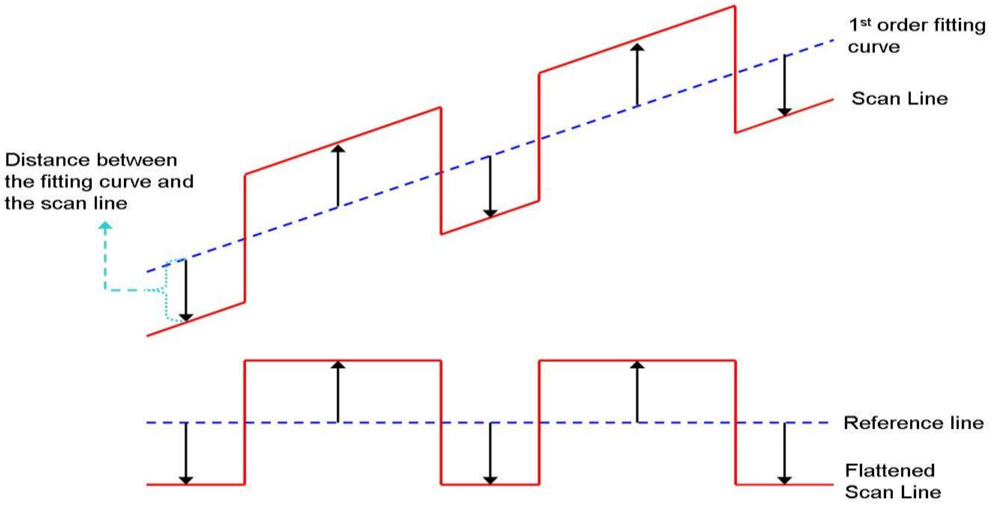
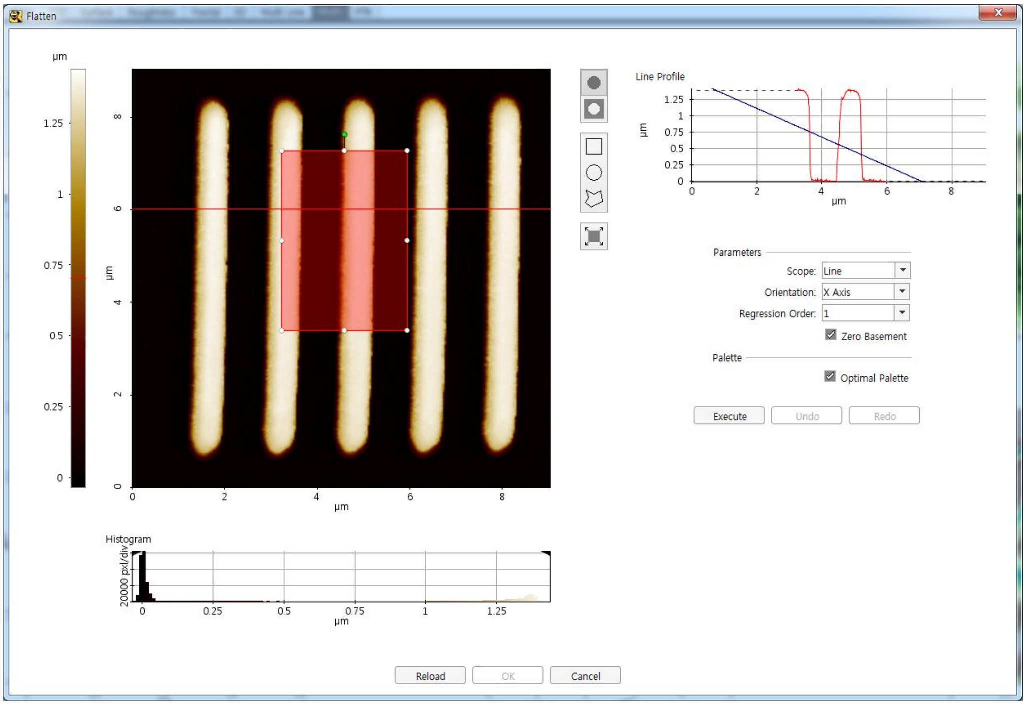


Figure 6-1. 1D example of the flattening

6-1. Flatten Process Dialog

To display the Flatten process dialog, select ‘Process>Flatten’ in the Menu or click the ‘Flatten’ icon in the Toolbar. Figure 6-1-1 shows the Flatten process dialog which is composed of several parts. The Image display panel shows the original image and the processed image. At the upper-right side of the Image display panel is the Region selection toolbar composed of several buttons that include and exclude regions for flattening. At the lower-right side of the Image display panel are several parameters used to flatten an image. At the right side of the Image display panel is the Line Profile panel which displays the average height profile and the fitting curve for flattening an image. Below the Image display panel is the Histogram of the entire image for height restriction.



Scope: Line
Orientation: X Axis
Regression Order: 1
☑ Zero Basement
☑ Optimal Palette

Figure 6-1-1. Flatten process dialog

The Flatten process dialog provides some parameters that are useful for applying different flattening techniques. These are described further in the following section.

6-1-1. Image Display Panel

The Image display panel displays an original image and a flattened image. After adding regions, it also shows the regions as partially transparent shapes. If the Scope is set to 'Line', you will see a movable line locator in the Image Panel.

6-1-2. Region Selection Toolbar

The Region selection toolbar is composed of several buttons that include or exclude any regions in an image. Data points that are in the included regions are collected to calculate fitting curves and data points that are in the excluded regions are not used. The function of the region selection toolbar is summarized below.

- Inclusion - Sets selected regions to be included in the fitting curve
- Exclusion - Sets selected regions to be excluded from the fitting curve
- Rectangle - Selects a rectangular region
- Ellipse - Selects an elliptical region
- Polygon - Selects a polygonal region
- Entire region - Selects entire image

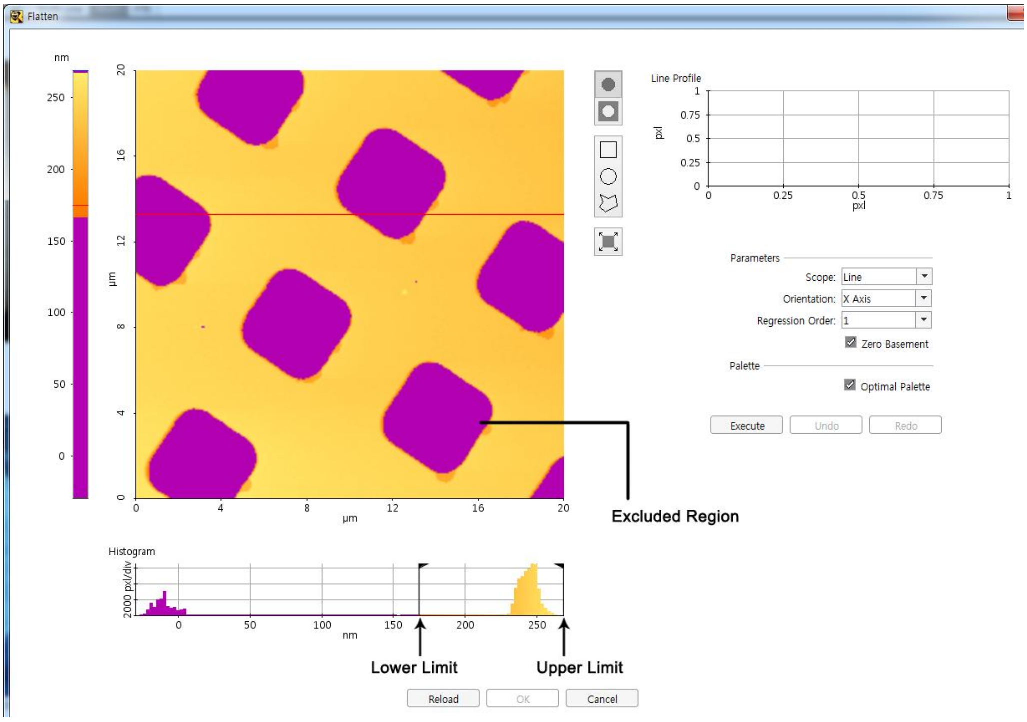
■ To select a region type

To specify the features of the image to be included and excluded, select the region type (rectangle, ellipse, and polygon) and create the regions in the image that will be included or excluded areas of the image. The shape and size of the selected region can be adjusted by dragging each small round tracker which is generated when you click any location within the selected region.

Especially, in the case of the polygonal region, after selecting the polygon in the Region selection toolbar, click the cursor onto any place where you want to create the region and then, move and click once onto each point of the polygon. Changing the shape and size of the polygon region is performed by the same steps described in the Region Analysis section. In addition, to move the selected region you have already created, click the cursor in the selected region and drag the four-way arrow to reposition the region. After selecting and grouping regions to be included and excluded for flattening, the Line profile automatically calculates and displays the average height profile and the fitting curve.

6-1-3. Histogram Panel

As shown in Figure 6-1-2, the Histogram panel shows a bar graph showing the distribution of heights in the image. The x axis is the height of data points in the sample surface, and the y axis is the number of data points. The Histogram panel has a pair of height restriction markers that restrict height range of data. One marker that has a flag directing right represents a lower limit and the other marker that has a flag directing left represents an upper limit. You can drag these markers to determine the height range to be included. Data points that have heights in the restricted height range are included and that have heights out of the range are excluded when calculating fitting curves. Included heights are painted with the original palette and excluded heights are painted with violet in the Palette panel, Image display panel, and the Histogram panel.



Scope: Line

Orientation: X Axis

Regression Order: 1

☑ Zero Basement

☑ Optimal Palette

Figure 6-1-2. Height restriction markers in the histogram

6-1-4. Flattening Parameters

■ Scope

The Scope is a range for collecting data and calculating a fitting curve that will be used for flattening. The flattening process collects data in the scope to calculate a fitting curve. The calculated fitting curve will be subtracted from the original image during flattening. There are two scopes: Whole and Line.

If the ‘Whole’ scope is selected, included data are used to calculate an average line profile and its fitting curve. The average line profile shows overall features of the image and the fitting curve calculated from this average line profile shows an overall distortion of the image. The fitting curve is subtracted from the entire image. The Line Profile panel displays this average line profile and its fitting curve.

If the ‘Line’ scope is selected, included data are used only to calculate a fitting curve for each line profile. Each fitting curve is subtracted from each line profile. In this scope, a movable line locator appears on the Image display so that you can examine a line profile at the locator and see its fitting curve in the Line Profile panel. You can move this line locator easily by dragging it. Whenever you move the line locator, the line profile is automatically updated.

The 'Difference' scope takes the first derivative of the data, and uses this data for flattening. This helps to reduce deviations in height offset between adjacent lines.

■ Orientation

Orientation indicates the direction of the flattening process. If the ‘Horizontal’ orientation is selected, a horizontal slope and curvature will be removed. The same manner is applied for the ‘Vertical’ orientation.

In the ‘Whole’ scope, all line profiles of the selected orientation are averaged to calculate a fitting curve for an overall image. In the ‘Line’ scope, a movable line locator that lies in the selected orientation appears on the Image display panel. You can examine a line profile of the selected orientation as well as the corresponding fitting curve.

In general, you may need to flatten an image both in the horizontal and vertical directions to eliminate all directional slope and curvature components from the image.

Regression Order

The Regression order is the order of a regression polynomial selected for flattening. A fitting curve is calculated by polynomial regression. There are four possible regression orders: the zeroth, first, second, and the third. Each is denoted by 0, 1, 2, and 3. The zeroth order subtracts a constant from each line. The first order is used to remove a slope caused by a slanted scan plane relative to the sample plane. The second order is used to remove curvature caused by a bending motion of the XY scanner. The third order is for eliminating more complex distortions, but is rarely used.

Zero Basement

The Zero Basement parameter will add a constant value to every pixel so that the average value of the data is 0.

6-1-4. Line Profile Panel

The Line profile panel displays both the line profile (red curve) and the fitting curve (blue curve) for flattening this Line Profile panel. In the Whole scope, this profile is an overall line profile. In the Line scope, this profile is a line profile located by a line locator in the Image display panel. The red curve is the line profile only for the included data and dashed lines are displayed for excluded data. A blue curve displayed simultaneously with the red curve is a fitting curve for flattening. The fitting curve is calculated only with the included data. Figure 6-1-3 shows two images before (left) and after (right) flattening. You can confirm whether the flattening process is executed well to see that the fitting curve becomes “flat” after executing the process.

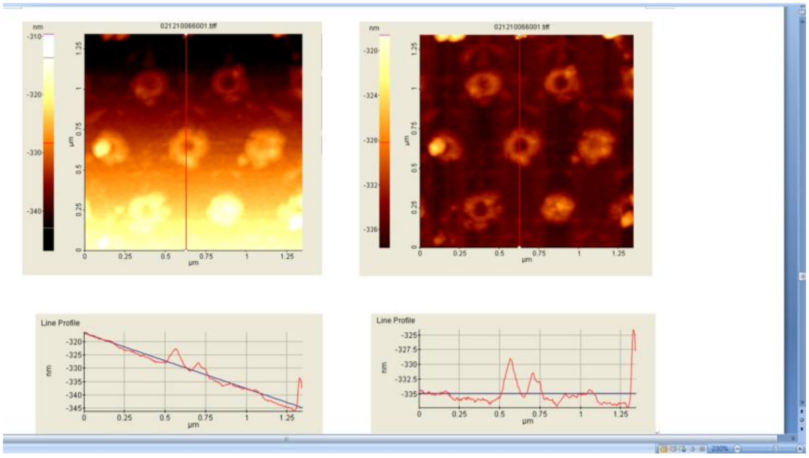


Figure 6-1-3. Line profiles with fitting curves

6-2. Flatten an Image

Flattening is carried out through three processes. As soon as you open the Flatten process dialog, the software determines automatically the average curvature and slope of the image. Then, the software calculates a set of values that will compensate for the slope and curvature. Finally, you can have the software subtract the compensating values from the data points of the image.

You can follow this general steps for eliminating the slope and curvature of the image (see Figure 6-2):

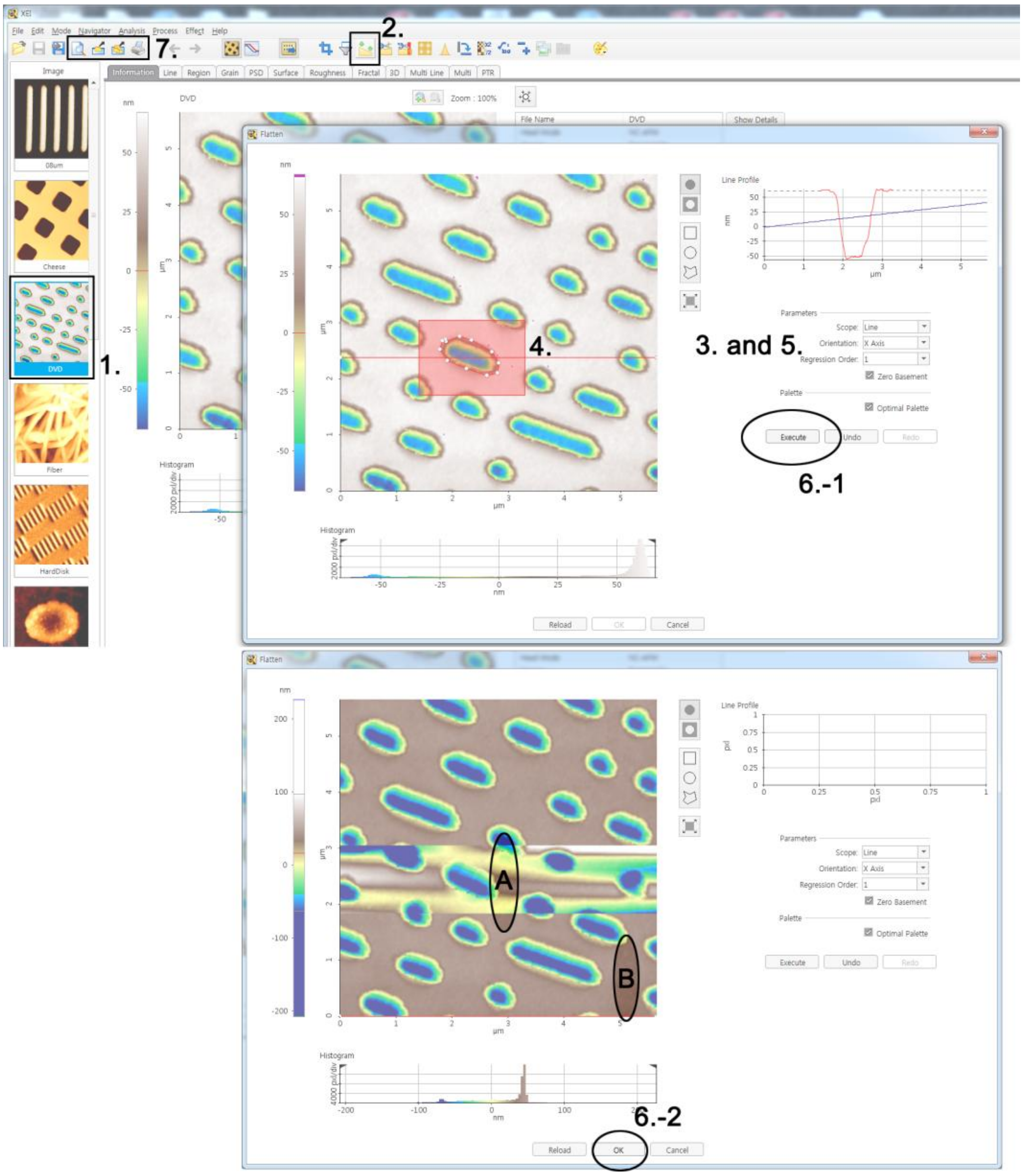
1. Load the image you want to flatten into the Image display panel.
2. Select the Flatten menu or click the ‘Flatten’ icon to open the Flatten process dialog.
3. Select the Orientation for flattening, appropriate Scope.
4. Create regions of the image to be included and/or excluded from the calculation of the fitting curve. If necessary, restricts heights using height restriction makers in the Histogram panel.
5. Select the Regression order, which determines the type of slope or curvature to be eliminated.
6. Adjust some parameters to get desirable fitting curves and click the ‘Execute’ button if desired.
7. Save, export or print this image for further processing and analysis if desired.

It may be necessary to flatten an image in both the horizontal and vertical directions and also to execute the image flattening using more than one regression order in subsequent steps to remove both curvature and slope from an image.

NOTE!

Applying the Flattening process to an image produces a new, processed image that can be saved or printed as a new file. Flattening does not change the original data unless you click the Save button..

Figure 6-2 shows the summarized procedure to flatten the selected region in an image.



Parameters
Scope: Line
Orientation: X Axis
Regression Order: 1
☑ Zero Basement

Palette
☑ Optimal Palette

Figure 6-2. Procedure to flatten an image

Chapter 7. Deglitch

Deglitching is used to remove glitches from an image. A glitch is a small artifact in an image that does not represent the true surface topography. You can apply deglitching in both the horizontal and vertical directions.

Usually, glitches occur in the fast scan direction and appear as discontinuities or streaks in an image. Long glitches are sometimes caused by loose, unidentified particles on the surface that are dragged by the tip.

7-1. Deglitch Process Dialog

To open the Deglitch process dialog, select ‘Process>Deglitch’ in the Menu or click the ‘Deglitch’ icon in the Toolbar.

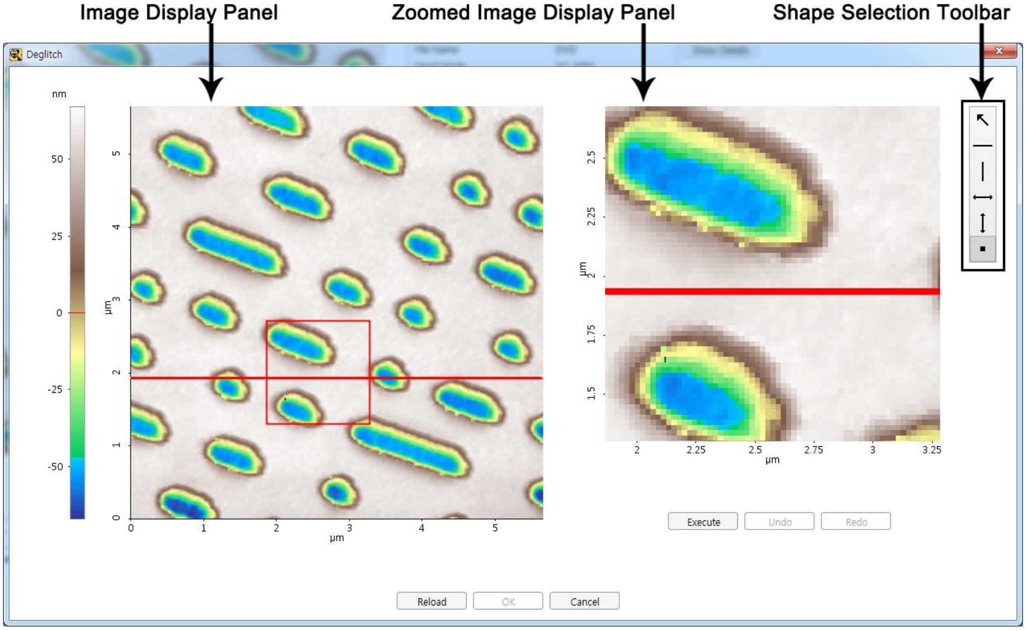


Image Display Panel

Zoomed Image Display Panel

Shape Selection Toolbar

Figure 7-1-1. Deglitch process dialog

As shown in Figure 7-1-1, the Deglitch process dialog is composed of two main parts; Image display panel and Zoomed Image display panel. At the left side, the Image display panel shows the original or processed image. At the right side, there is the Zoomed Image display panel with a Shape selection toolbar that is used to perform the glitch removal. Horizontal and vertical lines may be used as well as points.

7-1-1. Image Display Panel

The Image display panel displays an original image and a deglitched image. There is a red outlined square that indicates a zoomed region. After adding lines or points for deglitching, they will be displayed as dashed lines (Figure 7-1-1).

7-1-2. Zoomed Image Display Panel

The Zoomed Image display panel displays the magnified image of the zooming square. The Zoomed Image display panel magnifies the image dynamically while the zooming square is moved. Figure 7-1-2 shows that some glitch (see white outlined circles) disappear in the image after deglitching it in the Deglitch process dialog.

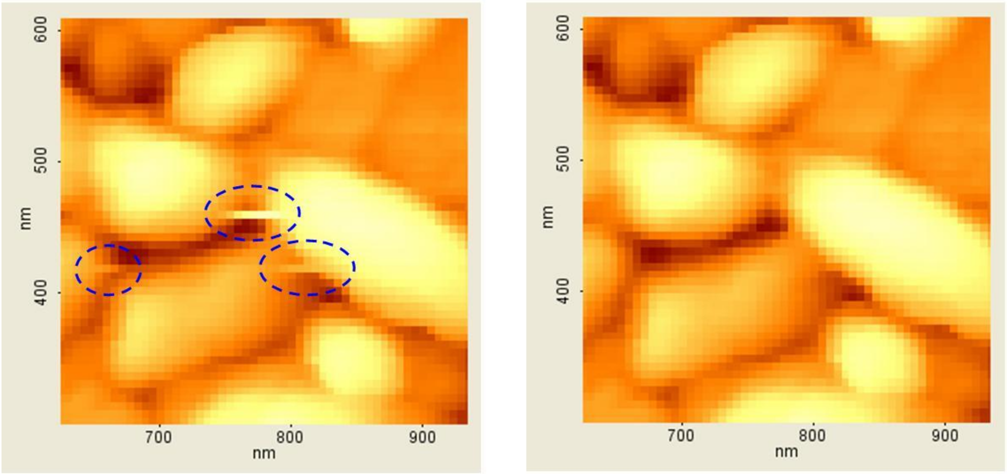


Figure 7-1-2. Deglitched image

7-1-3. Shape Selection Toolbar ↙ | — ▪

The Shape selection toolbar has both a horizontal and a vertical line button and a point. If you select the horizontal or vertical line button, you can generate related lines in the Zoomed Image display panel pixel by pixel (dashed line as shown in Figure 7-1-1). The drawn lines are also displayed in the Image display panel. You can deglitch the lines or points that you selected by clicking the ‘Execute’ button.

7-2. Deglitch an Image

Deglitching is processed according to the rule that glitches are replaced by the lines of pixels through the average filter. For deglitching a horizontal line, every pixel in the line you select is substituted by the average of its top neighbor and its bottom neighbor. A line can be selected that extends across the entire image. For deglitching a vertical line, every pixel in the line you select is substituted by the average of its left and its right neighbor. Points are deglitched by getting the average of four neighbor pixels, one from each cardinal direction.

The procedure to deglitch an image is as follows (see Figure 7-2-1):

1. Load the image you want to deglitch into the Analysis view.
2. Select ‘Process>Deglitch’ in the Menu or click the ‘Deglitch’ icon in the toolbar to display the Deglitch process dialog.
3. Move the zooming square to where you want to deglitch in the image.
4. Decide what shape (line or point) to deglitch with. Place the cursor in the Zoomed Image display panel and click the cursor onto glitches.
5. Preview the changes in the Image display panel after clicking the ‘Execute’ button executing the deglitching process. Update the deglitched image into the Analysis view if desired.
6. Save, export, or print this processed image for further analysis and processing

NOTE!

Applying the Deglitching process to an image produces a new, processed image that can be saved or printed as a new file. Glitch removal does not change the original data unless you click the Save button.

