Thermal Evaporator Kurt J. Lesker PVD 75

Version: May 10, 2023

This document provides short system description and short operation procedure of the PVD75. Official training is required for all users. Additional training is required for recipe writing.

General System Information : This Kurt J. Lesker PVD 75 deposition system equipped with only thermal deposition sources. Three thermal sources and one low temperature thermal evaporation source for organic materials. All sources can be loaded for multiple layer depositions, but source two and three are shearing a single power supply and a single shutter, therefore these sources can not be used at the same time. The system can process samples up to 20 cm in diameter. Almost all materials are approved in the system. Check the melting and evaporation temperatures for your material, for more details see the list of deposition materials. Other features include substrate rotation; substrate heating up to 350°C and two different gas inlets are available.
The system vacuum pumps are recipe controlled for safe and efficient use. Never run any procedure manually. Reaching the operation vacuum (5×10^{-5} Torr) can be reached in between 10 to 15 minutes, venting the camber can take as long as evacuation time. Evacuation overnight will lead to maximum vacuum around 10^{-8} Torr. The mechanical movements of the shutters are controlled by compressed air (3 bar) and the process chamber vented by pure nitrogen (6 bar).

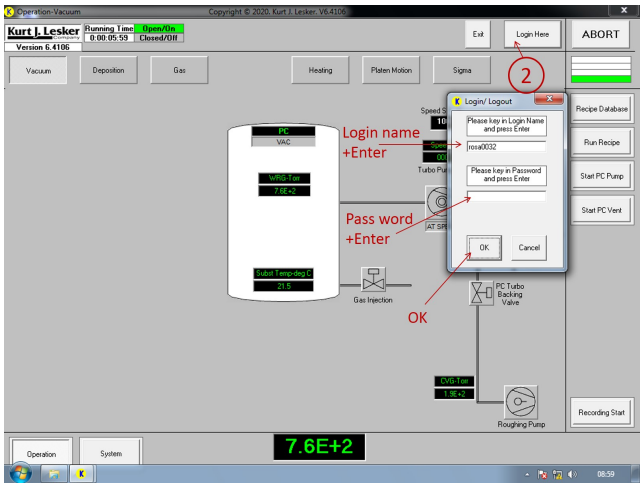
General Operating Instruction : All depositions are recipe controlled. Each recipe is programed for a specific material. A recipe for any material can be created in any of the four thermal sources. As a user, you have only the permission to run an existing recipe or copy it to your account, modify the layer thickness and running the recipe. Users have no permission to create a new recipe for any new material. Do not test functions you do not need by clicking on buttons for curiosity reasons. This can cause serious software or hardware damages.
Never start/stop any part manually.
Main system power supply, gas supply, compressed air supply, water cooling will kept always ON. As a user, you start by logging in and ending by logging off. The operation software and Sigma screen will kept always active. Vacuum pumps are kept off when the system is not