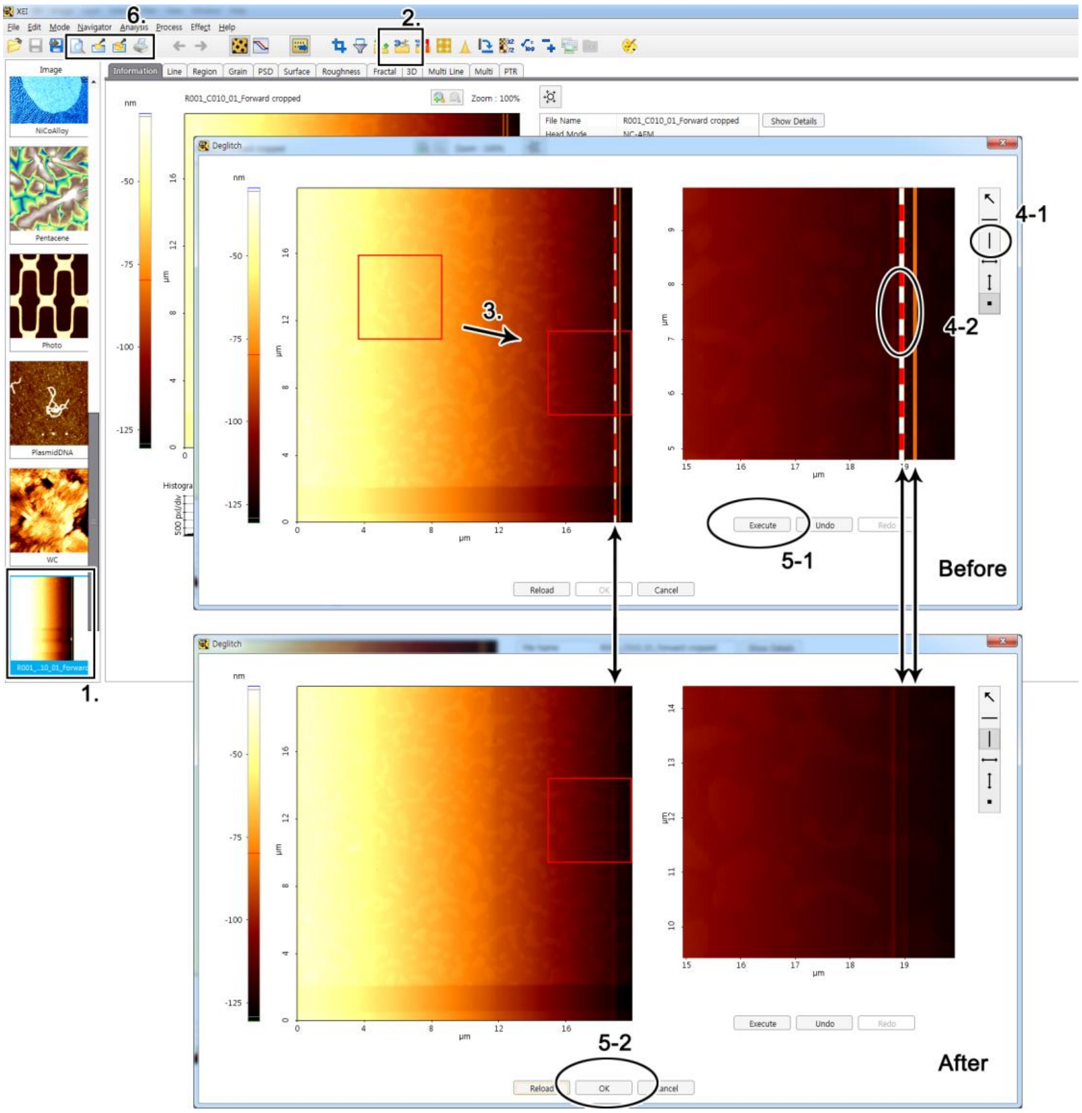


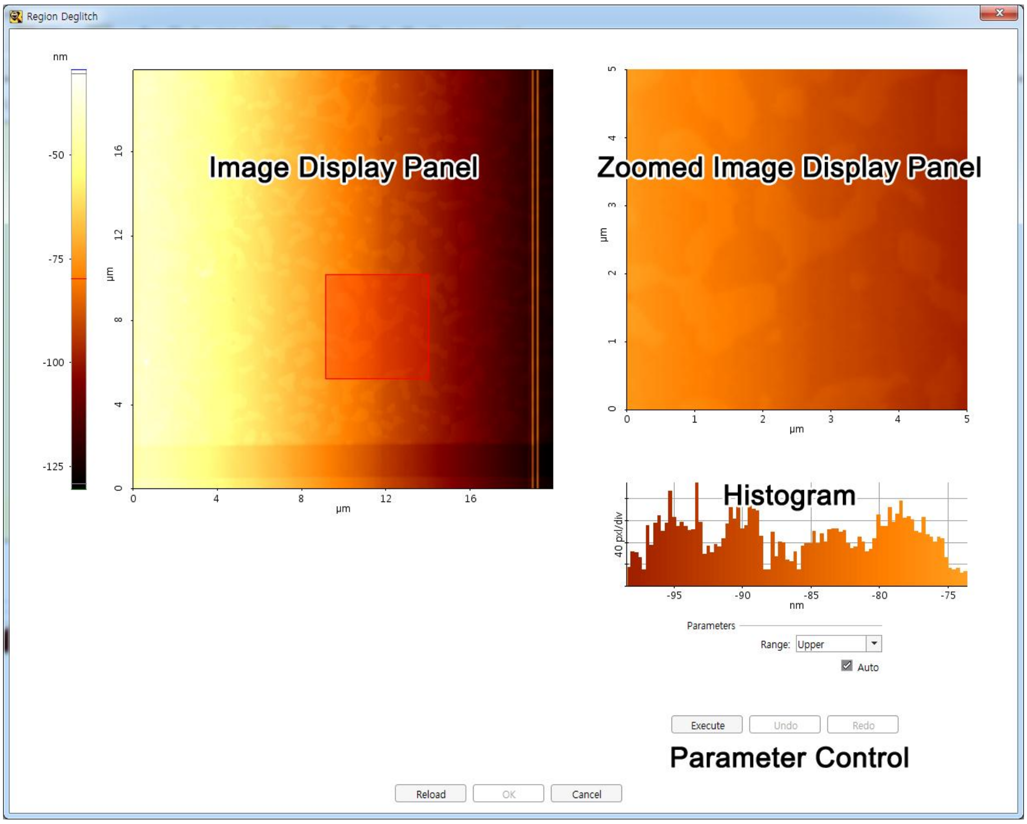
Figure 7-2-1. Procedure to deglitch an image

Chapter 8. Region Deglitch

Region Deglitching is used to remove glitches from an image. A glitch is a small artifact in an image that does not represent the true surface topography. The Region Deglitch process allows you to remove glitches in the horizontal and vertical directions. The Region Deglitch process allows removal of artifacts in larger areas, or removal of multiple artifacts in one go.

8-1. Region Deglitch Process Dialog

To open the Region Deglitch process dialog, select 'Process>Region Deglitch' in the Menu or click the 'Region Deglitch' icon in the Toolbar.



Range: Upper

☑ Auto

Figure 8-1-1. Region Deglitch process dialog

As shown in Figure 8-1-1, the Region Deglitch process dialog is composed of four main parts; Image display panel, Zoomed Image display panel, Histogram, and Parameter Control. At the left side, the Image display panel shows the whole image. At the right side, there is the Zoomed Image display panel that shows the region that is being deglitched.

8-1-1. Image Display Panel

The Image display panel displays the whole image that is currently being processed. There is a red rectangle that indicates the selected and zoomed region. The zooming rectangle can be moved by clicking dragging it, and resized by clicking and dragging one of its corners.

8-1-2. Zoomed Image Display Panel

The Zoomed Image display panel displays the magnified image of the zooming square. The Zoomed Image display panel magnifies the image dynamically while the zooming square is moved. In Region Deglitch, this area also represents the region that is being deglitched.

8-1-3. Histogram

The deglitch can be performed to remove artifacts that result in apparent low or apparent high values in the image. When these are determined manually, the histogram is used to set these upper or lower bounds.

8-1-4. Parameter Control

There are two settings that can be adjusted in Region Deglitch.

- Auto

  When this is selected, the software automatically fits a Gaussian curve to the histogram and considers points that are above or below the main curve to be due to artifacts. When unselected, the Histogram is used to manually determine the upper and lower bounds.
- Upper, Lower, Both

  When in Auto mode, you can decide to only consider points on the upper or lower extreme to be artifacts. If Both is selected, both upper and lower extremes will be considered artifacts.

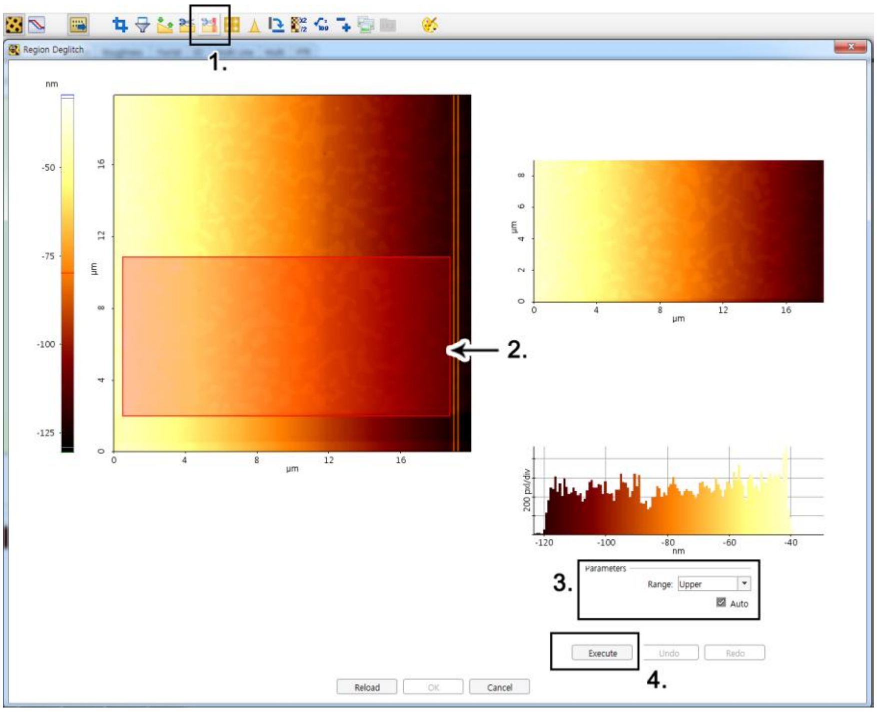
8-2. Region Deglitch an Image

Region Deglitching is based on the assumption that within the selected region, pixels above or below a certain threshold are caused by noise, and that their actual value can be more accurately represented by interpolating a value from the surrounding data. Within the region defined by the zooming square, every point that is considered too high or too low is given a new value based on its closest non-artifact neighbors in the four cardinal directions.

The following procedure can be used to perform Region Deglitch on an image with the Auto setting.

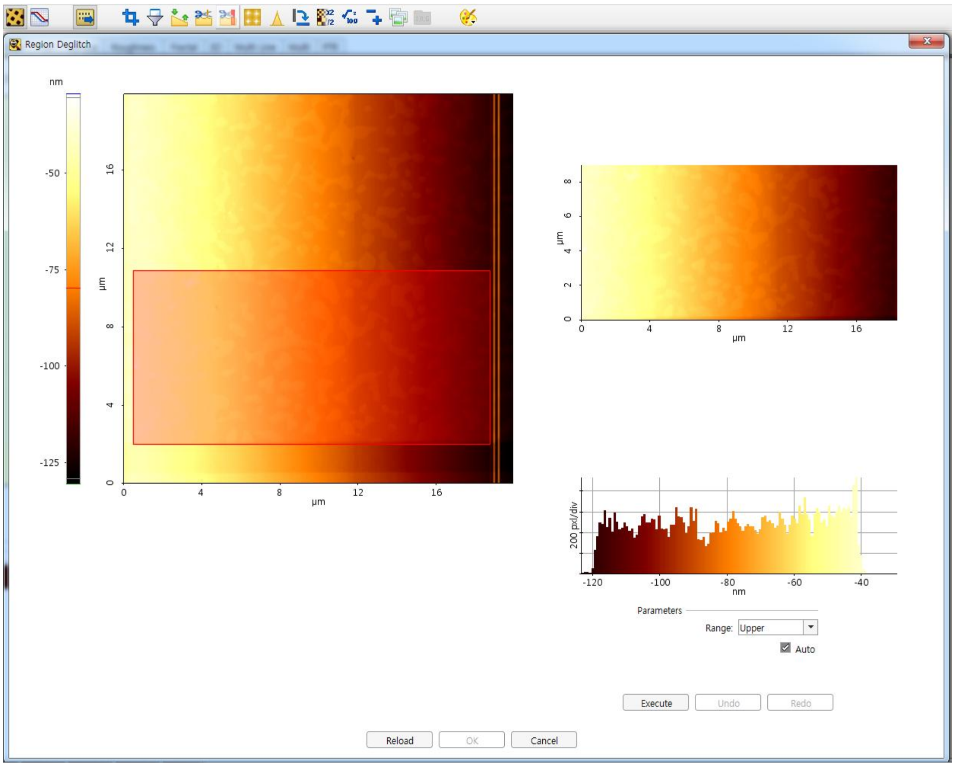
1. Open the file, and enter the Region Deglitch process.
2. Select the area you wish to deglitch.
3. Select the threshold type (Upper, Lower, or Both).
4. Click the ‘Execute’ button.

Figure 8-2-1 shows this process, and Figure 8-2-2 shows a deglitched image.



Parameters
Range: Upper
☑ Auto

Figure 8-2-1. Auto Region Deglitch



Range: Upper

☑ Auto

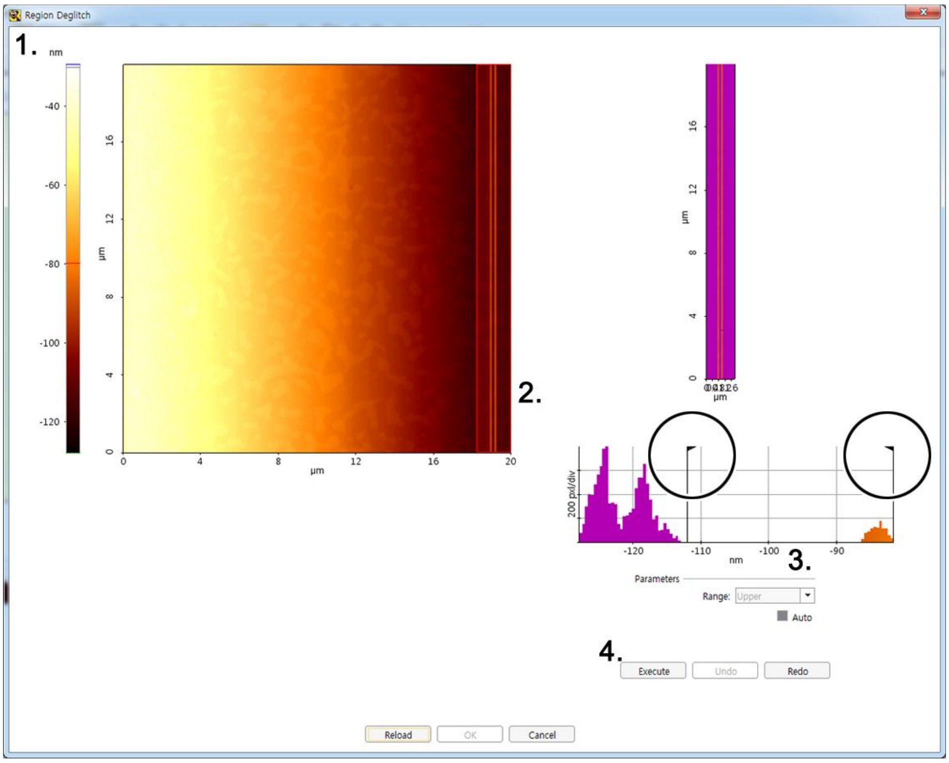
Figure 8-2-2. Auto Deglitched Image

The following procedure can be used for manual selection of the thresholds.

1. Open the file, and enter the Region Deglitch process.
2. Select the area to region deglitch.
3. Deselect Auto, and move the Histogram cursors to limit the points to the glitches. Excluded points will be shown in purple.
4. Click the Execute button.

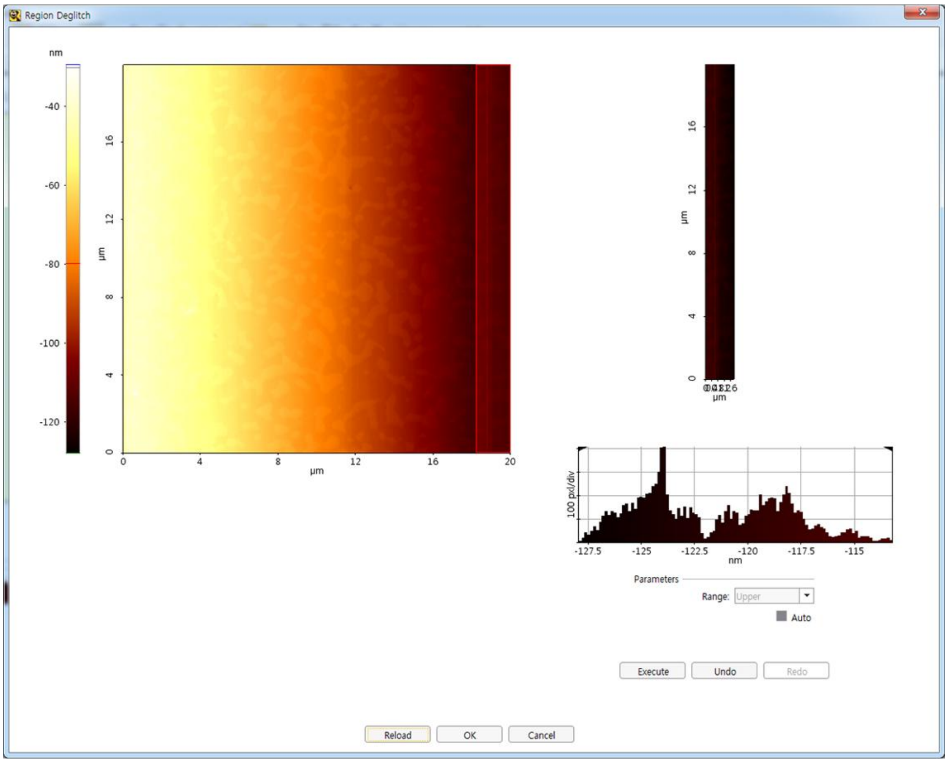
<u>NOTE!</u>

Applying the Region Deglitching process to an image produces a new, processed image that can be saved or printed as a new file. Glitch removal does not change the original data unless you click the Save button.



Range: Upper

Figure 8-2-3. Manual Region Deglitch



Range: Upper

Figure 8-2-4. Manual Deglitched Image

Chapter 9. Fourier Filter

You can use the Fourier Filter to remove unwanted frequency components from your data. A Fourier Filter is most commonly used to remove periodic noise that appears in an image, for instance, due to electrical noise or mechanical vibrations. A 2-dimensinal power spectrum of an image may be used to identify periodic noise. In the power spectrum, periodic noise will appear as a vertical band running through the center of the power spectrum. This noise can be removed by applying a Fourier Filter. Also, a Fourier Filter may be used to remove a selective frequency component from actual surface data. This technique is often applied in presenting atomic lattice data. In this case, a Fourier Filter is applied that includes only the frequencies that represent the symmetry of the atomic lattice.

9-1. Fourier Filter Process Dialog

To open the Fourier Filter process dialog, select the ‘Process>Fourier Filter’ option in the Menu or click the ‘Fourier Filter’ icon ▦ in the Toolbar.

As shown in Figure 9-1-1, the Fourier Filter dialog consists of an Image display panel and a 2D power spectrum display. On the left side, there is the Image display panel which shows the original image to which the Fourier Filter will be applied and will also show the transformed image after you have applied the Fourier Filter. At the right side of the Image display panel is a 2-dimensional power spectrum which includes a palette panel as well as tools used to either include or exclude regions (rectangle, ellipse, polygon or entire region) to be filtered.

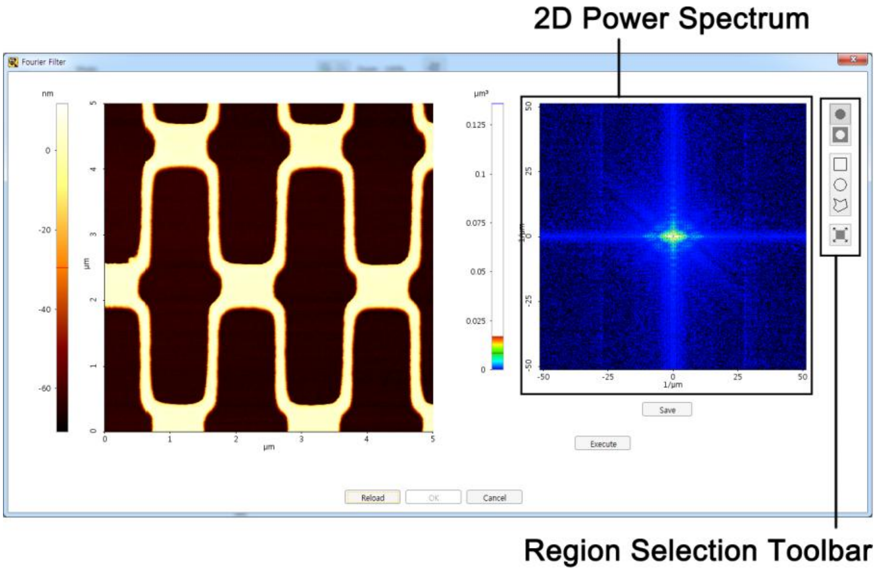


Figure 9-1-1. Fourier Filter process dialog

9-2. 2D Power Spectrum

When you open the Fourier Filter process dialog, the Fourier transform of the selected image is automatically calculated. The resulting power spectrum is displayed in a different color. Figure 9-2-1 shows the general 2D power spectrum which all height data in the spatial domain are converted to the frequency domain after Fourier transform. Peaks in the power spectrum appear bright on a dark background, and also, different colors are displayed in different intensities of frequency components in the data. You can adjust this scale using the palette panel to see various peaks in the power spectrum more clearly.

The unit of the z scale in the power spectrum is displayed at the left side of the palette panel as Å×µm^2, µm ×µm^2, V×µm^2, Å×nm^2, nm ×µm^2, V× Å^2 and so on that depending on the unit you selected as an input signal in the Input configuration dialog when the image was initially acquired. The units of x and y in the power spectrum are 1/µm, that is, the reciprocal of each unit of x and y in the image.

In a power spectrum, the x scan direction is displayed horizontally and the y scan direction is displayed vertically. Lower frequencies are near the origin and higher frequencies are further from the origin. Peaks in the power spectrum are symmetric about the origin.

Each spatial frequency in the real spatial image is represented by a peak in the power spectrum. Peaks can be due to actual surface periodicities such as the spacing between lines on a grating of a standard sample or the spacing between rows of atoms on a graphite surface. Peaks may also result from periodic noise. To apply the Fourier Filter to unwanted frequency components, remove or reduce the intensities of the unwanted peaks in the power spectrum.

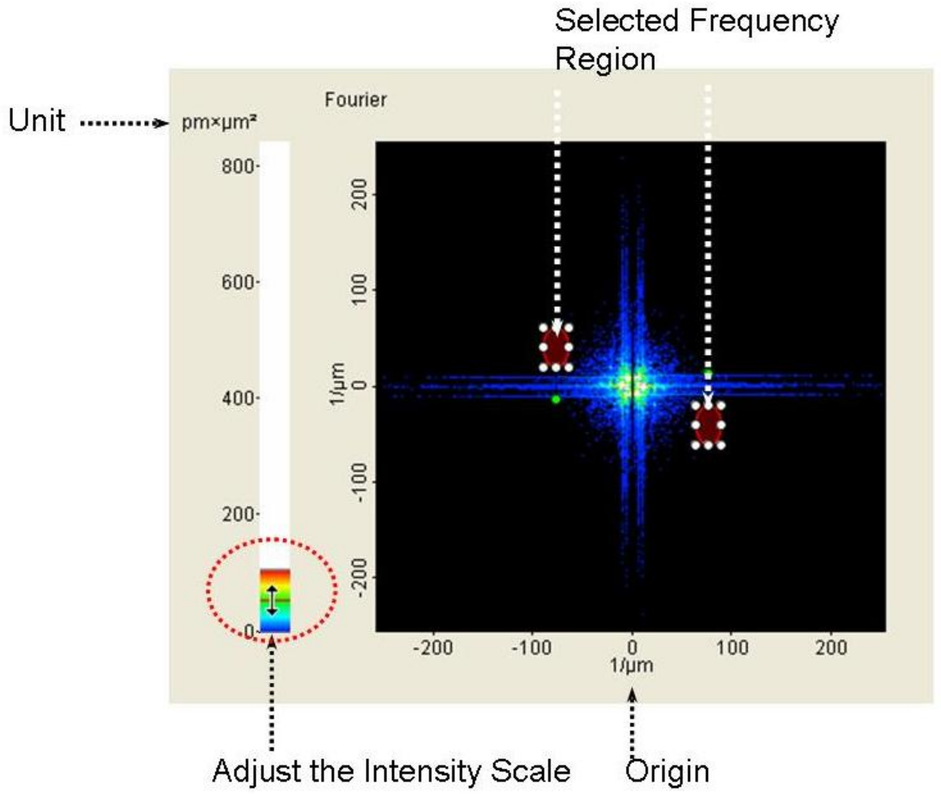


Figure 9-2-1. 2D power spectrum

9-3. Apply the Fourier Filter to an Image

A selective Fourier filter allows you to remove specific frequency components from the power spectrum of an image. This process is commonly used to remove peaks attributed to periodic noise. Furthermore, it can be useful when you wish to take an image with only chosen periodicities by including only those peaks in which you are interested.

In Fourier filtering, you select a region type to be used for including or excluding frequency components in the power spectrum. You can remove all periodic noise by excluding frequency components within the included region.

Since peaks in the power spectrum are reflected across the origin, both a selected region and its reflected region will be generated together.

You can apply the Fourier filter to an image by following these general steps (see Figure 8-3-1):

1. Load the image you want to apply Fourier Filter into the Analysis view.
2. Open the Fourier Filter process dialog by selecting ‘Process>Fourier Filter’ in the Menu or by clicking the ‘Fourier Filter’ icon ▦ on the Toolbar. When you open the Fourier Filter process dialog, the entire power spectrum is automatically displayed.
3. Select a region type (rectangle, ellipse, polygon or entire region) you wish to use to include or exclude selected frequencies, and draw it around the desired spectral features in the power spectrum.
4. Click the ‘Execute’ button to preview the effect of the Fourier Filter. Update the image in the Analysis view by selecting the ‘OK’ button if desired.
5. Save, export, process or analyze the filtered real spatial image.

Figure 9-3-1 shows the general procedure to apply the selective Fourier Filter and also, you can see a comparison of an original image and a Fourier filtered image. Furthermore, Figure 9-3-2 shown below is the atomic lattice image which the selective frequency components were passed through the Fourier Filter.

NOTE!

> Applying the Fourier Filter to an image produces a new, processed image that can be saved or printed as a new file. This application does not change the original data unless you click the Save button.

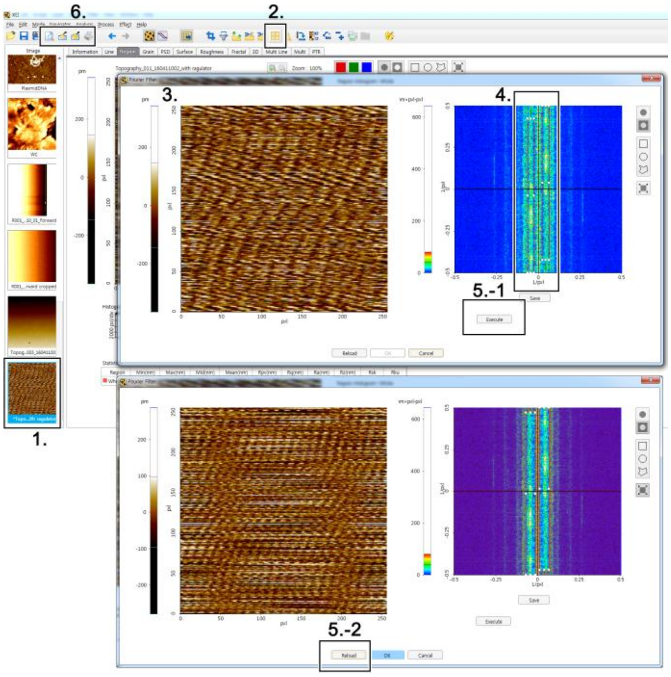


Figure 9-3-1. Procedure to apply the Fourier Filter to an image

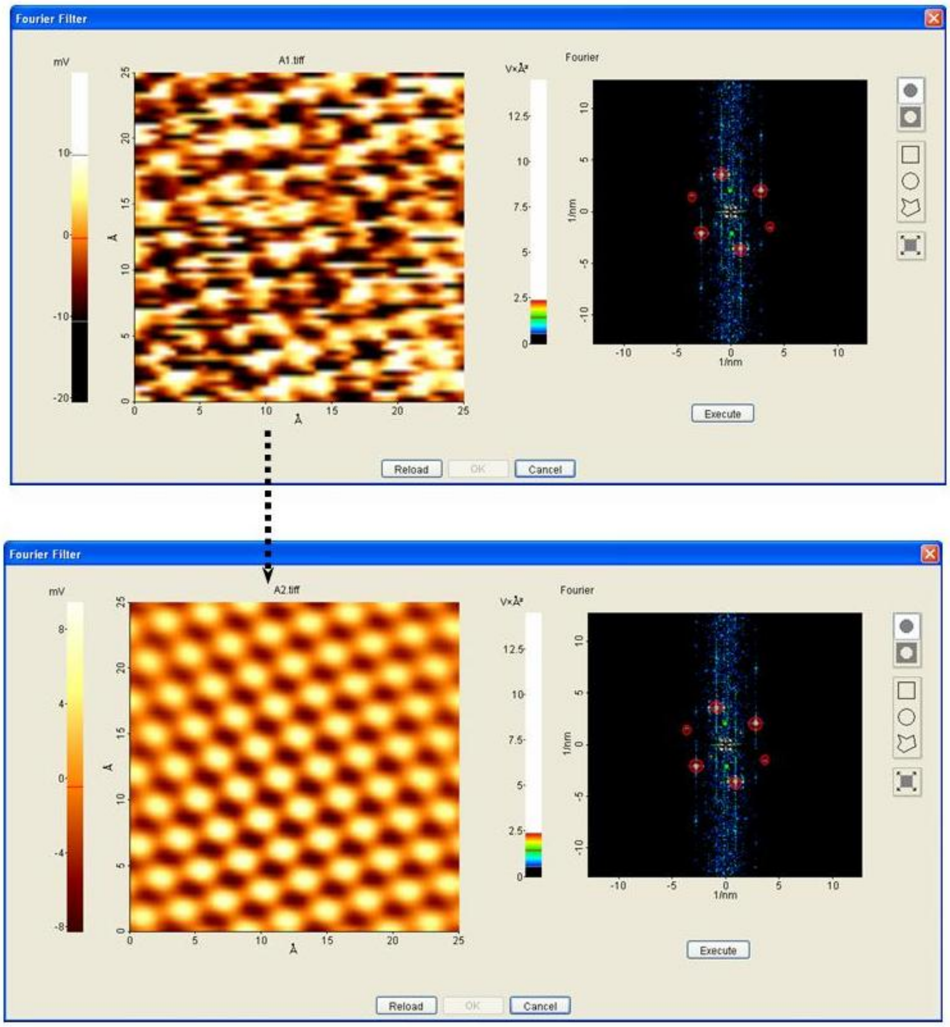


Figure 9-3-2. Fourier Filter applied to Atomic lattice image

Chapter 10. Tip Estimation

As the size of the tip is finite, the images obtained by the SPM are affected by the shape of tip. In professional words, image of the tip is ‘convoluted’ to the image of the sample surface obtained with the tip (i.e. Tip Convolution). Tip Convolution generates error in the dimensions of the sample surface measured with the SPM. Figure 10-1 shows simple example how shape of the tip affects the dimensions of the hills and trenches measured with the SPM.

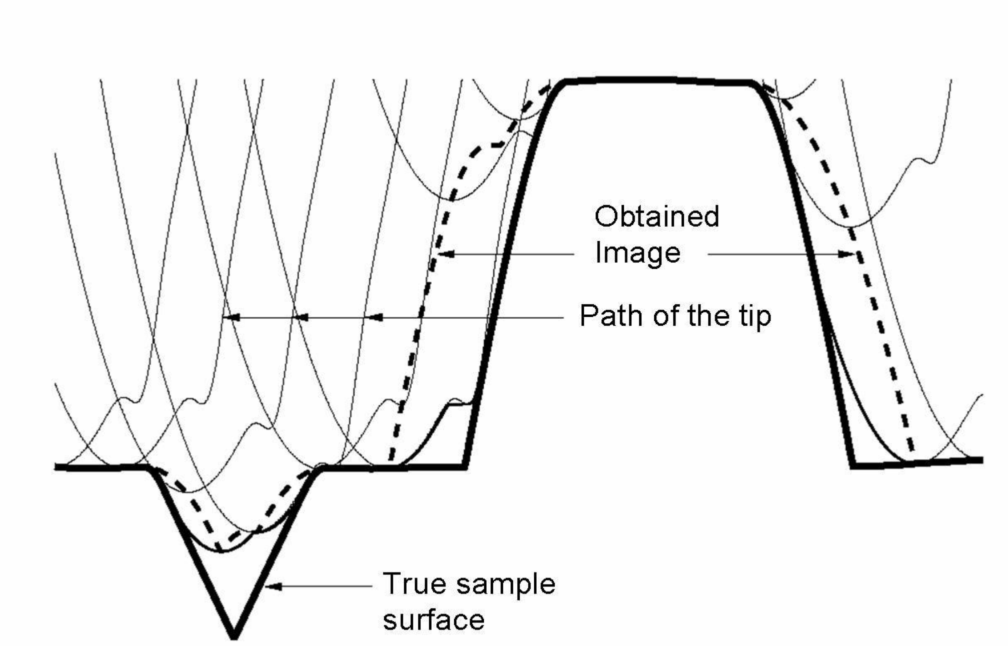


Figure 10-1. Example of tip convoltion

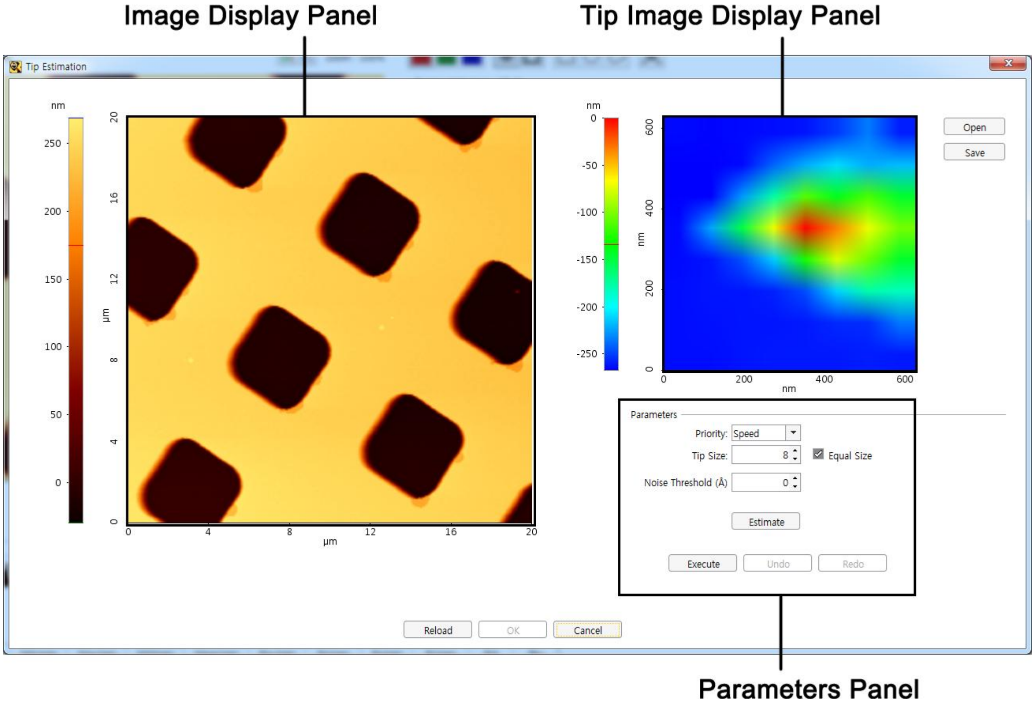
To remove such an affect of the ‘tip convolution’, XEI offers ‘Tip Estimation’ process. During the ‘Tip Estimation’ process, XEI first ‘estimates’ the shape of the tip used to obtain the image. Then, XEI calculates the artifacts caused by tip and removes them from the loaded image. (Tip de-convolution)

This part of the manual is mainly focused on how to use the ‘Tip Estimation’ function of the XEI. For detailed information regarding the algorithm of the 'Tip Estimation' process, please refer to *"Algorithms for Scanned Probe Microscope Image Simulation, Surface Reconstruction, and Tip Estimation"* by *J. S. Villarrubia*. ('Volume 102, Number 4, July–August 1997 Journal of Research of the National Institute of Standards and Technology)

10-1. Tip Estimation Process Dialog

To open the Tip Estimation process dialog, select the item from the Process menu or click the 'Tip Estimation' icon in the Toolbar.

As shown in Figure 10-1-1, the Tip Estimation dialog consists of two image display panel, one for the loaded image (Image Display Panel) and the other for the estimated tip shape (Tip Image Display Panel), and Parameters panel.



Priority: Speed
Tip Size: 8
☑ Equal Size
Noise Threshold (Å) 0

Figure 10-1-1. Tip Estimation process dialog

10-1-1 Image Display Panel

The Image display panel is on the left side shows the original image to which the tip deconvolution will be applied and will also show the transformed image after you have applied the deconvolution. Image before and after tip deconvolution is displayed in the Image Display Panel.

10-1-2 Tip Image Display Panel

2 dimensional representation of the estimated tip shape is displayed on 'Tip Image Display Panel'. Also, the estimated tip shape can be saved and loaded for further analysis.

- **Opening & Saving the Estimated Tip Shape**

Estimated tip shape can be saved as a tiff file by clicking 'Save' button. The tiff file of the estimated tip shape will be saved under the same directory where the image loaded for "Tip Estimation' process is saved. The file name of the saved tip shape will be in forms of '*File name of the image loaded for tip estimation process*_tip.tiff'.

Saved tip shape can be loaded to the 'Tip Image Display Panel' later on and used as an estimated tip shape for other samples as well. To load the saved tip shape, click 'Open' button and browse to find the saved tip shape. Figure 10-1-2 shows a tiff file of the saved tip shape loaded in 3D view of the XEI.

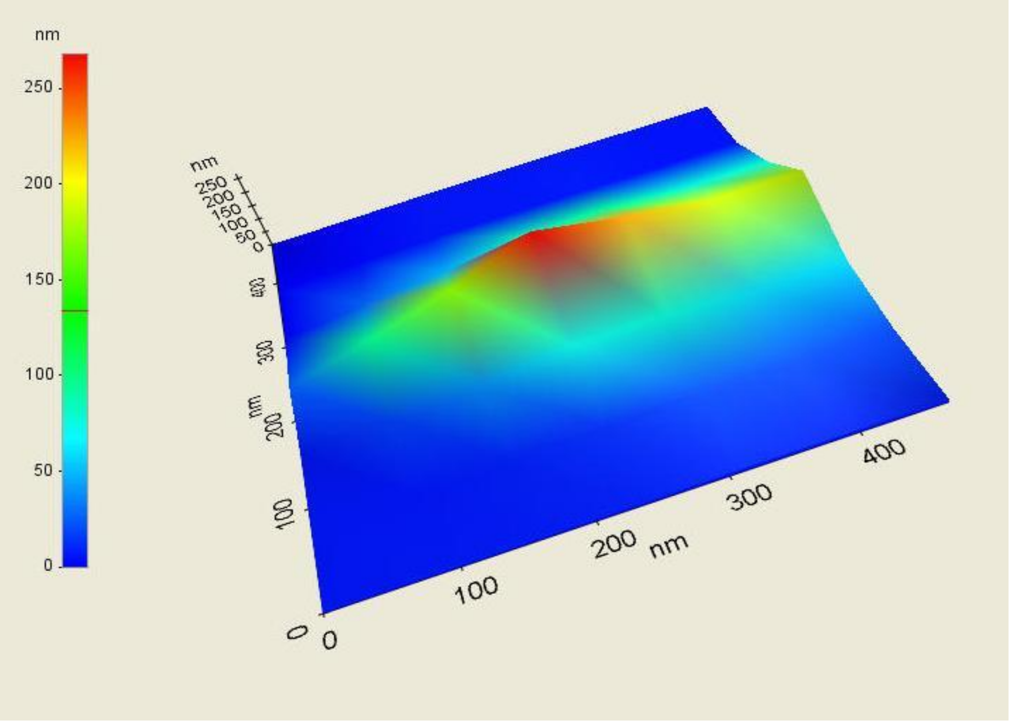


Figure 10-1-2. Estimated tip shape saved as tiff file

Saving and loading the tip shape can be useful if you have more than 2 images that have been obtained using the same tip. You can save the tip shape estimated from one sample and load it to deconvolute other images that have been obtained with same tip without repeating tip estimation process.

10-1-3 Parameters Panel

Parameters related to optimization of tip estimation and deconvolution process are controlled through this panel.

■ Priority

User can select to give priority of tip estimation and deconvolution algorithm to either ‘Speed’ or ‘Accuracy’. When the ‘Priority’ is given to ‘Speed’, XEI uses partial estimation algorithm to perform fast tip estimation and when the ‘Priority’ is given to ‘Accuracy’, XEI uses full estimation algorithm to perform more accurate tip estimation.

■ Tip size

Tip size can be set in units of the ‘pixels’. Selecting an appropriate tip size is important for good tip estimation results. Typical tip size that gives accurate estimation result is 0.04 to 0.2 of the image size. For example, if the size of the loaded image is 20um with 256 pixel size, typical tip size that will give good estimation result will be 10.24 to 51.2.

■ Noise Threshold

Variations that are smaller than this value are ignored during the tip estimation process as contributed by noise. Typical values range from 2Å to 5Å.

10-2. Applying Tip Estimation process to the Image

The tip shape will be automatically calculated when the dialog window is initialized. You can recalculate the tip shape if you have better knowledge of the actual tip size. Put the size (height and width) of the tip into the appropriate fields and click the Estimate button. A new estimation will be made.

Once a good approximation of the tip shape has been made, it can be applied to the image to remove artifacts created by the tip. This can be helpful for images including sheer slopes. Tip deconvolution is applied to the whole image. You can estimate the tip shape and apply the estimation to an image by following these general steps:

1. Load the image to which you want to apply tip deconvolution into the Analysis view.
2. Select Tip Estimation from the Process menu or click the ‘Tip Estimation’ icon in the Toolbar.
3. Input the size of the tip, select priority, and then click ‘Estimate’ to

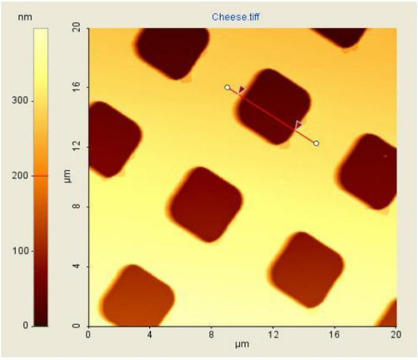
calculate the shape of the tip. If you had estimated the shape of the tip that was used to obtain the loaded image.

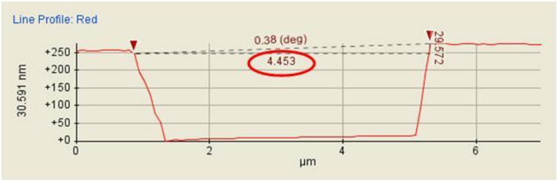
4. Click the ‘Execute’ button to preview the effect of the tip deconvolution. Update the image in the Analysis view by selecting the ‘OK’ button if desired.
5. Save, export, process or analyze the new image.

NOTE!

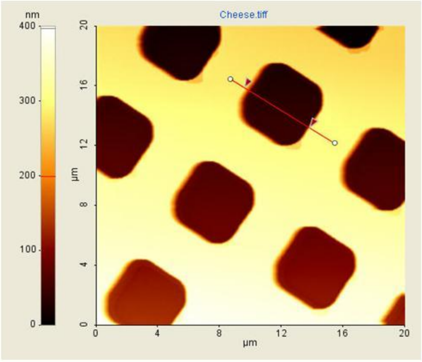
> Applying the Tip Estimation process to an image produces a new, processed image that can be saved or printed as a new file. This application does not change the original data unless you click Save button.

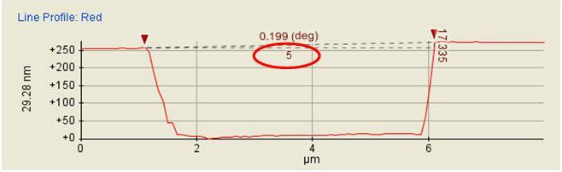
Figure 10-2-1 shows the resulting image when the estimated tip shape is applied to the original data.





Before Deconvolution – measured width of trench (4.5um) is smaller than its known width 5um due to the effect of tip convolution.





After Deconvolution – Tip shape is deconvoluted from the image and now the measured width of trench (5um) matches the known width 5um.

Figure 10-2-1. Application of Tip Estimation

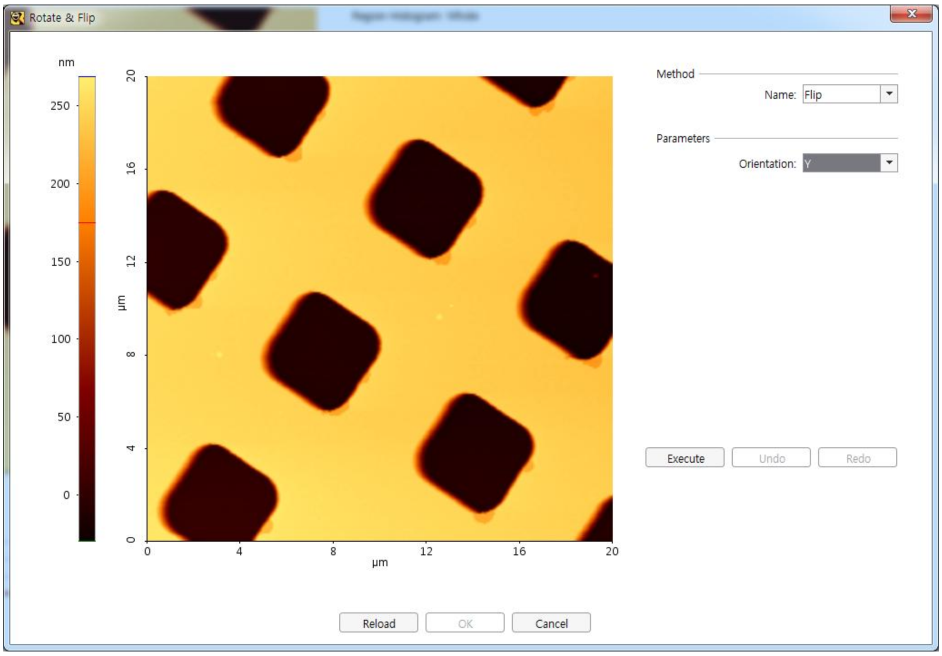
In actual experiments, there is special sample designed for tip shape estimation. Accurate tip shape can be obtained when the tip shape is estimated from the image of this sample. Then, the estimated tip shape can be loaded for tip deconvolution of other images measured with same tip.

Chapter 11. Rotate & Flip

It may be desirable to change the orientation of an image. The Rotate & Flip process can be used to rotate SPM images left or right, or flip the image across one of its axes. This may be helpful for comparison of images taken at different orientations.

11-1. Rotate & Flip Process Dialog

To open the Rotation & Flip process dialog, select ‘Process>Rotate & Flip’ in the Menu or click the ‘Rotate & Flip’ icon in the Toolbar.



Name: Flip

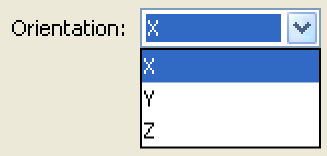
Orientation: Y

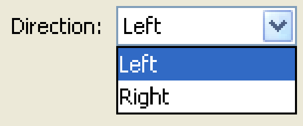
Figure 11-1-1. Rotate & Flip process dialog

As shown in Figure 10-1-1, the Rotate & Flip dialog has two settings that can be modified.

11-1-1. Method

You can choose to flip the image or to rotate the image with this option. Flipping around an axis will invert the value of that axis for every pixel in the image. Rotating will swap the X and Y axes with different signs.





11-1-2. Parameters

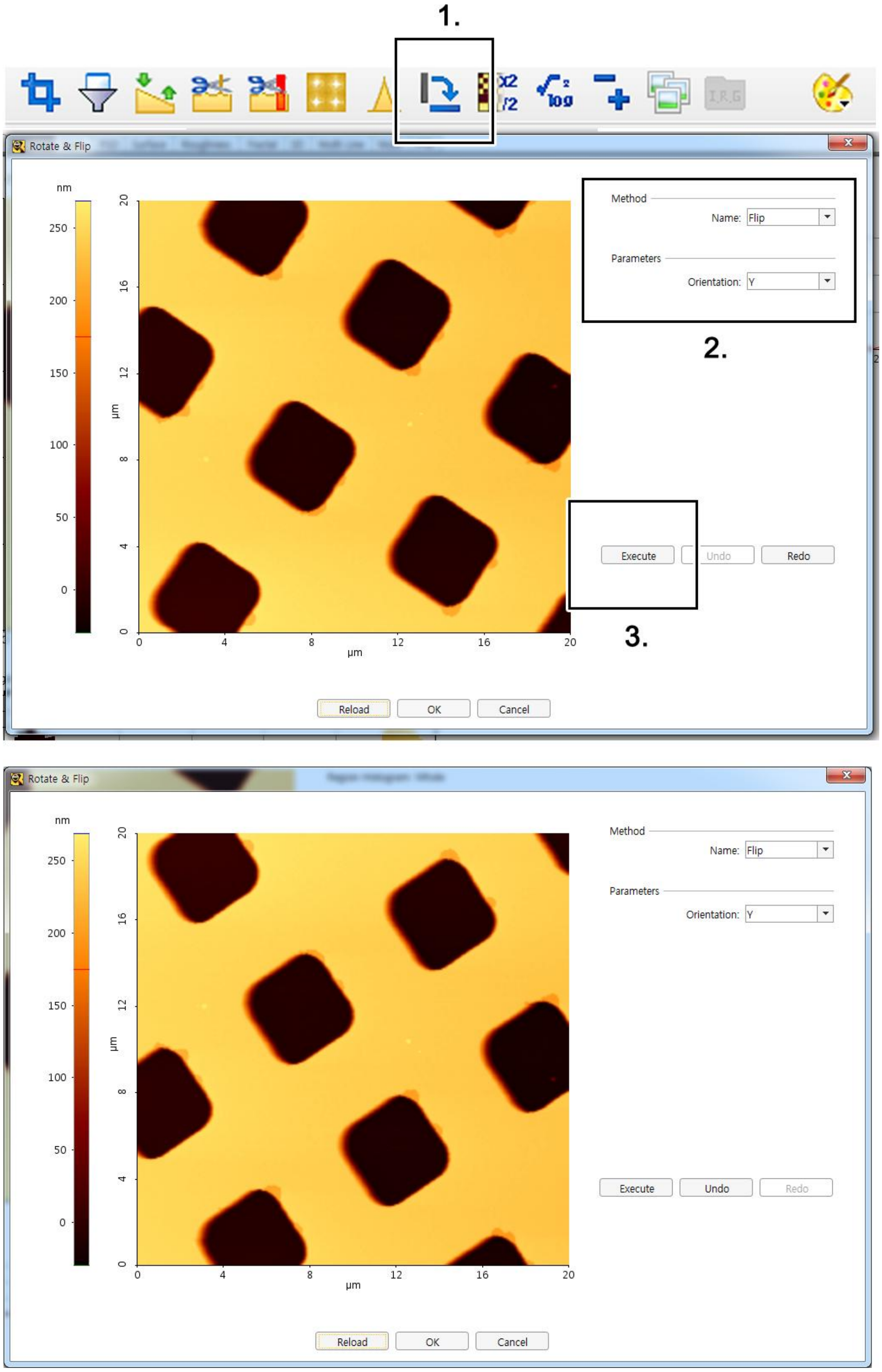
The parameter options allow you to select, for the Flip method, X, Y, or Z. This determines which axis the image is flipped around. For Rotate, the field changes to Left or Right, which determines whether the image is rotated counter-clockwise or clockwise, respectively.

11-2. Rotate & Flip an Image

To rotate or flip an image, perform the following steps:

1. Open the file, and enter the Flip & Rotate process.
2. Select the Method and Parameters for the operation.
3. Click the ‘Execute’ button.

Figure 11-2-1 shows this process for flipping an image around its Y axis.



Method

Name: Flip

Parameters

Orientation: Y

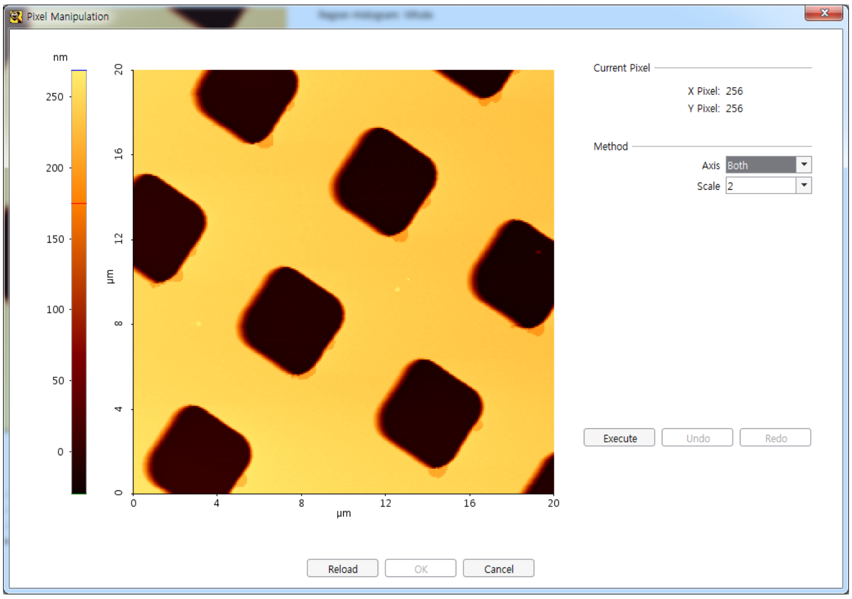
Figure 11-2-1. Perform Y Axis Flip

Chapter 12. Pixel Manipulation

The Pixel Manipulation Process resamples the image to increase or decrease the number of pixels in the file. This is particularly useful when comparing images of differing resolutions, as some operations can only work on images of the same resolution.

12-1. Pixel Manipulation Process Dialog

To open the Pixel Manipulation process dialog, select ‘Process>Pixel Manipulation’ in the Menu or click the ‘Pixel Manipulation’’ icon in the Toolbar.



X Pixel: 256
Y Pixel: 256
Axis Both
Scale 2

Figure 12-1-1. Pixel Manipulation process dialog

12-1-1. Current Pixel

The current resolution of the file is shown in number of pixels for the X and Y axes.

12-1-2. Method

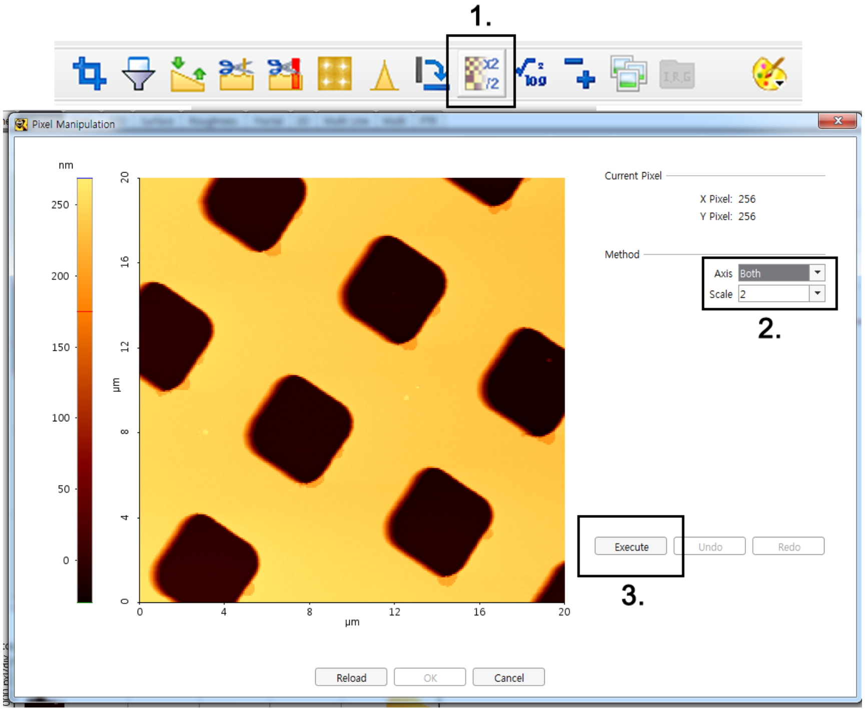
You can select which axis to change using the ‘Axis’ drop-down menu: X, Y, or Both.

The amount by which the selected axis is changed is determined by the ‘Scale’ drop-down menu: Halve the number of pixels, or double them.

12-2. Applying Pixel Manipulation

To apply Pixel Manipulation to an image, perform the following steps:

1. Open the file, and enter the Pixel Manipulation process.
2. Select the Method.
3. Click the ‘Execute’ button.



X Pixel: 256
Y Pixel: 256
Axis: Both
Scale: 2

Figure 12-2-1. Perform Pixel Manipulation

Chapter 13. Unary Arithmetic

The Unary Arithmetic Process can perform several arithmetic operations on an image.

13-1. Unary Arithmetic Process Dialog

To open the Unary Arithmetic process dialog, select 'Process> Unary Arithmetic' in the Menu or click the 'Unary Arithmetic' icon in the Toolbar.

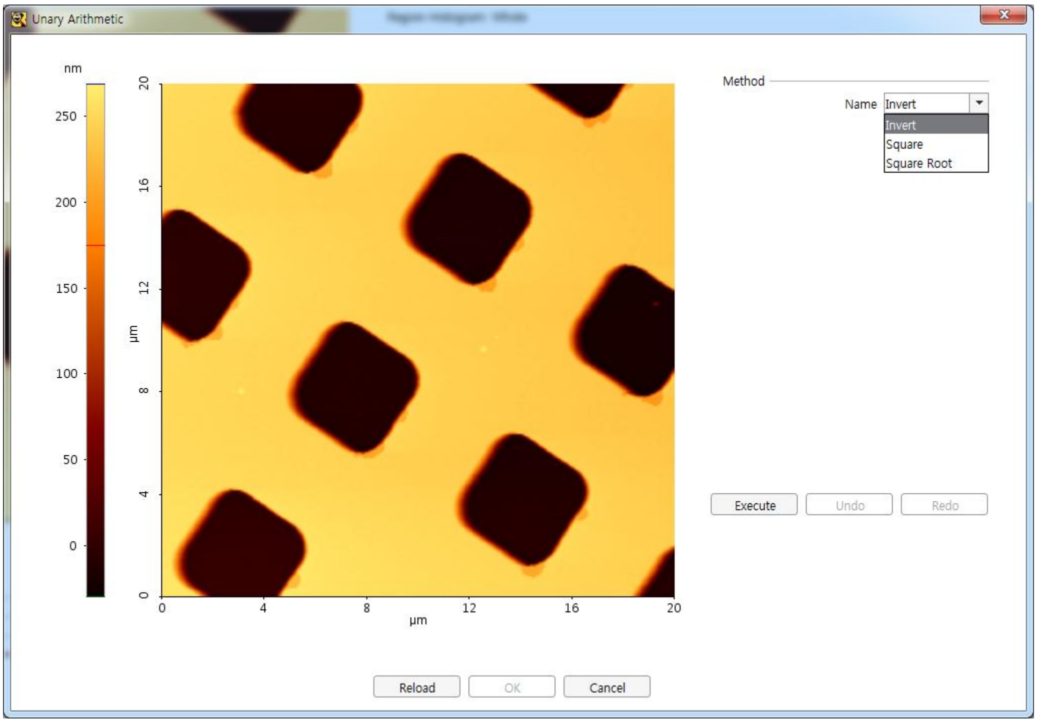


Figure 13-1-1. Unary Arithmetic process dialog

As shown in Figure 13-1-1, the Unary Arithmetic process has one parameter.

13-1-1. Method

The methods available are Invert, Square, and Square Root.

- Invert

  Every pixel is multiplied by -1 in the Z direction.

- Square

  Every pixel is squared.

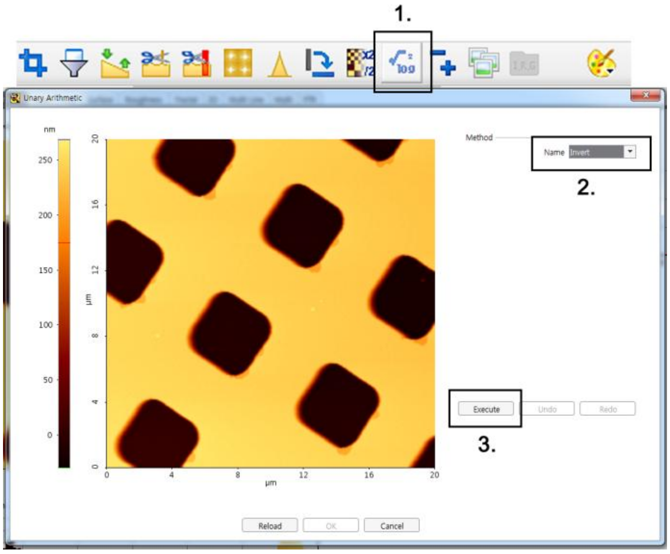
- Square Root

  The square of every pixel is taken.

13-2. Applying Unary Arithmetic

To apply Unary Arithmetic to an image, perform the following steps:

1. Open the file, and enter the Unary Arithmetic process.
2. Select the Method.
3. Click the ‘Execute’ button.



Name: Invert

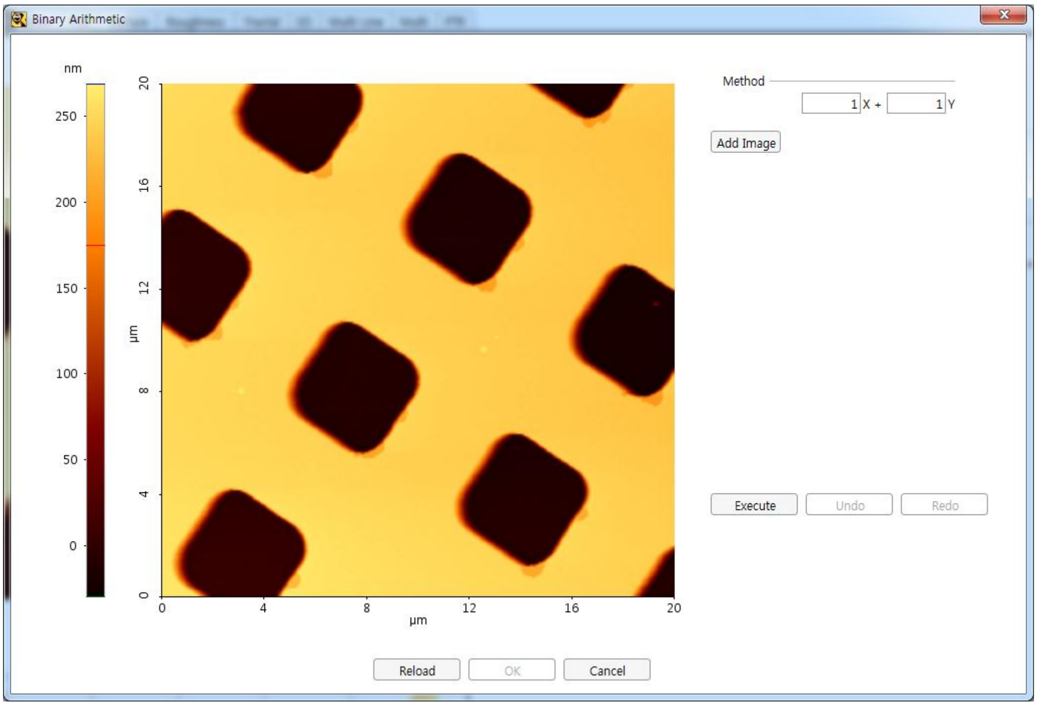
Figure 13-2-1. Apply Unary Arithmetic

Chapter 14. Binary Arithmetic

The Binary Arithmetic process is used mostly for the direct comparison of two images.

14-1. Binary Arithmetic Process Dialog

To open the Binary Arithmetic process dialog, select ‘Process> Binary Arithmetic’ in the Menu or click the ‘Binary Arithmetic’ icon in the Toolbar.



Method
1 X + 1 Y

Figure 14-1-1. Binary Arithmetic process dialog

As shown in Figure 14-1-1, the Binary Arithmetic dialog has two parameters, X and Y.

14-1-1. Method

The X and Y fields denote the left and right images. The currently loaded image is shown on the left, and the second image which is to be added to the opened image is shown on the right.

The values in the X and Y fields determine their weight in the result. As the type of data can differ between images, such as with Topography and Error images, a trial and error approach is recommended to find satisfactory values for these fields.

14-2. Applying Binary Arithmetic

To apply Binary Arithmetic to an image, perform the following steps. In this example, the MFM data of a hard drive is added to the Topography signal.

1. Open the file, and enter the Binary Arithmetic process.

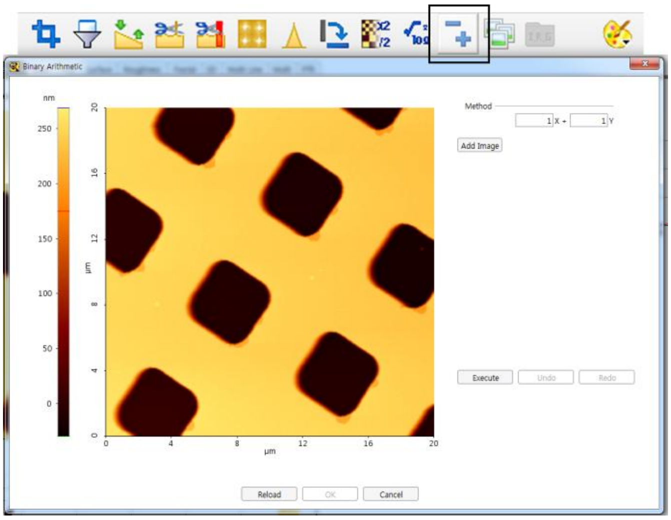
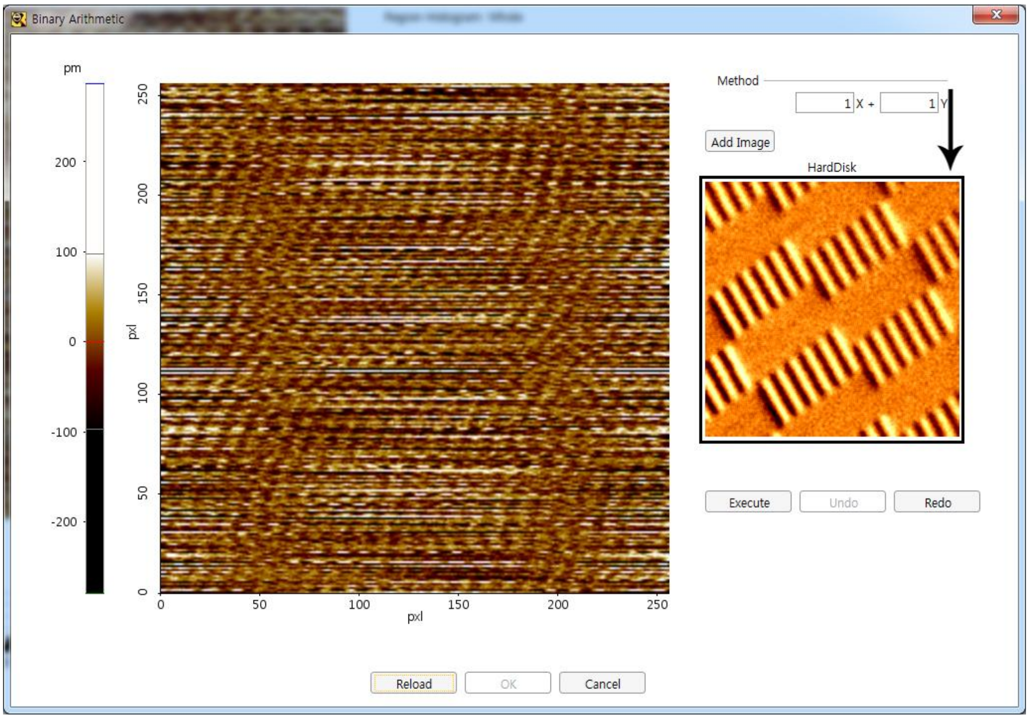


Figure 14-2-1. Start Binary Arithmetic

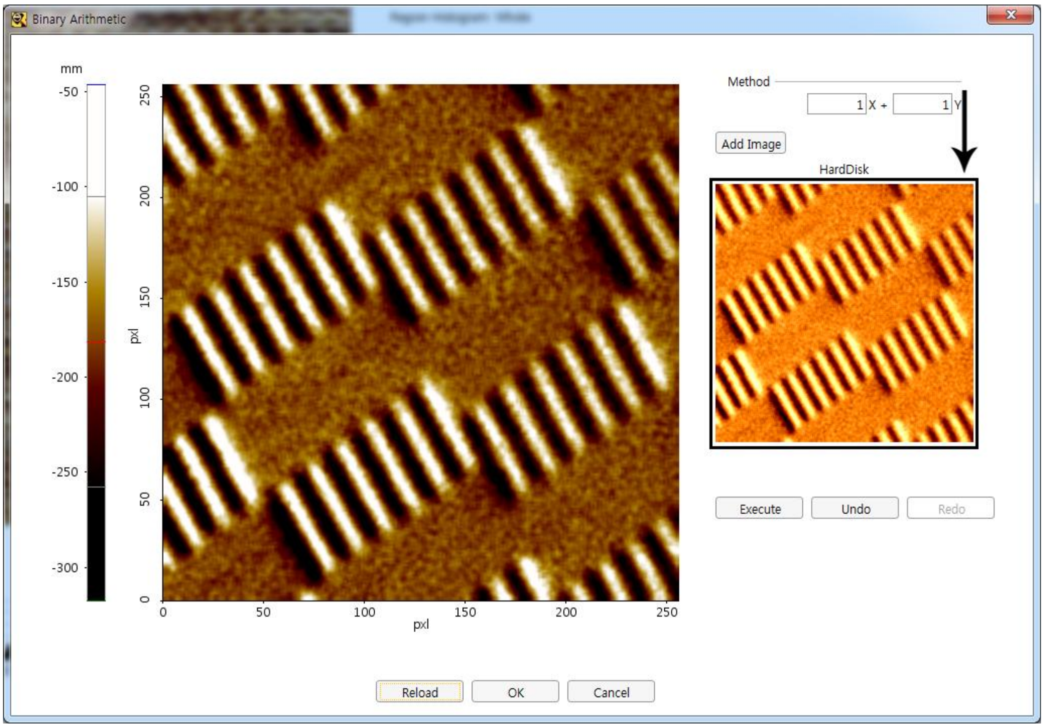
2. Click [Add Image] button and select the desired image. Then click [Open] button. The selected image will be shown additionally in the Zoom Image Display panel.



1 X + 1 Y

Figure 14-2-2. Select Second Image

3. Specify values for the X and Y weights.
4. Click the [Execute] button.



1 X + 1 Y

Figure 14-2-3. Binary Arithmetic Result

Chapter 15. Spectroscopy Mode

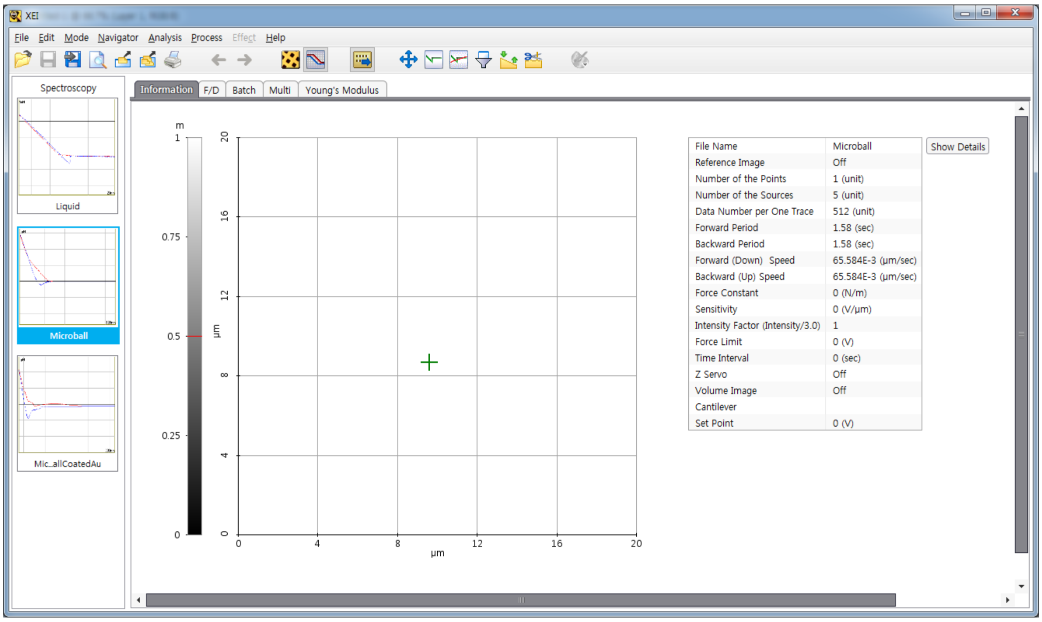
Spectroscopy Mode is used for analysis of Force-Distance (F/D) curves, Nano-Indentation curves, Current-Voltage (I/V) curves and Photo Current curves. Spectroscopy Mode can be enabled by clicking the “Spectroscopy Mode” button in the toolbar, or by selecting the “Spectroscopy” item in the Mode menu.

15-1. Views

Spectroscopy Mode is composed of three Views. Information View displays information on the reference image and spectroscopy curves. Batch View allows for the analysis of a set of curves. Multi View is used for the direct comparison of two curves. For F/D and Nano-Indentation curves, a Young’s Modulus view is added.

15-1-1. Information View

Information View displays basic metadata. It consists of an image display panel and an information table. The Information View can be selected by selecting the Information tab, and is identical to the Information View for Image Mode.

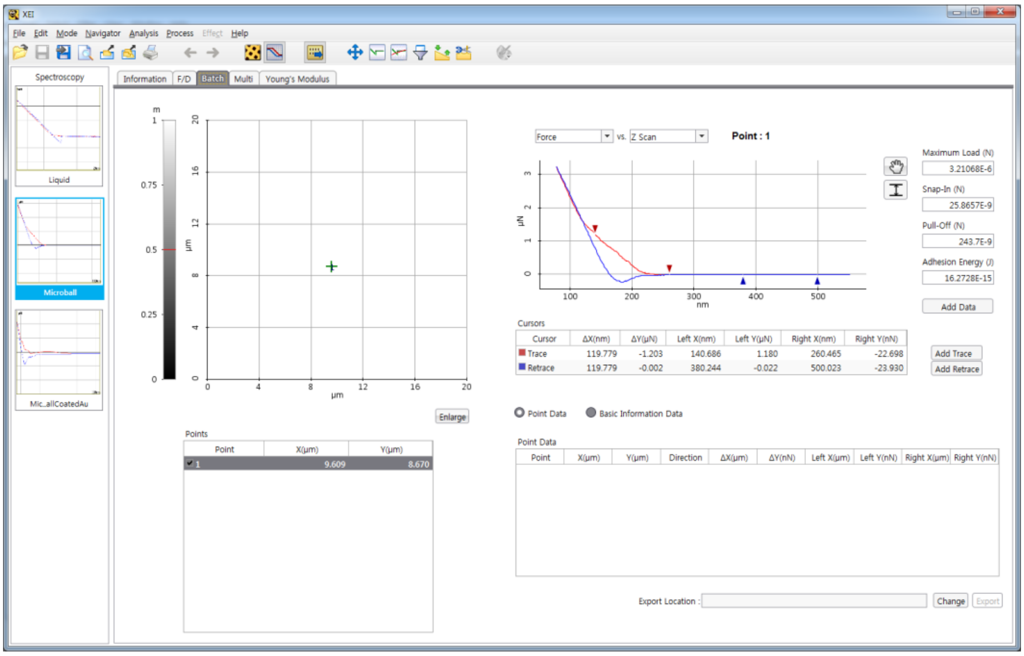


File Name	Microball
Reference Image	Off
Number of the Points	1 (unit)
Number of the Sources	5 (unit)
Data Number per One Trace	512 (unit)
Forward Period	1.58 (sec)
Backward Period	1.58 (sec)
Forward (Down) Speed	65.584E-3 (µm/sec)
Backward (Up) Speed	65.584E-3 (µm/sec)
Force Constant	0 (N/m)
Sensitivity	0 (V/µm)
Intensity Factor (Intensity/3.0)	1
Force Limit	0 (V)
Time Interval	0 (sec)
Z Servo	Off
Volume Image	Off
Cantilever	
Set Point	0 (V)

Figure 15-1-1. Information View

15-1-2. Batch View

Batch View can be enabled by clicking the Batch tab when Spectroscopy Mode is enabled. Batch View is designed to assist processing of multiple spectroscopy curves, and export the processed data for further analysis. The Batch View is consists of several components, as shown in Figure 15-1-2.



Force vs. Z Scan Point : 1

Maximum Load (N): 3.21068E-6

Snap-In (N): 25.8657E-9

Pull-Off (N): 243.7E-9

Adhesion Energy (J): 16.2728E-15

Points

Point	X(µm)	Y(µm)
☑ 1	9.609	8.670

Cursors

Cursor	ΔX(nm)	ΔY(µN)	Left X(nm)	Left Y(µN)	Right X(nm)	Right Y(nN)
🟥 Trace	119.779	-1.203	140.686	1.180	260.465	-22.698
🟦 Retrace	119.779	-0.002	380.244	-0.022	500.023	-23.930

○ Point Data ● Basic Information Data

Point Data

Point	X(µm)	Y(µm)	Direction	ΔX(µm)	ΔY(nN)	Left X(µm)	Left Y(nN)	Right X(µm)	Right Y(nN)

Export Location :

Figure 15-1-2. Batch View Figure

15-1-2-1. Image Display Panel

The Image Display Panel shows a representation of the sample surface, overlaid with a green grid to show the spectroscopy locations.

The Reference and Volume buttons will switch the display between showing the Reference image and image derived from the Spectroscopy measurements.

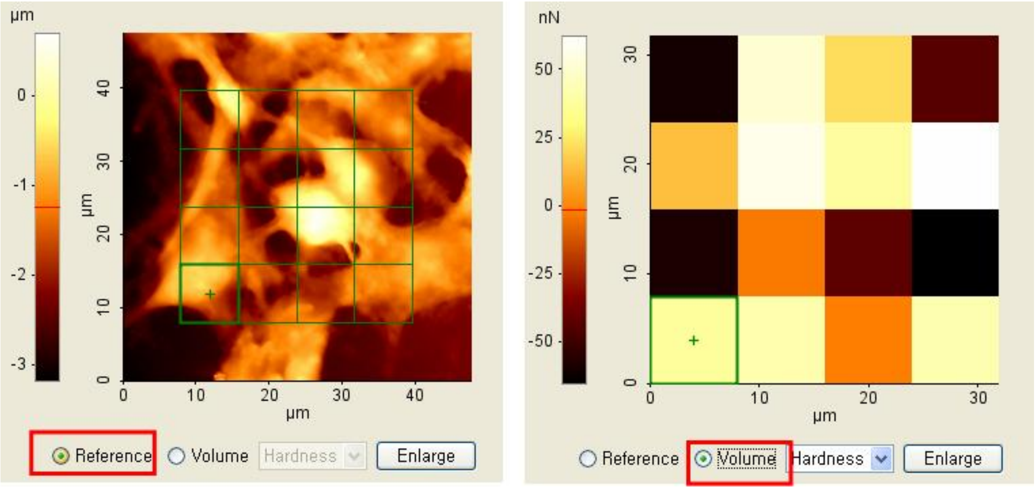


Figure 15-1-3. Reference and Volume

While the Volume option is selected, what it represents can be changed using the activated down arrow button. Volume image can be exported as tiff, text and image file by clicking on the right click on image.

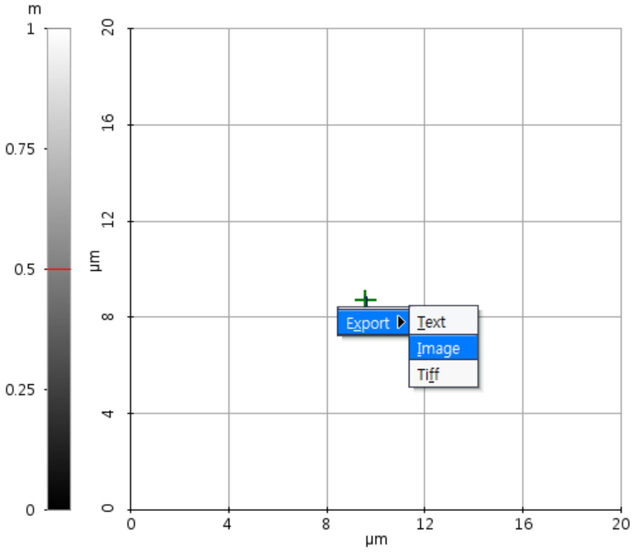


Figure 15-1-4. Volume Image Export

This volume option is only shown for measurement which got from mapping.

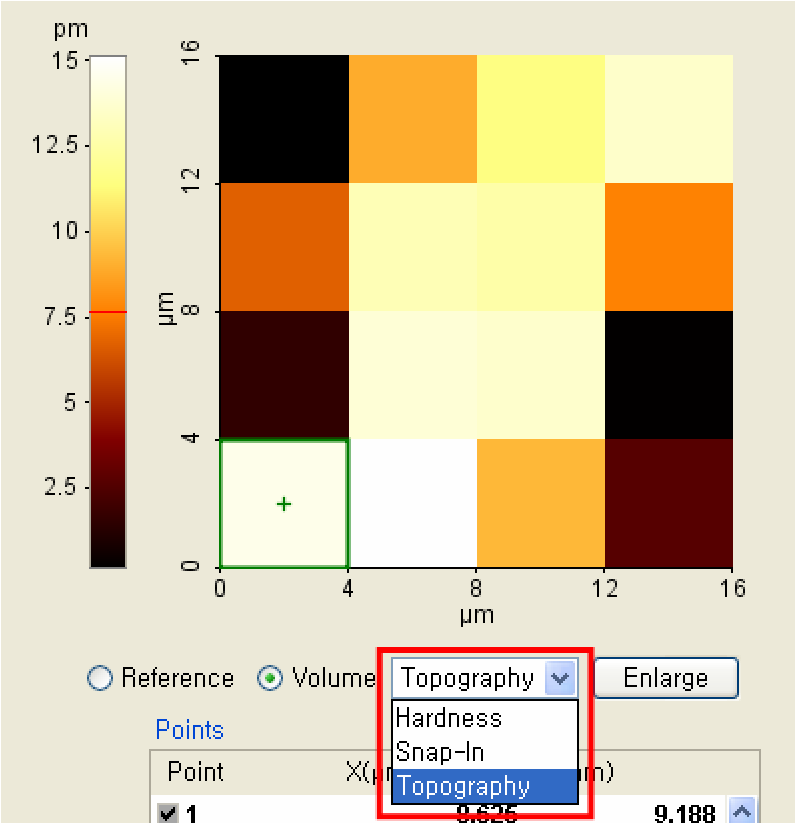
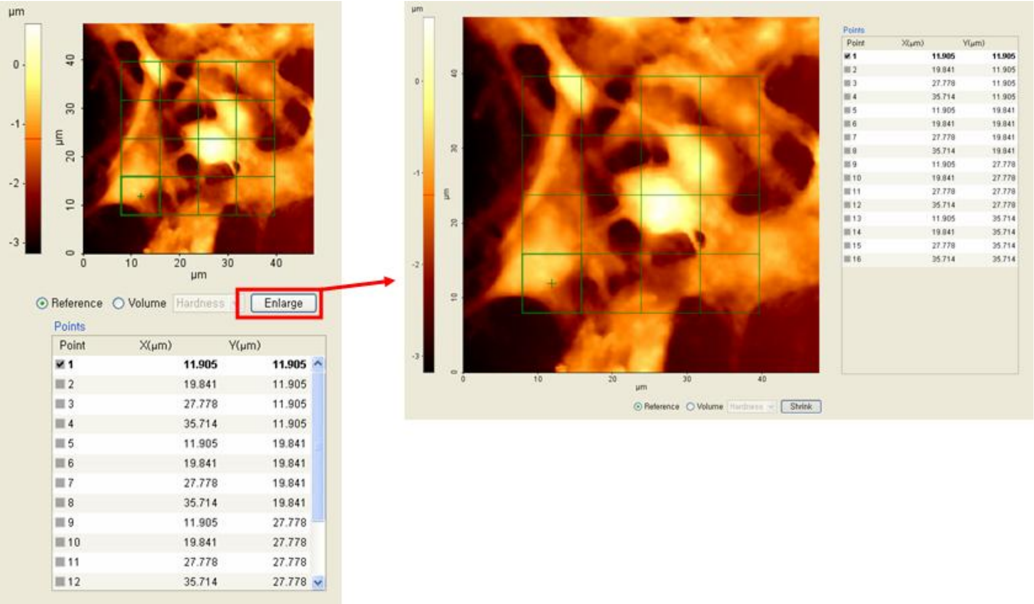


Figure 15-1-5. Volume Option

The Enlarge button will maximize the Image Display Panel. Figure 15-1-6 shows the display with this button enabled. When in this state, the Enlarge button is changed to “Shrink”, which when pressed will revert the view to the previous state.



● Reference ○ Volume

Points

Point	X(µm)	Y(µm)
☑ **1**	**11.905**	**11.905**
☐ 2	19.841	11.905
☐ 3	27.778	11.905
☐ 4	35.714	11.905
☐ 5	11.905	19.841
☐ 6	19.841	19.841
☐ 7	27.778	19.841
☐ 8	35.714	19.841
☐ 9	11.905	27.778
☐ 10	19.841	27.778
☐ 11	27.778	27.778
☐ 12	35.714	27.778

Points

Point	X(µm)	Y(µm)
☑ **1**	**11.905**	**11.905**
☐ 2	19.841	11.905
☐ 3	27.778	11.905
☐ 4	35.714	11.905
☐ 5	11.905	19.841
☐ 6	19.841	19.841
☐ 7	27.778	19.841
☐ 8	35.714	19.841
☐ 9	11.905	27.778
☐ 10	19.841	27.778
☐ 11	27.778	27.778
☐ 12	35.714	27.778
☐ 13	11.905	35.714
☐ 14	19.841	35.714
☐ 15	27.778	35.714
☐ 16	35.714	35.714

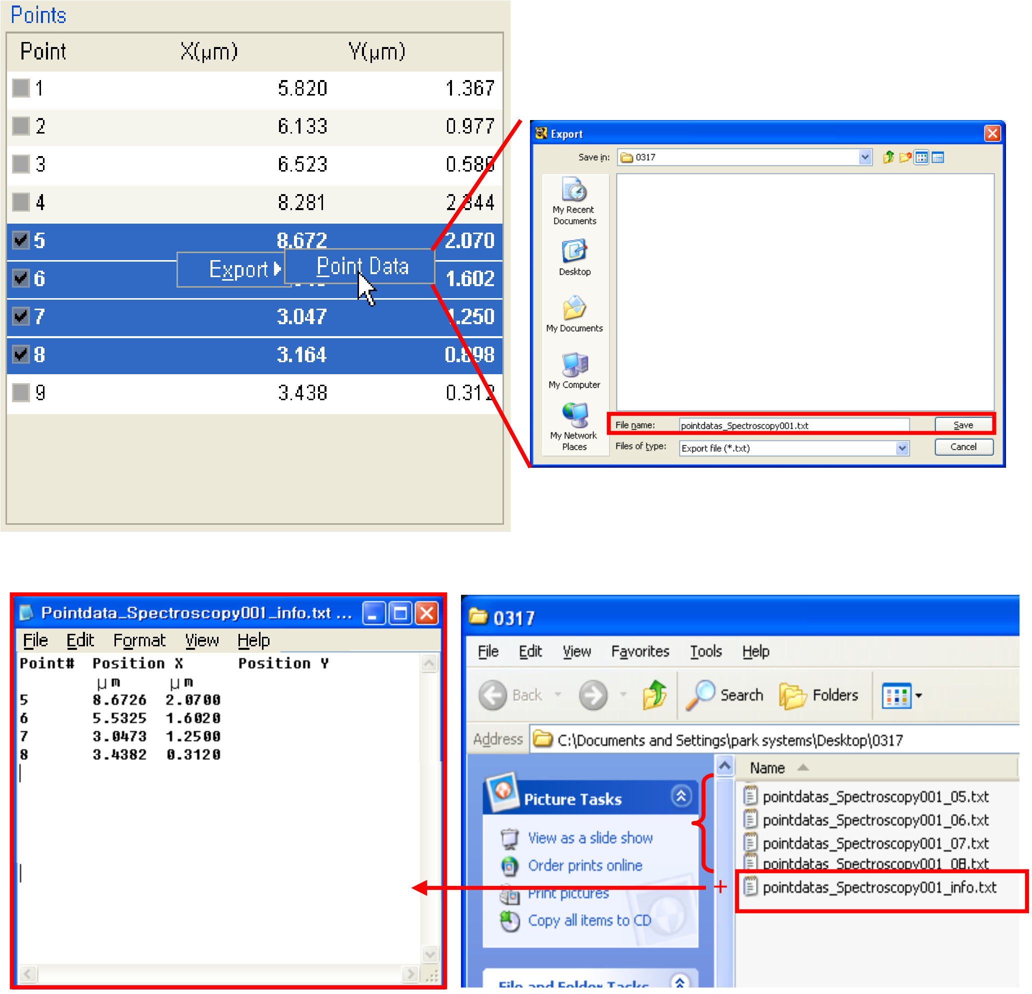
● Reference ○ Volume

Figure 15-1-6. Image Display Panel (enlarged and normal view)

15-1-2-2. Points Table

The Points Table lists the points taken in the current batch of data, along with their X and Y positions within the image. These are also visually represented in the Image Display Panel. You can select which of the curves to analyze by checking the box in the Point column.

The points selected in this table will be loaded for analysis. Also, you can export them by notepad or spread sheet by clicking on the right of mouse. You can select and export multi points if you click other point after clicking ‘Shift’ button on the keyboard. In this case, ‘info’ file which has position information, is also created together with spectroscopy measurement file for each point.



Points

Point	X(µm)	Y(µm)
☐ 1	5.820	1.367
☐ 2	6.133	0.977
☐ 3	6.523	0.586
☐ 4	8.281	2.344
☑ 5	8.672	2.070
☑ 6	[illegible]	1.602
☑ 7	3.047	1.250
☑ 8	3.164	0.898
☐ 9	3.438	0.312

File name: pointdatas_Spectroscopy001.txt

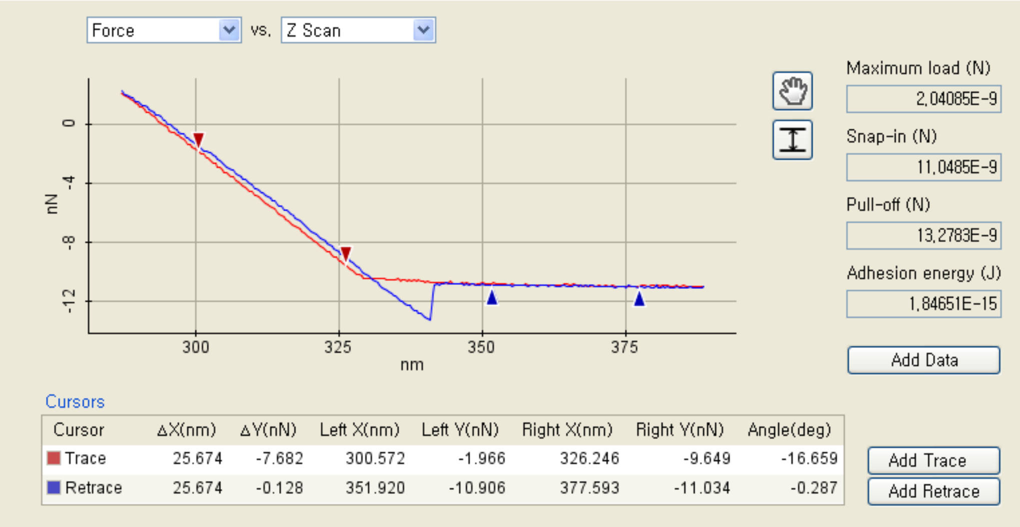
Files of type: Export file (*.txt)

```
Point#  Position X      Position Y
         µm       µm
5        8.6726  2.0700
6        5.5325  1.6020
7        3.0473  1.2500
8        3.4382  0.3120
```

Figure 15-1-7. Points Table

15-1-2-3. Line Display Panel

The Line Display Panel displays the selected curve. The forwards direction is drawn in red, and the backwards direction is drawn in blue.



Maximum load (N): 2.04085E-9

Snap-in (N): 11.0485E-9

Pull-off (N): 13.2783E-9

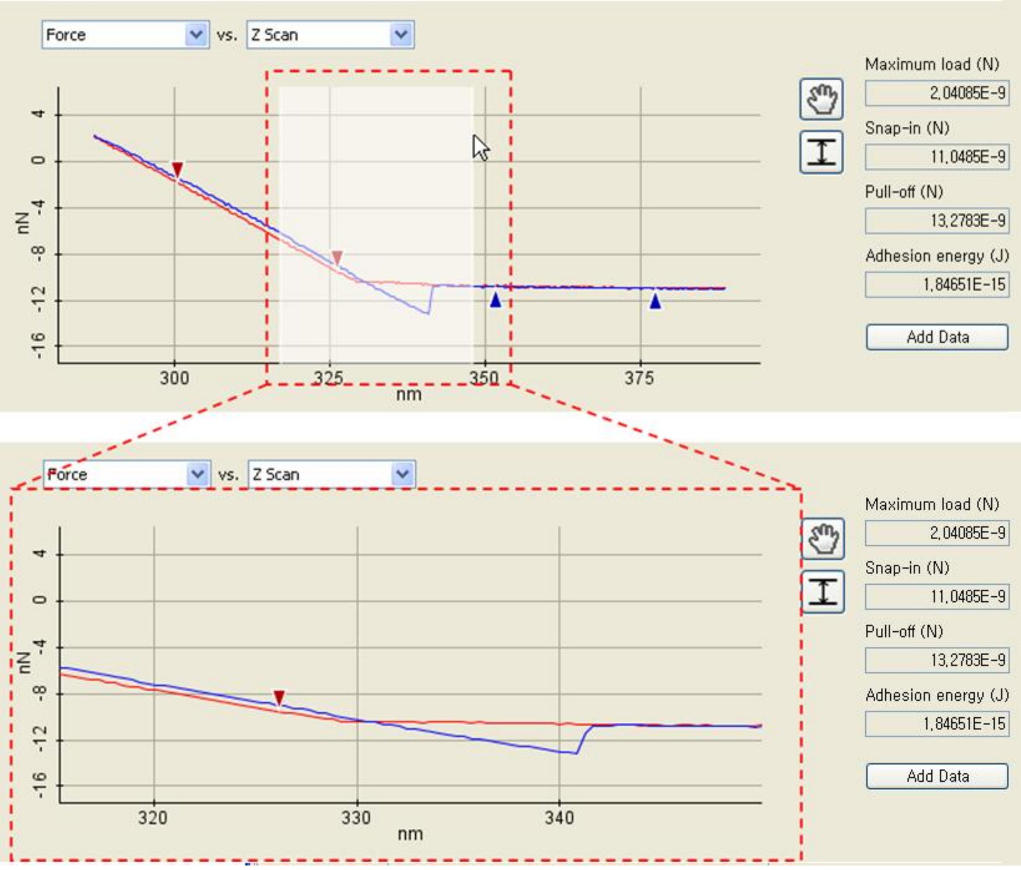
Adhesion energy (J): 1.84651E-15

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)	Angle(deg)
🟥 Trace	25.674	-7.682	300.572	-1.966	326.246	-9.649	-16.659
🟦 Retrace	25.674	-0.128	351.920	-10.906	377.593	-11.034	-0.287

Figure 15-1-8. Line Display Panel

You can change the range of the display with the mouse scroll button. The zoom can be changed by clicking and dragging over an area. To reset the zoom and offset to the default field of view, double-click on the display panel.



Maximum load (N): 2.04085E-9

Snap-in (N): 11.0485E-9

Pull-off (N): 13.2783E-9

Adhesion energy (J): 1.84651E-15

Figure 15-1-9. Zoom in

There are two pairs of cursors, color-coded for their lines. As these cursors are moved, the cursor information table (Section 15-1-2-4) changes to reflect the new locations. The cursors can be clicked and dragged, or moved with pixel precision with the ← and → keys on the keyboard.

Right-clicking on the Line Display will open a context menu.

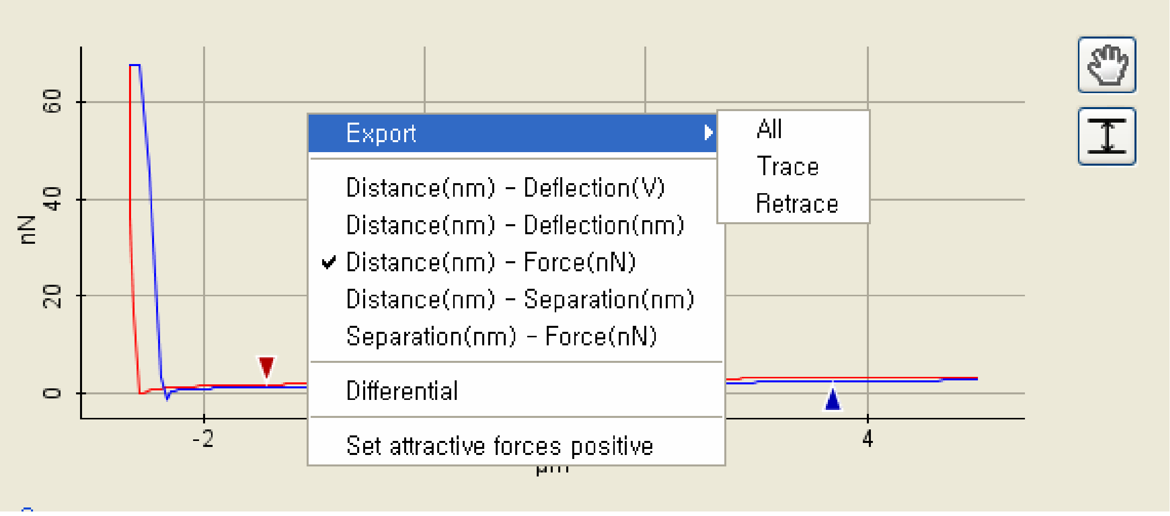

nN
60
40
20
0
-2
4
µm
Export
Distance(nm) - Deflection(V)
Distance(nm) - Deflection(nm)
✔ Distance(nm) - Force(nN)
Distance(nm) - Separation(nm)
Separation(nm) - Force(nN)
Differential
Set attractive forces positive
All
Trace
Retrace

Figure 15-1-10. Line Display context menu

- **Export**

  You can export the trace, retrace, or both trace and retrace lines currently shown.

- **Signal**

  The line can be changed to show different signals. This can also be accomplished by changing the signal in the Signal Selection box.

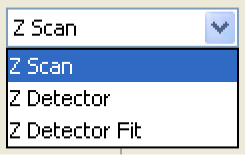
- **Differential**

  Checking this option will change the display to show the first-order differential of the line.

- **Set attractive forces positive**

  This option negates the Y axis for F/D curve analysis.

There are several other useful objects in the Line Display panel.



- **Signal Selection boxes**

  The signal that is represented by the X and Y axes may be changed using these boxes. The options are dependent on the signals saved during acquisition.

- **Panning tool**

  When this is selected, the mouse cursor changes to a hand. You can click and drag the line display to change its offset. Alternatively, you can middle-click and drag for the same effect without this tool selected.

- **Zoom Out**

  When clicked, the display's zoom and offset are reset so that the whole curve is visible.

- **Maximum Load field**

  When an F/D curve is loaded in Batch view, the maximum force in the curve is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Snap-in field**

  When an F/D curve is loaded in Batch view, the snap-in force is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Pull-off field**

  When an F/D curve is loaded in Batch view, the pull-off force is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Adhesion energy field**

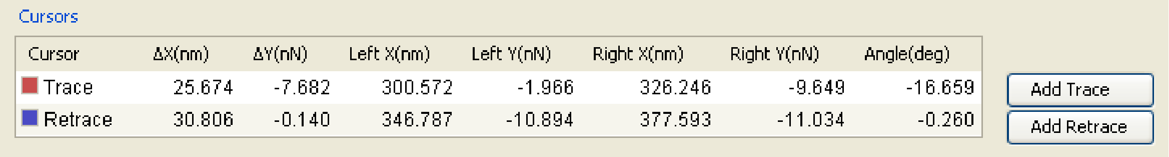
  When an F/D curve is loaded in Batch view, the adhesion energy is calculated and displayed in this field. For detail information, please see XE user’s manual.

- **Add Data button** Add Data

  This button will load the calculated values for Maximum Load, Snap-in, and Pull-off to the Basic Information panel (Section 15-1-2-7).

15-1-2-4. Cursor Statistics Table

The Cursor Statistics Table displays information on the cursors shown in the Line Display. The individual items in this table are defined as follows.



Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)	Angle(deg)
🟥 Trace	25.674	-7.682	300.572	-1.966	326.246	-9.649	-16.659
🟦 Retrace	30.806	-0.140	346.787	-10.894	377.593	-11.034	-0.260

Figure 15-1-11. Cursor Statistics Table

- **ΔX**

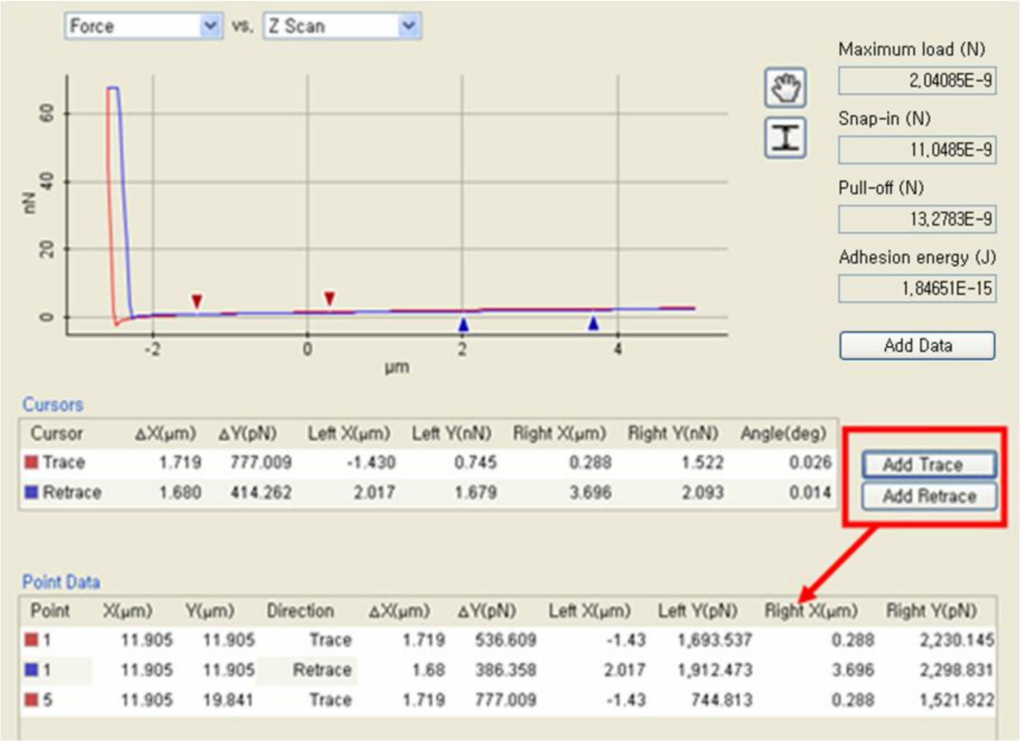
  This item displays the difference in X position between the cursors, or |Left X – Right X|.
- **ΔY**

  This item displays the difference in Y position between the cursors, or |Left Y – Right Y|.
- **Left and Right coordinates**

  The Left and Right cursors’ X and Y values are shown in these fields.
- **Angle**

  This item shows the angle between the two cursors.

The two buttons to the right of the Cursor Information Table, Add Trace and Add Retrace are used to add the forward and backward data to the Point Data Table.



Maximum load (N): 2.04085E-9
Snap-in (N): 11.0485E-9
Pull-off (N): 13.2783E-9
Adhesion energy (J): 1.84651E-15

Cursors

Cursor	ΔX(µm)	ΔY(pN)	Left X(µm)	Left Y(nN)	Right X(µm)	Right Y(nN)	Angle(deg)
🟥 Trace	1.719	777.009	-1.430	0.745	0.288	1.522	0.026
🟦 Retrace	1.680	414.262	2.017	1.679	3.696	2.093	0.014

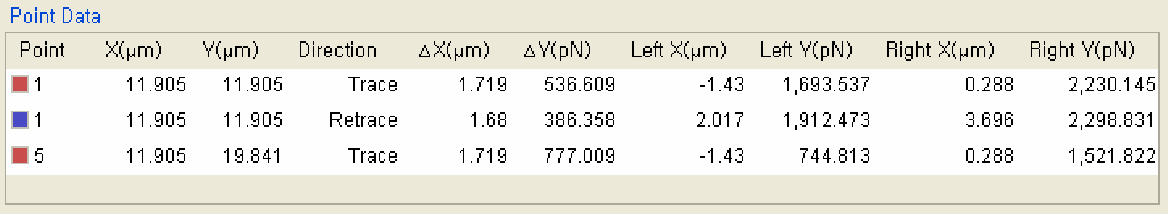
Point Data

Point	X(µm)	Y(µm)	Direction	ΔX(µm)	ΔY(pN)	Left X(µm)	Left Y(pN)	Right X(µm)	Right Y(pN)
🟥 1	11.905	11.905	Trace	1.719	536.609	-1.43	1,693.537	0.288	2,230.145
🟦 1	11.905	11.905	Retrace	1.68	386.358	2.017	1,912.473	3.696	2,298.831
🟥 5	11.905	19.841	Trace	1.719	777.009	-1.43	744.813	0.288	1,521.822

Figure 15-1-12. Addding Trace Lines to Point Data

15-1-2-5. Point Data Table

The Point Data Table displays information about the points selected in the Points Table (Section 15-1-13). The individual items in this table are defined as follows.



Point Data

Point	X(µm)	Y(µm)	Direction	ΔX(µm)	ΔY(pN)	Left X(µm)	Left Y(pN)	Right X(µm)	Right Y(pN)
🟥 1	11.905	11.905	Trace	1.719	536.609	-1.43	1,693.537	0.288	2,230.145
🟦 1	11.905	11.905	Retrace	1.68	386.358	2.017	1,912.473	3.696	2,298.831
🟥 5	11.905	19.841	Trace	1.719	777.009	-1.43	744.813	0.288	1,521.822

Figure 15-1-13. Point Data table

- **X and Y coordinates**

  These fields show the XY scanner's position when this measurement was taken.

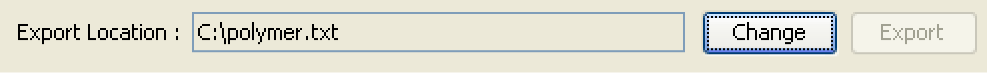
- **Direction**

  The Direction indicates whether this line was acquired in the trace direction (Z scanner extension) or the retrace direction (Z scanner retraction).

The rest of the items in the Point Data Table are the same as those in the Cursor Statistics Table (Section 15-1-2-4).

15-1-2-6. Export Panel

The Export Panel allows for the conversion of the data in the Point Data Table into a text (.txt) format.



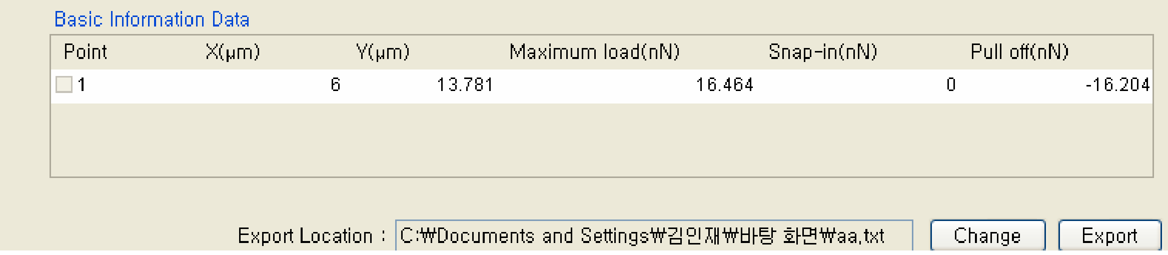
Export Location : C:\polymer.txt

Figure 15-1-14. Export Panel

The Export Panel has three items: the file path field, which shows the name and location of the export file, the Change button, which allows the user to change this name and location, and the Export button, which executes the export.

15-1-2-7. Basic Information Panel

This holds the information selected by clicking the Add Data button in the Image Display panel. It has its own Export panel.



Basic Information Data

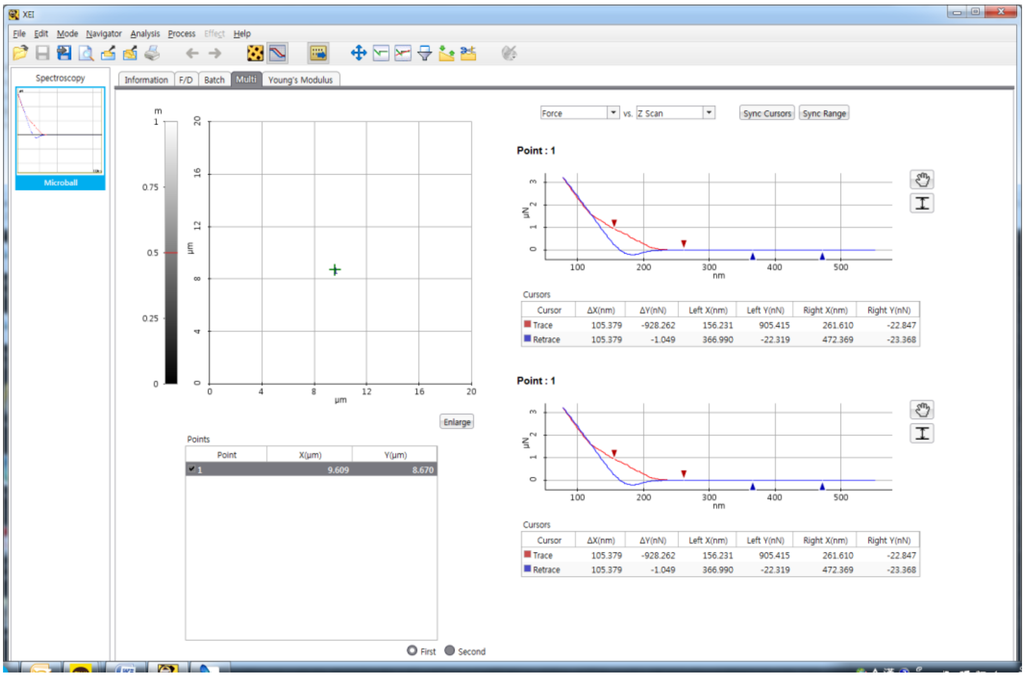
Point	X(μm)	Y(μm)	Maximum load(nN)	Snap-in(nN)	Pull off(nN)
☐ 1	6	13.781	16.464	0	-16.204

Export Location : C:₩Documents and Settings₩김인재₩바탕 화면₩aa.txt

Figure 15-1-15. Basic Information panel

15-1-3. Multi View

Multi View is used for the direct comparison of two curves. It consists of an Image Display panel, Points table, two Line Display panels, and two Cursor Statistics tables.



Points

Point	X(μm)	Y(μm)
☑ 1	9.609	8.670

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)
🟥 Trace	105.379	-928.262	156.231	905.415	261.610	-22.847
🟦 Retrace	105.379	-1.049	366.990	-22.319	472.369	-23.368

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)
🟥 Trace	105.379	-928.262	156.231	905.415	261.610	-22.847
🟦 Retrace	105.379	-1.049	366.990	-22.319	472.369	-23.368

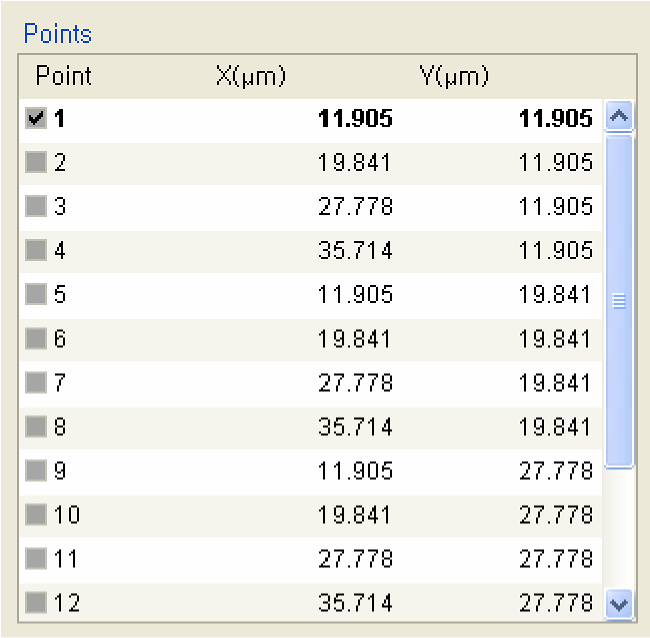
Figure 15-1-16. Multi View

15-1-3-1. Image Display Panel

The Image Display panel shows the reference image taken together with the spectroscopy measurements, if there was one, and the relative locations of the measurements. It is identical to the one in Batch View (Section 15-1-2-1).

15-1-3-2. Points Table

The points table lists all of the spectroscopy measurement points in the currently opened file, as well as their X and Y locations in relation to the XY scanner. Selecting a point in the table will load it to a Line Display panel.



Points

Point	X(µm)	Y(µm)
☑ **1**	**11.905**	**11.905**
☐ 2	19.841	11.905
☐ 3	27.778	11.905
☐ 4	35.714	11.905
☐ 5	11.905	19.841
☐ 6	19.841	19.841
☐ 7	27.778	19.841
☐ 8	35.714	19.841
☐ 9	11.905	27.778
☐ 10	19.841	27.778
☐ 11	27.778	27.778
☐ 12	35.714	27.778

Figure 15-1-17. Points Table

- **Point field**

  The spectroscopy curve's number is displayed in this field. If multiple measurements were saved to the same .tiff file, their order in the Point field indicates the order in which they were taken.

- **X and Y fields**

  The X and Y fields show the XY stage's position when the measurements were taken.

- **First and Second buttons**

  The selected point's curve is displayed on either the first or the second Line Display panel (Section 15-1-3-3), depending on which of these is selected.

15-1-3-3. Line Display Panel

There are two Line Display panels. They are identical to the Line Display panel for Batch View (Section 15-1-2-3).

In Multi View, there are two additional buttons in the first Line Display panel.

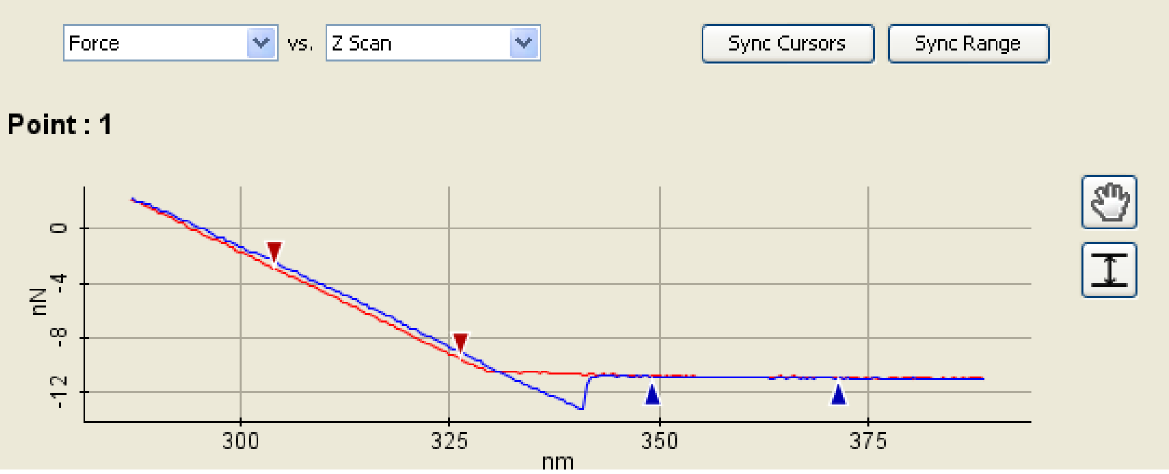


Figure 15-1-18. Line Display panel

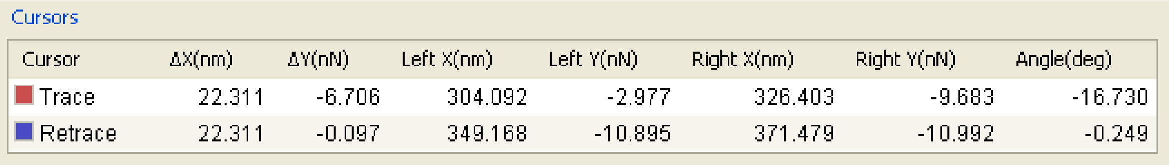
- **Sync Cursors**

  When selected, the positions of the cursors in the two Line Display panels will be matched. Moving a cursor when Sync Cursors is selected will move its corresponding cursor in the other Line Display panel.

- **Sync Range**

  When selected, the field of view of the two Line Display panels will be matched, and changing one will change the other by the same amount.

15-1-3-4. Cursor Statistics Table



Cursors

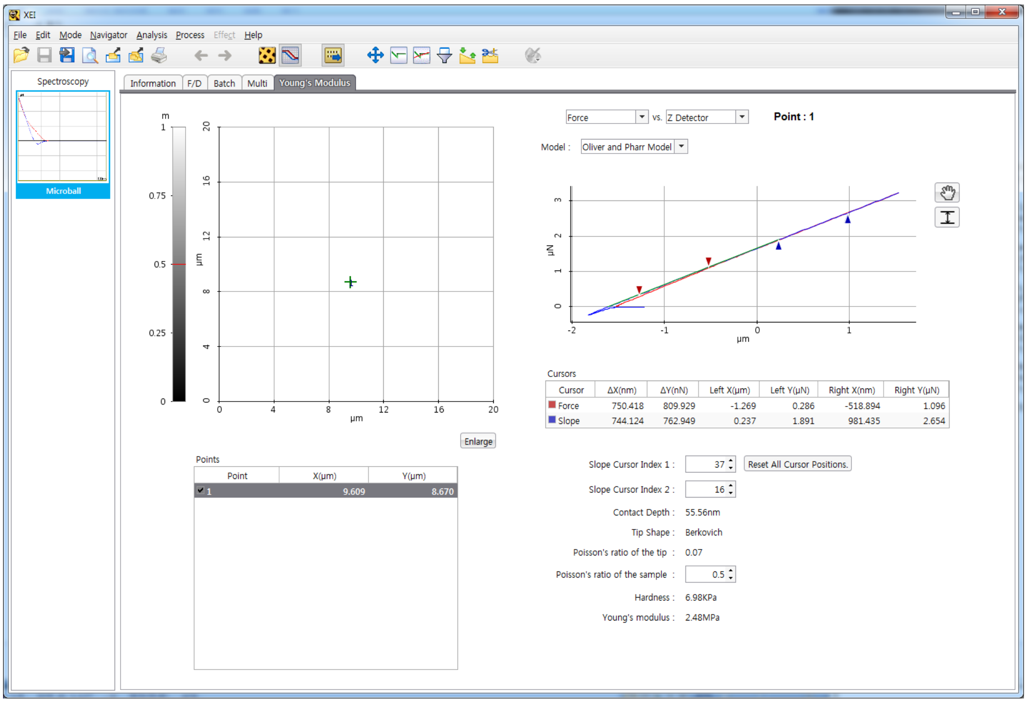
Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)	Angle(deg)
🟥 Trace	22.311	-6.706	304.092	-2.977	326.403	-9.683	-16.730
🟦 Retrace	22.311	-0.097	349.168	-10.895	371.479	-10.992	-0.249

Figure 15-1-19. Cursor Statistics table

There are two Cursor Statistics tables. These tables are identical to the one in Batch View (Section 15-1-2-4).

15-1-4. Young’s Modulus View

Young’s Modulus View is enabled by clicking the Young’s Modulus tab when Spectroscopy Mode is enabled. Young’s Modulus View is designed to support the analysis of F/D and Nano-Indentation curves from XEP. XEI software uses the Hertz and Oliver & Pharr methods to calculate the Young’s Modulus. Please select the proper method according to the sample to calculate the Young’s Modulus.



Force vs. Z Detector

Point : 1

Model : Oliver and Pharr Model

Points

Point	X(µm)	Y(µm)
☑ 1	9.609	8.670

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(µm)	Left Y(µN)	Right X(nm)	Right Y(µN)
🟥 Force	750.418	809.929	-1.269	0.286	-518.894	1.096
🟦 Slope	744.124	762.949	0.237	1.891	981.435	2.654

Slope Cursor Index 1 : 37 Reset All Cursor Positions.

Slope Cursor Index 2 : 16

Contact Depth : 55.56nm

Tip Shape : Berkovich

Poisson's ratio of the tip : 0.07

Poisson's ratio of the sample : 0.5

Hardness : 6.98KPa

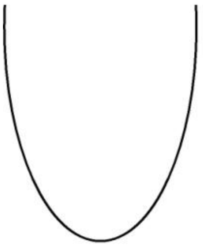
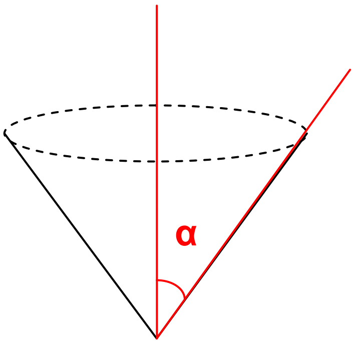
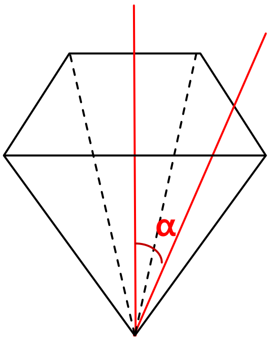
Young's modulus : 2.48MPa

Figure 15-1-20. Young’s Modulus View

15-1-4-1. Methods

- **Hertzian Method**

Hertzian method views the half space for sample/tip as an isotropic, linear elastic solid. On the words, the method assumes no other interaction other than elasticity and therefore no plastic deformation between sample/tip. It will calculate Young’s Modulus of the sample E = F (Loading force, Indentation depth). This equation is influenced by the Indenter tip geometries. Below are equations for E using different tip geometries.

Parabolic	Conical	Four-sided pyramid
		
$F = \frac{4}{3}\frac{E}{1-v^2}\sqrt{R}\delta^{3/2}$	$F = \frac{2\tan\alpha}{\pi}\frac{E}{1-v^2}\delta^2$	$F = \frac{E}{1-v^2}\frac{\tan\alpha}{\sqrt{2}}\delta^2$

R, δ, α and v represent the radius of tip curvature, indentation depth, face angle with respect to vertical direction and poisson's ratio of sample respectively. When sample is soft, such as rubber, v will be set to 0.5. Hence, when acquiring Force-Z displacement curve plot through F/D or Nano-Indentation, the value for E will be calculated. When there are changes on Force-Z displacement, the cantilever will deflect to the opposite direction as tip contacts sample. Hence, in addition to indentation depth, F/k (k=Cantilever Spring Constant) changes must be considered. The revised plot of the cantilever deflection in XEI will transform to display a Force-Separation curve (F, (Z-F/k)), and this will be used for calculating the value for E. For an accurate revision, the cantilever's spring constant (K), and A-B sensitivity (changes on A-B through Z Displacement) must be calibrated prior to the analysis.

■ Oliver-Pharr Method

Oliver-Pharr Method follows Sneddon's assumption that any deformation occurring during unloading is totally due to elasticity. At this point, the relationship between tip and sample can be calculated with the modulus of elasticity.

$$\frac{1}{E_{eff}} = \frac{1-v_s^2}{E_s} + \frac{1-v_i^2}{E_i}$$

E_s: sample's modulus of elasticity

E_i: Tip's modulus of elasticity

(Material for Berkovich tip is diamond, in this case, Ei=1141Gpa, Vi=0.07)

ν_s: Poisson's ratio of sample

E_{eff} represents the converted modulus of elasticity, related to the sample's and tip's modulus of elasticity. Under assumption of Sneddon, the tip is assumed as a rigid solid, and the sample is assumed as homogeneous isotropic elastic half space. The function below explains this contact with E_{eff} and contact stiffness. S, A and β representing the contact stiffness, contact area and tip's shape intercept factor. Contact area is under the influence of the tip geometry. The tip shape intercept factor is 1.034 for a Berkovich tip shape.

$$S = \frac{dF}{dh} = 2\beta E_{eff}\sqrt{\frac{A}{\pi}},$$

According to Sneddon's assumption, when elastic contact is influenced by the tip geometry, Oliver-Pharr acquires the maximum load contact area, and decides contact depth as below function.

$$h_c = h_{max} - h_s = h_{max} - \varepsilon\frac{F_{max}}{S}$$

ε represents the tip's intercept factor, for a Berkovich tip, the factor is 0.75, and for a cone shape tip, the value is 0.72 (current XEI version supports Young's modulus auto calibration only for the Berkovich shape tip). Contact stiffness is acquired after fitting the unloading curve. After the contact depth (h_c) is acquired, the Young's modulus (E_s) for the sample can be acquired. At this point, the indentation hardness (H) can be obtained as '$H=F_{max}/A$' (where the contact area is a function of the tip shape, $A=f(h_c)$) and contact depth (h_c). If the tip is the Berkovich shape, the contact area will be as below function.

$$A = 3\sqrt{3}\,h_c^2\tan^2\theta = 24.5\,h_c^2$$

NOTE!

The indentation hardness acquired is not a conventional material hardness! To acqurie conventional hardness requires different test proccedures.

To calculate the Young's Modulus, XEI uses the difference in the Force (Red) cursor pair, ΔX, to determine the value for $h_{max.}$ The difference in the Depth (Green) curor pair, ΔY, is used to determine the Maximum Load. Stiffness data is calculated from the slope of data between Slope (Green) Cursor Pair after fitting.

Below is schematic diagram of this analysis.

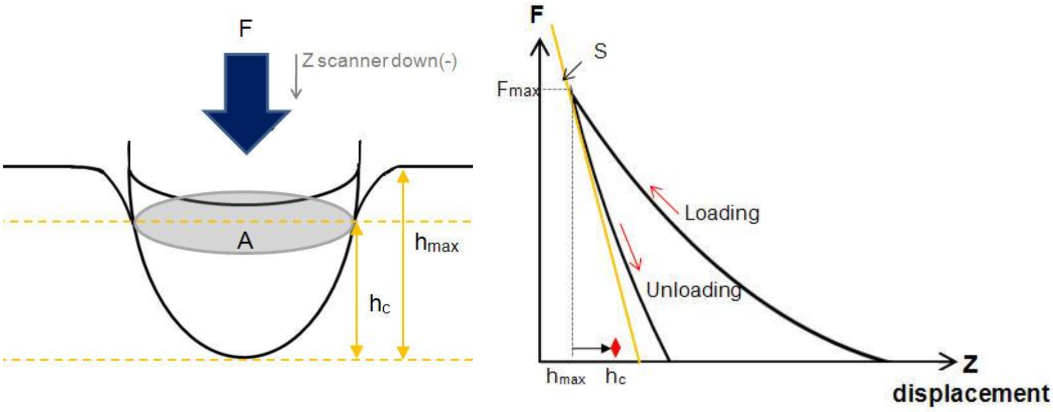


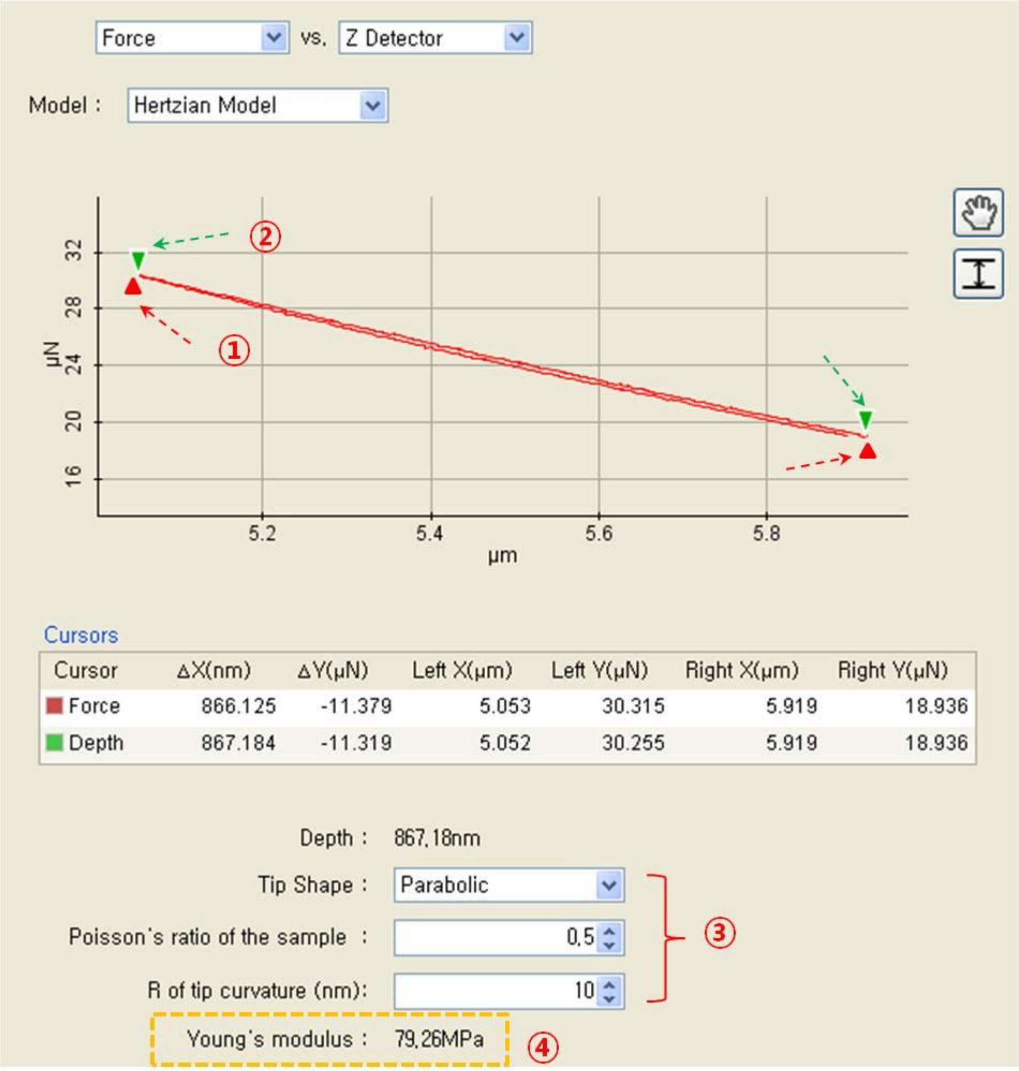
Figure 14-1-21. Calculating Young's Modulus and Hardness(Oliver & Pharr)

15-1-4-2. Acquiring Young's Modulus

Young's Modulus View can be enabled by clicking the Young's Modulus tab when Spectroscopy Mode is enabled. Then, the Spectroscopy data is automatically displayed to 'Separation-Force' for calculating the Young's Modulus.

To get the Young's Modulus from Spectroscopy data, perform Cantilever's Spring Constant (K) and A-B Sensitivity (A-B changes according to Z displacement) calibration prior to the following steps.

- **Hertzian Method**
  1. Place the Force (Red) Cursor Pair at min/max positions of loading force on the loading curve.
  2. Choose the depth position (Loading curve's contact point (right) and end point (left)) by moving the Depth (Green) Cursor Pair on the loading curve.
  3. Input parameters (Tip Shape, Poisson's Ratio of sample, Radius of Tip Curvature)
  4. The Young's Modulus (E) is calculated automatically.



Cursors

Cursor	ΔX(nm)	ΔY(μN)	Left X(μm)	Left Y(μN)	Right X(μm)	Right Y(μN)
🟥 Force	866.125	-11.379	5.053	30.315	5.919	18.936
🟩 Depth	867.184	-11.319	5.052	30.255	5.919	18.936

Depth : 867.18nm

Tip Shape : Parabolic

Poisson's ratio of the sample : 0.5

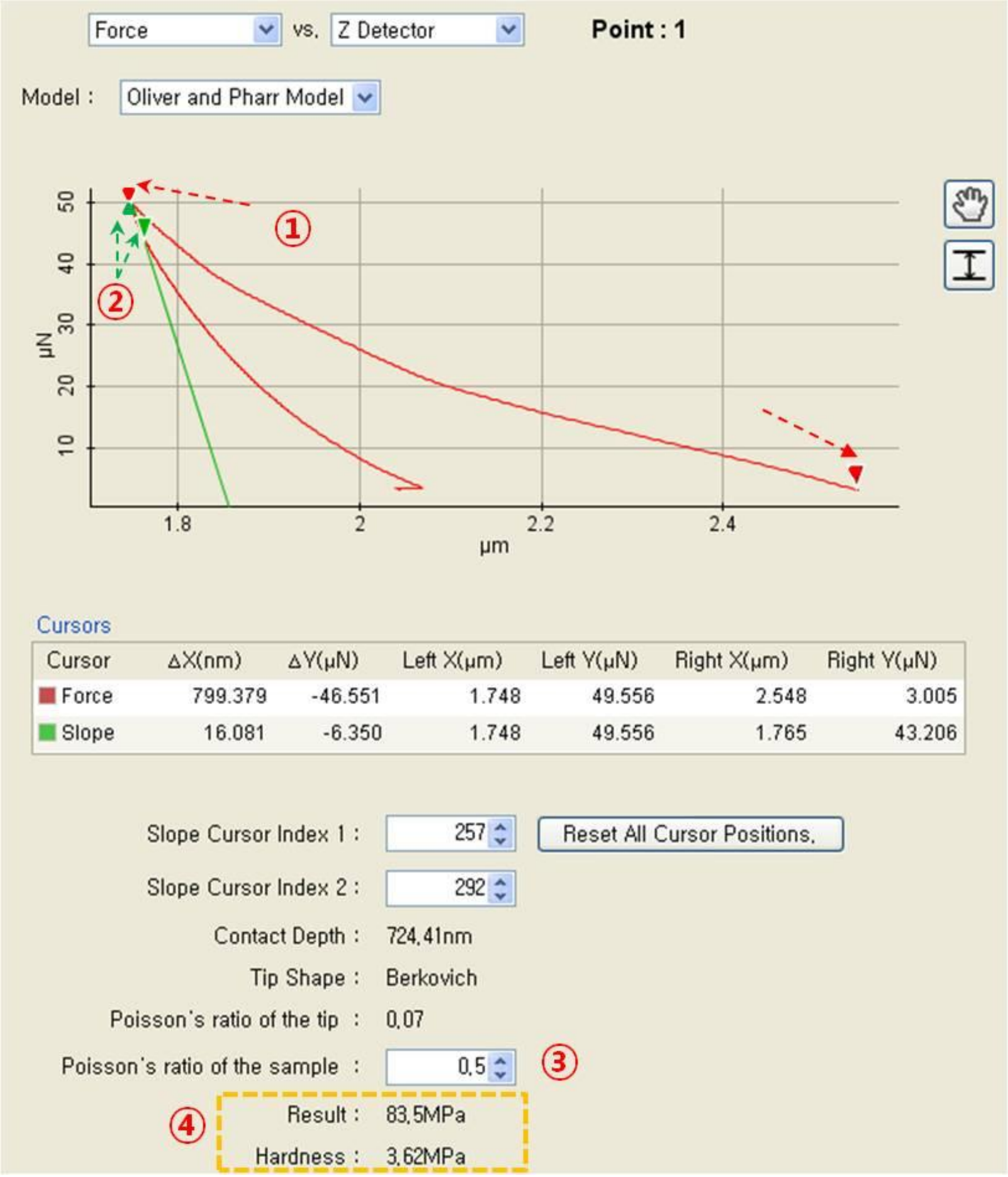
R of tip curvature (nm): 10

Young's modulus : 79.26MPa

Figure 15-1-22. Acquiring Young's Modulus and Hardness(Hertzian)

■ Oliver and Pharr Method

1. Place Force (Red) Cursor Pair at min/max position of loading force on loading curve.
2. Place Slope (Green) Cursor Pair to be at the tangent line of maximum unloading force on unloading curve.
3. Input the Poisson's ratio of the sample.
4. The Young's Modulus (E) and Hardness (H) are calculated automatically.



Cursors

Cursor	ΔX(nm)	ΔY(μN)	Left X(μm)	Left Y(μN)	Right X(μm)	Right Y(μN)
🟥 Force	799.379	-46.551	1.748	49.556	2.548	3.005
🟩 Slope	16.081	-6.350	1.748	49.556	1.765	43.206

Slope Cursor Index 1 : 257

Slope Cursor Index 2 : 292

Contact Depth : 724.41nm

Tip Shape : Berkovich

Poisson's ratio of the tip : 0.07

Poisson's ratio of the sample : 0.5

Result : 83.5MPa

Hardness : 3.62MPa

Figure 15-1-23. Acquiring Young's Modulus and Hardness (Oliver and Pharr)

15-2. Processes

Spectroscopy Mode in XEI provides data processing tools specific to spectroscopy data. These processes may be accessed by clicking on their respective icons in the toolbar, or by selecting them from the Process menu.

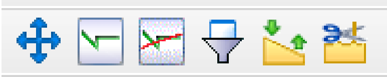
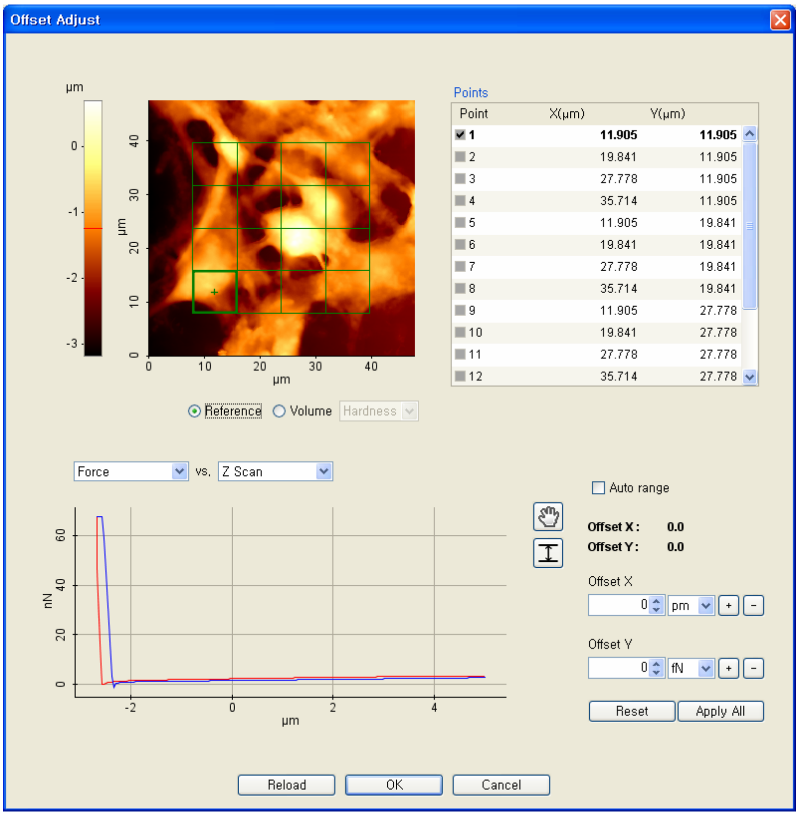


Figure 15-2-1. Process Tool Bar

15-2-1. Offset Adjust

The Offset Adjust process is used to improve correlation between two data sets in Multi View. One can adjust the X and Y offsets by clicking on the + and – buttons. Each click will increment or decrement the offset by the value in the Offset fields. The current total offset is displayed above the control panel.



Offset Adjust

Points

Point	X(µm)	Y(µm)
☑ 1	11.905	11.905
2	19.841	11.905
3	27.778	11.905
4	35.714	11.905
5	11.905	19.841
6	19.841	19.841
7	27.778	19.841
8	35.714	19.841
9	11.905	27.778
10	19.841	27.778
11	27.778	27.778
12	35.714	27.778

● Reference ○ Volume Hardness

Force vs. Z Scan

☐ Auto range

Offset X : 0.0
Offset Y : 0.0

Offset X: 0 pm
Offset Y: 0 fN

Figure 15-2-2. Offset Process dialog

- ### Auto Range

When selected, automatically adjusts the range of the display so that the whole curve is visible.

- ### Offset X and Y labels

The Offset X and Y labels show the current total offset. These change as the + and – buttons are pressed.

- ### Offset X and Y fields

The amount that the + and – buttons increment and decrement from the offset per click is determined by these fields.

- **+ and - buttons**

  Every click of the + button increments the offset, and each click of the – button decrements the offset.

- **Reset**

  Reverts the Offset X and Y to 0.

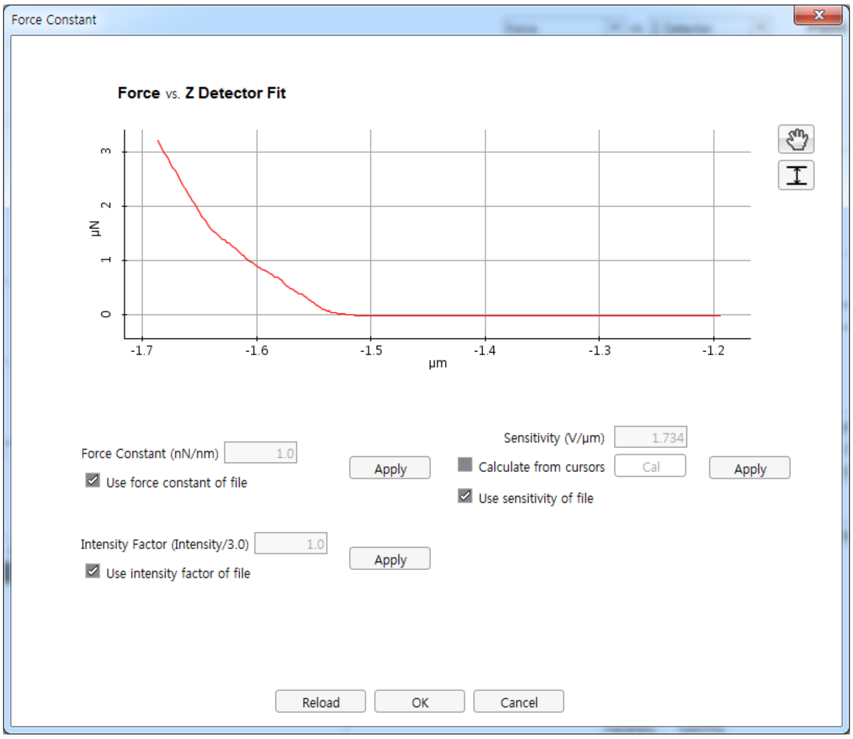
- **Apply All**

  Applies the Offset X and Y to every point in the tiff file.

Clicking the Apply All and OK buttons will permanently change your data.

15-2-2. Force Constant

The Force Constant dialog is used to calculate the force constant of the cantilever from the data.



Force Constant (nN/nm) 1.0

☑ Use force constant of file

Intensity Factor (Intensity/3.0) 1.0

☑ Use intensity factor of file

Sensitivity (V/µm) 1.734

☐ Calculate from cursors

☑ Use sensitivity of file

Figure 15-2-3. Force Constant Process dialog

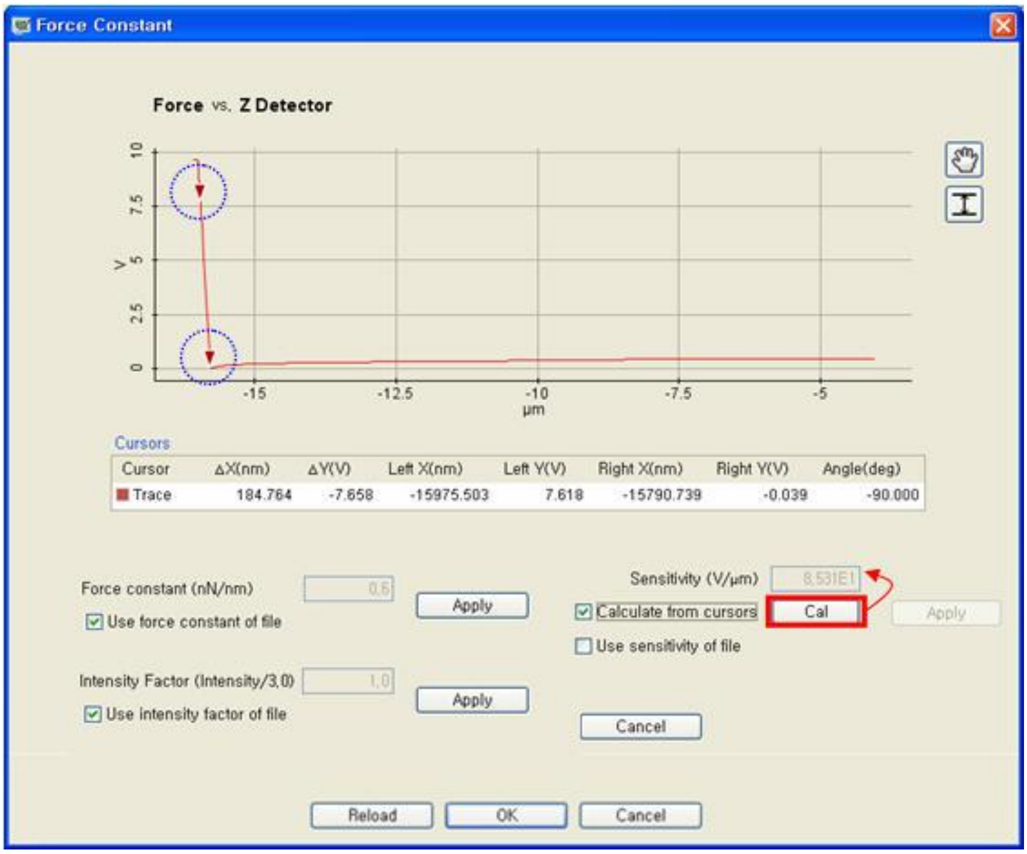
There are three values that can be changed by this process.

15-2-2-1. Force Constant

If the 'Use force constant of file' checkbox is selected, the force constant used when acquiring the image is applied. Deselecting this checkbox will enable the Force constant field, in which the user can input a new value. Clicking the Apply button will save these changes.

15-2-2-2. Sensitivity

The 'Use sensitivity of file' option will apply the sensitivity value that was saved during imaging. Selecting 'Calculate from cursors' will display 2 cursors on the Line Display panel. After moving these cursors, clicking the 'Cal' button will update the sensitivity. Clicking the 'Apply' button will use this new value for measurement analysis.



Cursors

Cursor	ΔX(nm)	ΔY(V)	Left X(nm)	Left Y(V)	Right X(nm)	Right Y(V)	Angle(deg)
🟥 Trace	184.764	-7.658	-15975.503	7.618	-15790.739	-0.039	-90.000

Force constant (nN/nm) 0.6
☑ Use force constant of file

Intensity Factor (Intensity/3.0) 1.0
☑ Use intensity factor of file

Sensitivity (V/µm) 8.531E1
☑ Calculate from cursors
Cal
☐ Use sensitivity of file

Figure 15-2-4. Sensitivity Calibration

15-2-2-3. Intensity factor

(A-B) DC value is influenced by the PSPD beam intensity. Hence, the XE-AFM calculates the force using a beam intensity normalization factor following the function below:

$$\mathbf{Force= (A\text{-}B)DC \times \underset{1\ /\ \text{Intensity Factor}}{\underline{3.0\ (Volt)\ /\ (A+B)}}}$$

The beam intensity factor for normalized as (A+B) / 3.0 (Volt) since XE software assumes that the A+B, beam intensity is 3 Volts. This value is automatically applied to the force calculation.

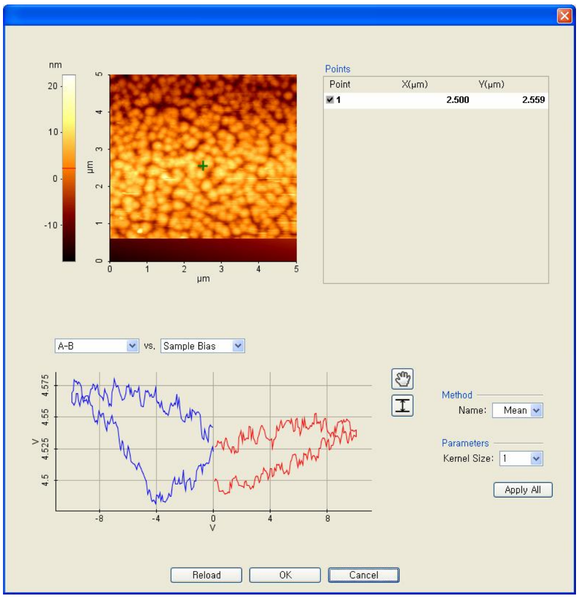
NOTE!

> The intensity factor is properly calculated and saved in the file obtained by the F/D and NanoIndentation Spectroscopy only after the image file is acquired.

If you want to change this value manually, please deselect 'Use intensity factor of file' check box and input the desired value on the activated text field above. Clicking the [Apply] button will use this new value for measurement analysis.

14-2-3. Filter

Filtering can be applied to remove noise from the data.



Points

Point	X(μm)	Y(μm)
☑ 1	2.500	2.559

A-B vs. Sample Bias

Method

Name: Mean

Parameters

Kernel Size: 1

Figure 15-2-5. Filter Process Dialog

As spectroscopy data is two-dimensional, removing noise is performed by taking the average of a data point's neighbors, and assigning that number as the pixel's new value.

- **Method Name**

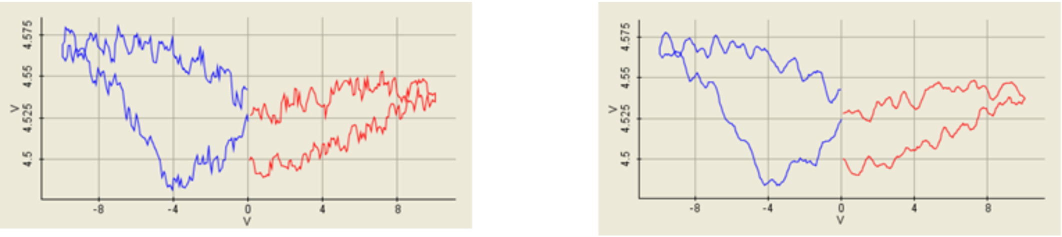
  This parameter decides how the average is calculated. The two options are Mean and Median.

- **Kernel Size**

  The number of neighboring data points to consider is determined by this number. A higher value will result in a smoother curve, but may result in loss of actual data.

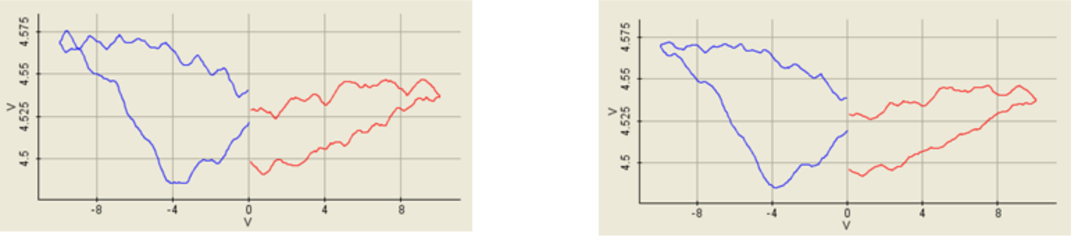
- **Apply All**

  Applies the filter to every curve selected in the Points table.



Kernel Size : 1

Kernel Size : 5



Kernel Size : 9

Kernel Size : 13

Figure 15-2-6. Filtering with Various Kernel Sizes

15-2-4. Flatten

This function is used for the reference image, if there is one. It is identical to the Flatten process for images (Section 2-5-3).

15-2-5. Deglitch

This function is used for the reference image, if there is one. It is identical to the Deglitch process for images (Section 2-5-4).

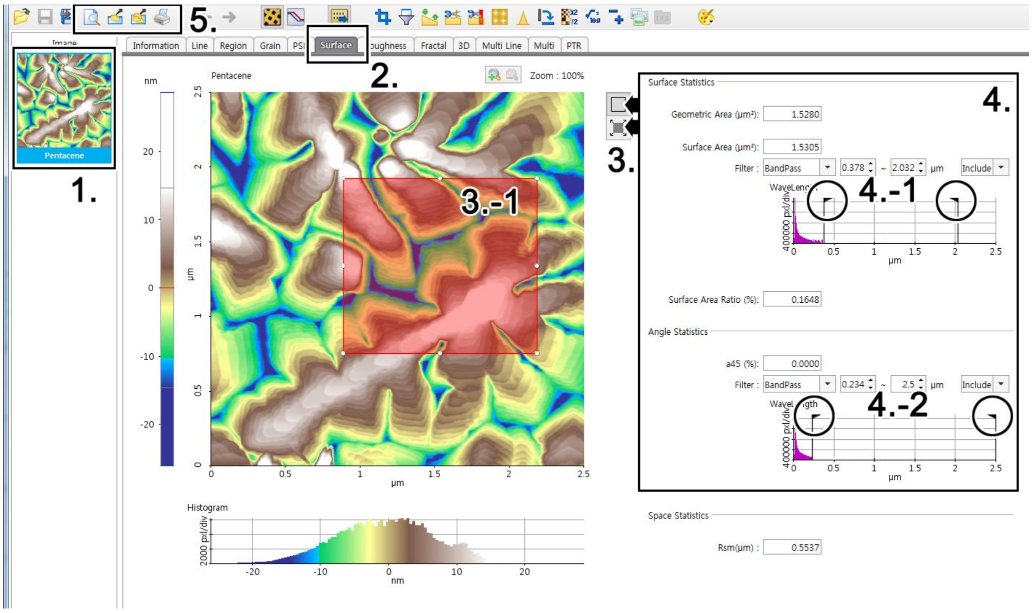
Chapter 16. Surface Analysis

In the Surface view, you can measure and analyze surface area of an image. You can make quantitative measurements of surface features in the selected regions and collect surface statistics such as geometric area, surface area and surface area ratio. These statistical values are displayed on the right of image.

In general, you can go through the following steps in Surface Analysis View:

1. Load an image you want to analyze into the Analysis view from the Navigator view.
2. Select the Surface view.
3. Select region of the image like Region Analysis view(Entire area or rectangle).
4. Once selecting region, the statistical values are generated with results and updated whenever the change of the selected region occurs.
5. Filter if needed.
6. Save and print your Surface view results

Figure 16-1 shows the summarized procedure to analyze the region of an image.



Geometric Area (μm²): 1.5280

Surface Area (μm²): 1.5305

Filter : BandPass 0.378 ~ 2.032 μm Include

Surface Area Ratio (%): 0.1648

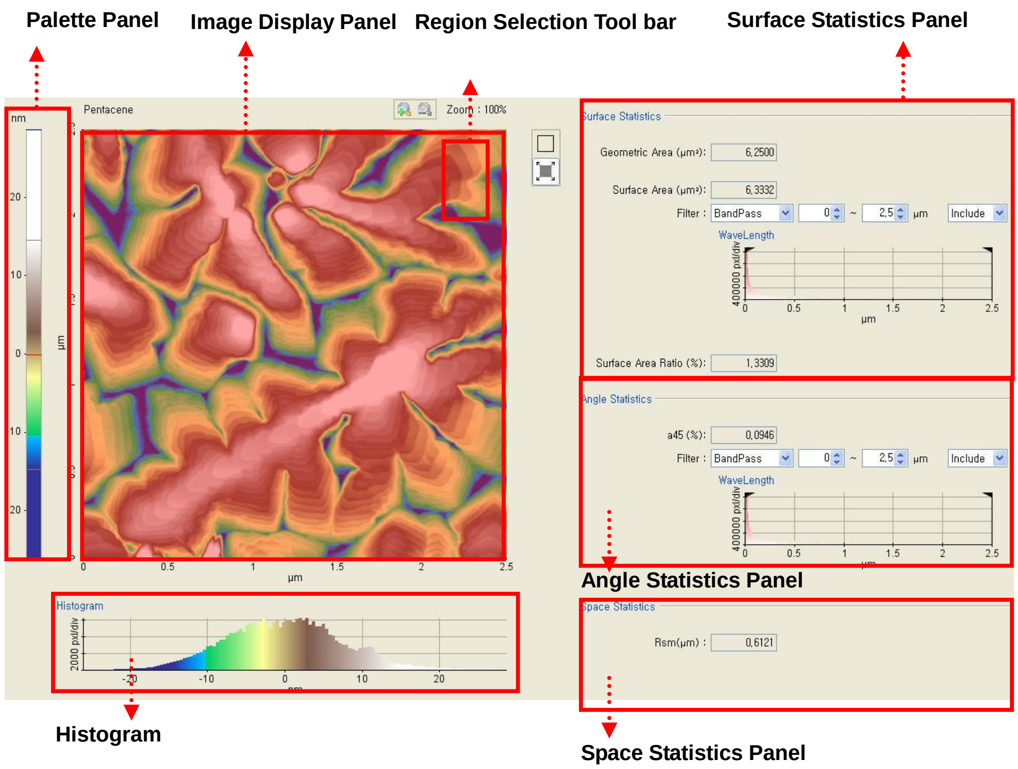
a45 (%): 0.0000

Filter : BandPass 0.234 ~ 2.5 μm Include

Rsm(μm) : 0.5537

Figure 16-1. Procedure for Region view

To enable the Surface view, select ‘Analysis>Surface’ menu or click the Surface tab below the Toolbar. The Surface view consists of the Palette Panel, Image Display Panel, Region Selection Toolbar, Region Histogram, Surface Statistics Panel, Angle Statistics Panel, Space Statistics. Figure 16-2 shows the Surface view that is divided into several parts.



Geometric Area (µm²): 6.2500

Surface Area (µm²): 6.3332

Filter : BandPass 0 ~ 2.5 µm Include

Surface Area Ratio (%): 1.3309

a45 (%): 0.0946

Filter : BandPass 0 ~ 2.5 µm Include

Rsm(µm) : 0.6121

Figure 16-2. Surface view

16-1. Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel. It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI. Please refer to Chapter 3-2 and 3-3 for details.

Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views.

16-2. Region Selection toolbar

Region selection toolbar, where the Tools for selecting region for the analysis are gathered, is at the right side of the Image Display Panel.

- **Rectangle** ☐

Currently, you can create a specific place by using ‘Rectangle’ ☐ button. Then press the cursor at the point you want to create the top-left corner of a ‘selected area’, and drag the mouse pointer at the point you want to create bottom-right corner of a ‘selected area’.

- **Entire Region** ▣

To set the entire image as ‘selected area’, click the ‘Entire Region’ button.

16-3. Surface Statistics Panel

On the right of the Image Display Panel, the Surface Statistics Panel is shown. The Surface Statistics Panel, shown in Figure 16-2, displays the surface statistics of the all data points in the selected region. The results of the statistics on the selected region are updated automatically when you change the selected region by resizing or moving the region selector. Values are related to surface, hence those data that uses metric unite of X, Y, and Z, which are topography, and Z detector data.

- **Geometric Area (μm^2)**

Area of selected region (plane)

- **Surface Area (μm^2)**

Suppose surface area as 1 by 1pixel. 1 by 1pixel is an area composed with four different points. As shown in Figure 16-3-1, each point’ height values are named as Z1, Z2, Z3, and Z4. Z5 is calculated as average high value from Z1 to Z4 and located in the middle of them. Now, there are four surface (A1, A2, A3, and A4), which adds up for area of 1 by 1 pixel. This is how surface area is calculated.

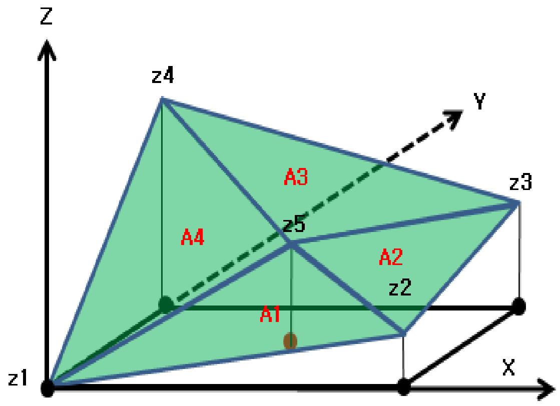


Figure 16-3-1. 1 by 1 pixel surface area

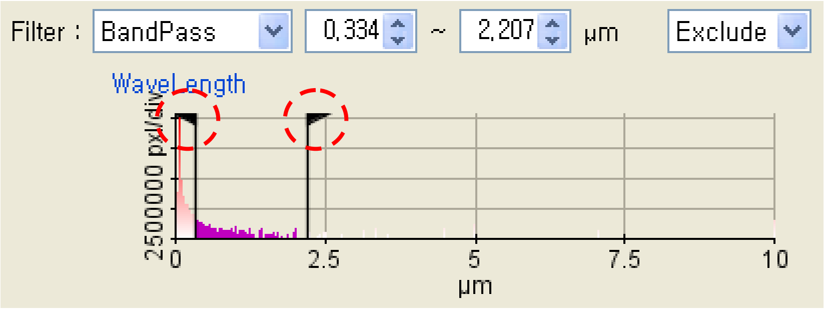
■ Surface Area Ratio(%)

100(%) x (Geometric Area – Surface Area) / (Geometric Area)

■ Filter

Histogram of surface area is displayed when selecting bandpass filter. In Histogram, X axis indicates wavelength of surface area, and Y axis indicates magnitude of normal vector on wavelength. Within ‘Height restriction markers’, there are two flags (as lower and upper) displayed, using them, wavelength can be exclude/include in selected area for filtering.

For example, click on down arrow button then select ‘Exclude’, drag these two ‘Height restriction Markers’ on the each side of the histogram to set the lower and upper value of the pixels to be selected. Pixels with the wavelength lower than the ‘Lower Height restriction Marker’ or higher than the ‘Upper Height restriction Marker’ will be excluded from the surface area analysis. Pixels that are excluded from the analysis are marked in violet color at Palette bar. The ‘Height restriction marker’ is located on top of Histogram. If ‘Filter’ option is not desired, ‘None’ can be selected.



Filter : BandPass 0.334 ~ 2.207 µm Exclude

Figure 16-3-2. Filter

15-4. Angle Statistics Panel

On the right of the Image display panel, the Angle Statistics panel is shown. The Angle Statistics panel, shown in Figure 15-2, displays the angle statistics of the all data points in the selected region. The results of the statistics on the selected region are updated automatically when you change the selected region by resizing or moving the region selector. Values are related to surface angle, hence those data that uses Metric unite of X, Y, and Z, which are topography, and Z detector data.

- **a45(%)**

Suppose surface area as four points of 1 by 1pixel. Green triangle, made of three points' (one datum point and two adjacent points) height, goes exceeds over 45°. It represents the ratio between number of 1 by 1pixel area and green triangle, made of three points' (one datum point and two adjacent points) height, where exceeds over 45° per white plane. With this function, level of roughness in surface area can be distinguished.

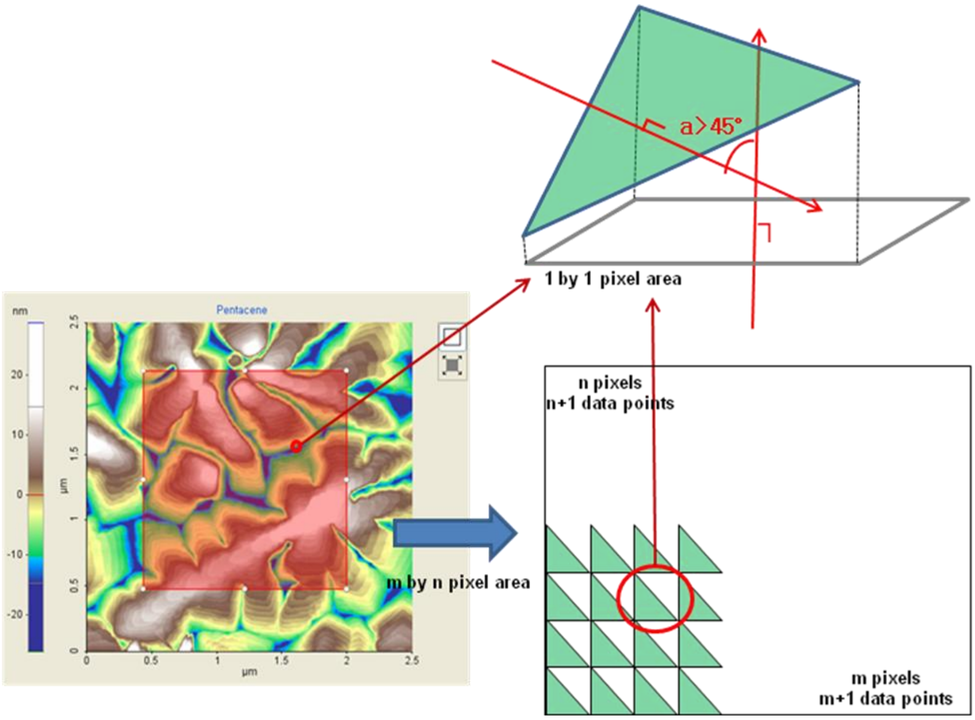


Figure 16-3-3. a45

■ Filter

Filter for ‘a45’ value is selectable. Bandpass filter is supported. It is same option in surface area. Therefore, for detail information, please see Section 16-3.

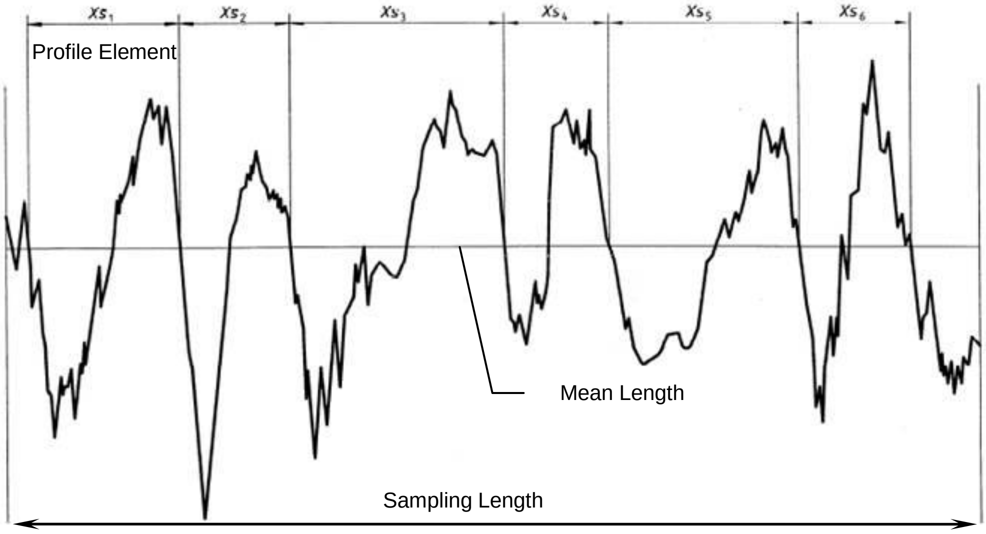
16-5. Space Statistics Panel

On the right of the Image display panel, the Space Statistics panel is shown. The Space Statistics panel, shown in Figure 16-2, displays average line space statistic of the selected region. The results of the statistics on the selected region are updated automatically when you change the selected region by resizing or moving the region selector.

■ RSm

Mean ‘RSm’ of the line profiles in the fast scan direction is displayed. (The Mean width of the profile elements($X_{s)}$ within a sampling length is defined as ‘RSm’ from ISO 4287_1997.)

$$RSm = \frac{1}{m}\sum_{i=1}^{m} Xs_i$$



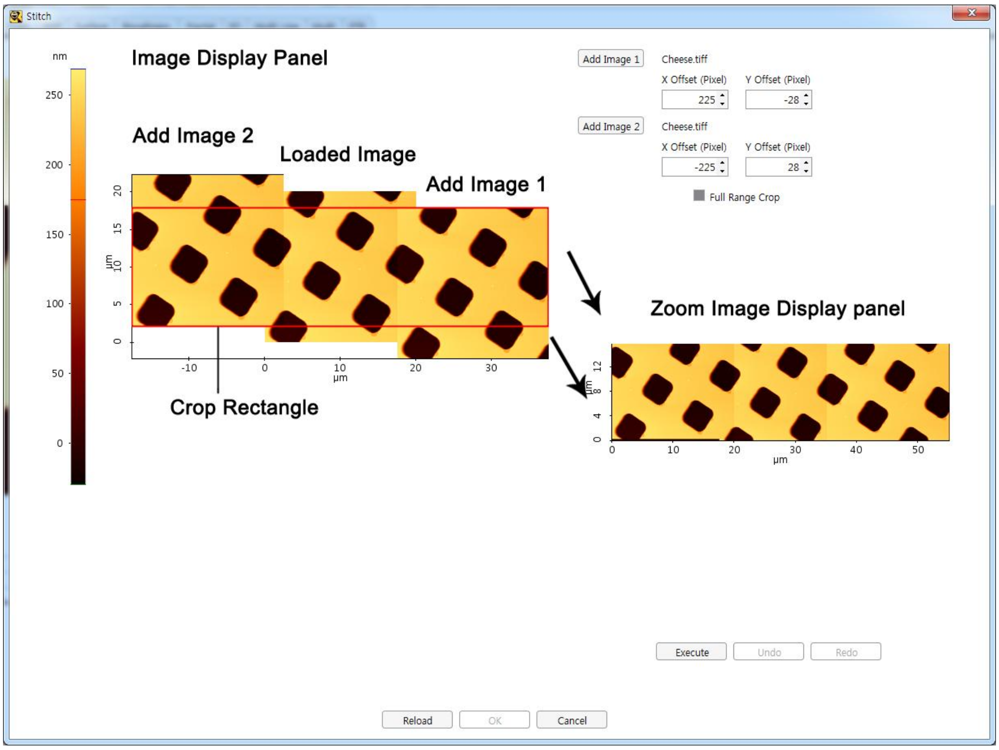
(From ISO 4287_1997)

Chapter 17. Stitch

Using the Stitch Processing tool, images can be stitched together.

17-1. Stitch Process Dialog

To open the Stitch process dialog, select [Process>Stitch] in the Menu or click the icon in the Toolbar. The Stitch process dialog is composed of two panels, the Image display panel and the Zoom Image Display panel, this is similar to the Crop process dialog. Figure 17-1-1 shows the Stitch process dialog.



Add Image 1: Cheese.tiff
X Offset (Pixel): 225
Y Offset (Pixel): -28

Add Image 2: Cheese.tiff
X Offset (Pixel): -225
Y Offset (Pixel): 28

Figure 17-1-1. Stitch process dialog

- **Add Image 1(2)**

  Opens a dialog box where you can choose the desired data files. Images will be displayed in Image Display Panel and its' file name will appear on the right. The selected file can be moved by inputting offset values for X/Y pixel. For example, in Figure 17-1-1, the initial loaded image is 256x256 pixels and pixel offsets of Image 1 is 225, -28 and for Image 2 is -225, 28.

- **Execute**

  Crops the selected region (crop rectangle) and displays the image in the Image Display panel.

- **Undo**

  Undo the previous command.

- **Redo**

  Redo the previous command.

- **Reload**

  Initializes the Stitch Process Dialog.

- **Okay**

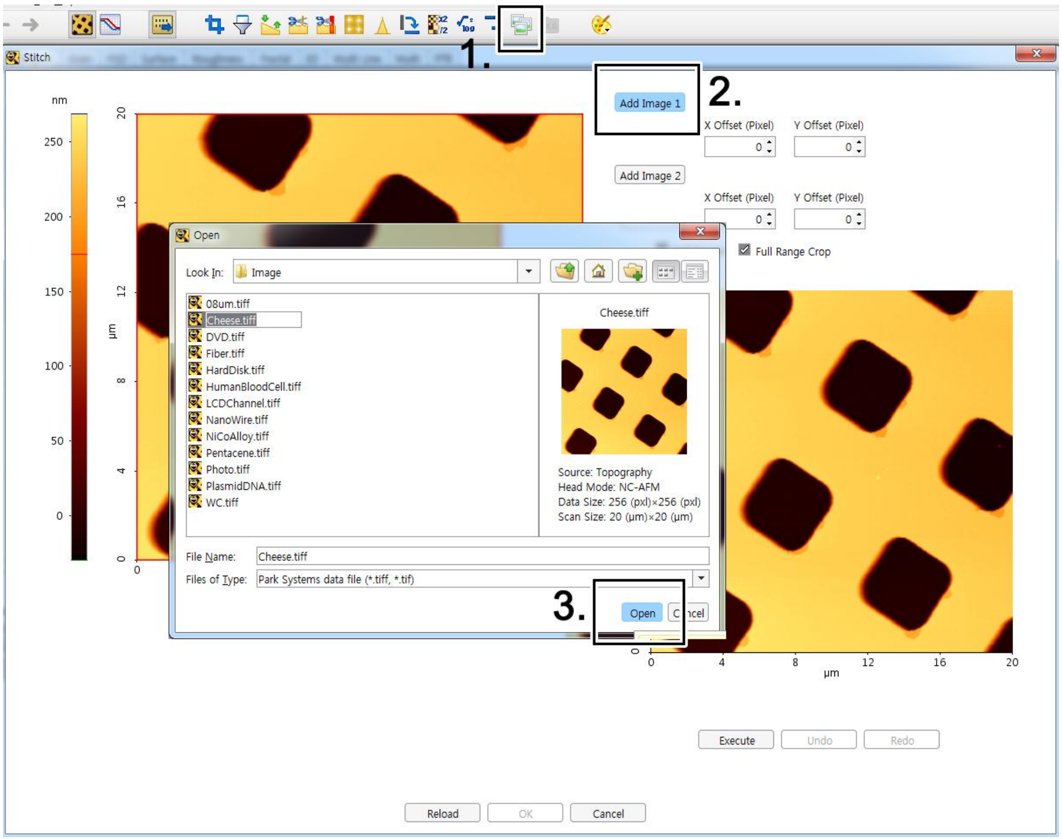
  Saves the Cropped image and closes the Stitch Process Dialog.

- **Cancel**

  Stops Stitch Process and closes the window.

17-2. Stitching Images

Loads an image file into the Analysis view from the Image Navigator view. To stitch images together, perform the following steps:



X Offset (Pixel): 0
Y Offset (Pixel): 0

X Offset (Pixel): 0
Y Offset (Pixel): 0

☑ Full Range Crop

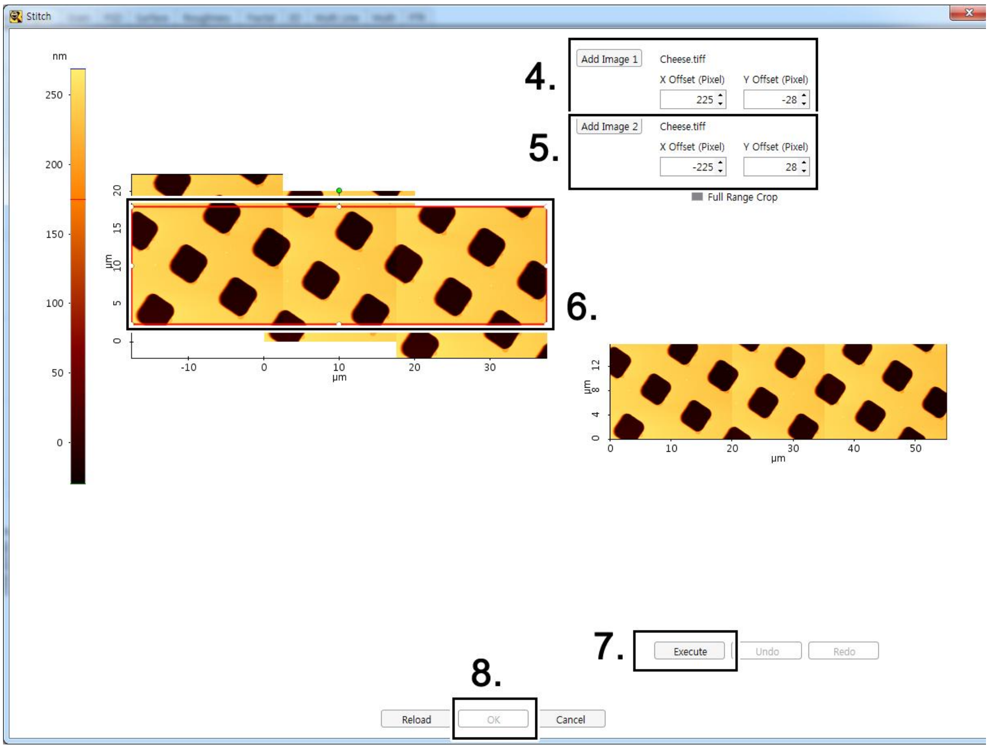
Look In: Image

08um.tiff
Cheese.tiff
DVD.tiff
Fiber.tiff
HardDisk.tiff
HumanBloodCell.tiff
LCDChannel.tiff
NanoWire.tiff
NiCoAlloy.tiff
Pentacene.tiff
Photo.tiff
PlasmidDNA.tiff
WC.tiff

Cheese.tiff
Source: Topography
Head Mode: NC-AFM
Data Size: 256 (pxl)×256 (pxl)
Scan Size: 20 (µm)×20 (µm)

File Name: Cheese.tiff
Files of Type: Park Systems data file (*.tiff, *.tif)

1. Open the stitching dialog by clicking [process->stitch] or by clicking the icon in the Toolbar.
2. Add the image file by clicking the [Add Image 1(2)] button.
3. Select the desired image and click the [Open] button. Then, the selected image will be shown in the Image Display panel.



Add Image 1: Cheese.tiff — X Offset (Pixel): 225, Y Offset (Pixel): -28

Add Image 2: Cheese.tiff — X Offset (Pixel): -225, Y Offset (Pixel): 28

4. Adjust the image position by adding X,Y pixel offsets in the text field of added image file as desired.
5. Move the crop rectangle over the region to be cropped. Once you are satisfied with the new area in Zoom Image Display panel, click the [Execute] button and the [OK] button to create a newly cropped image that will be generated with a default name of ‘original name + stitched.tiff’ in the Image Navigator view. The cropped image will automatically be displayed in the Image Display panel.
6. Save the cropped stitched image as another file name for further image processing and analysis.

Appendix A. XEI Keyboard Shortcut

For each window in XEI, a keyboard shortcut is available. Please refer to the table below.

Shortcut	Menu window	Function
ESC	All Process View	Cancel
Right and Left arrow ← / →	- Region Analysis View >Region Histogram View -Line Analysis View>Line Profile View	Selected cursor can be moved
	Line Analysis View>Line Profile View	Selected line will move by pixel.
	Image Navigator Panel	Move images to choose
Ctrl + A	-Line Analysis View, Region Analysis View, Flatten Process View>Image View -Multi View	Select all shapes
Delete	-Line Analysis View, Region Analysis View, Flatten Process View>Image View -Multi View	Delete selected shape
	Line Analysis View>Line Profile View	Delete selected cursor
Enter	Image Navigator Panel	Load selected image

Index

1

1

  1 Visual Ratio 73

2

2D Power Spectrum 176

3

3D view 33, 121, 122

A

a45 240

Analysis 27

Analysis tab 3

Analysis view screen 3

Angle Statistics 240

  Filter 241

arithmetic filter 149

Axis Options 112

B

Batch Export 24

Bearing Ratio 92

Binary Arithmetic 199

Box Counting 118

C

Conservative 152

Contrast

  Level Adjustment 50

  Max 49

  Min 49

  range 49

Copy 26

Copy to Clipboard 78, 80

Crop 145

Crop Process Dialog 145

Cut 26

D

Data Gain 61

Deglitch 37, 165, 169

Delete 7, 26

Delete All 7

E

Edit 26, 27

Edit Data range 49

Effect 45

Enable Ambient Light 129

Enable Perspective 130

Enhanced Color 51

Exclusion 87, 157

Exit 24

Export 20, 74, 79, 91

Export Panel 217

F

F1114

Fast Scan Dir 60

Fast Scan direction 59

File 17

Fill Border 134, 135

Filter...36
Filter Level..100
Filter process dialog....................................149
Flatten 37
Flattening 155
Fourier Filter...38
Fourier Filter..175
Fractal View..115
Full
  Data range...50
  Palette Range..50
Full Data range..49

G

Gaussian Blur..151
Geometric Area 238
glitch 165, 169
Grain view..31
Grain View 97

H

Height Restriction Markers............................90
Help...46
High Pass 152
histogram 55
Horizontal Unit 80

I

Image
  Copy to Clipboard 55
  Export...54
  Load..53
Image display panel 3, 53
Inclusion...87, 157
Information table...58
Information view.....................................28, 47
Insert a cursor pair...................................74, 93
Interpolation..76, 117
Isotropic Z scale 128

K

kernel matrix 149
Keyboard Shortcut 249

L

Laplacian 153
Laplacian of Gaussian 152
leveling... 77
Light 129
Line Histogram Panel 81
Line Profile Panel 73, 160
Line scope 159
Line selection toolbar................................... 66
Line Statistics table 79
Line view...29, 63, 65
Load 6
Low Pass Filter 59
Luminosity 129

M

Max..81, 94
Mean..81, 94
Mean Filter... 150
Median 151
Menu Bar... 2
Mid 81, 94
Min 81, 94
Move 73
Move Tool 89
  Line.. 71
Multi view...34, 139

N

Navigator View 5

O

Orientation 160
Over Scan 59

P

P12 114
Palette 45
Palette panel 48
Pan 53
Partitioning 118
Paste 26
Pixel Manipulation 191
Position 129
Power Spectrum Panel 78
Preferences 22
Preview 19
Print 22
Priority 184
Process 35
Profile Range 77
PS Version 58
PSD 2D 110
PSD Graphs 109
PSD View 107
PSD X(Y) 110
PSD1 114

R

Ra 81, 95
Range 95
Redo 26
Reflexibility 129
Region Deglitch 169
Region Histogram Panel 91
Region selection toolbar 86
Region Selection Toolbar 157
Region Statistics table 94
Region view 30, 83
Region View 85
Regression Order 160
Reopen 7
Reset Bounds 98
Resolution 125
Restore Defaults 128, 137
Restore Grain 103
Rku 81, 95
RMS 81, 95
Roberts 153
Rotate & Flip 187
Rotation 128
Rotation Angle 60
Rpv 81
Rq12 114
Rsk 81, 95
Rz 81, 95

S

Sample Bias 61
Sampling Number 126
Save 19
Save As 19
Save warning 19
Scale 128
Scan Rate 60
Scientific Notation 80
Scope 159
Select All 26
Set Point 60
Show Hills 103

Show Items 80
Show Number 103
Show Valleys..103
Show Wire Frame 131
Show XY Axis 132
Show Z Axis...133
Sine Scan..59
Slow Scan Dir 60
Sobel 153
Spectroscopy Mode 205
Spectroscopy Processes................................227
Stitch 243
Surface Analysis...235
Surface Area...238
  Filter 239
Surface Area Ratio 239
Surface Statistics 238
Surface view 235

T

Threshold 98
Tip Bias...60
Tip Estimation..181
Tip shape..183
Tip size...184
Title Bar 2
Toolbar...3
Transform... 127
Translation 128
Triangulation 118

U

Unary Arithmetic... 195
Undo.. 26
Uninstallation 7

W

Watershed... 99
Whole scope.. 159

X

X Offset 60

Y

Y Offset 60
Young’s Modulus 221
  Hertzian Method 221
  Oliver-Pharr Method............................... 222

Z

Zoom In... 52
Zoom out 52
Zoom Out 73
Zoomed Image Panel............................166, 171

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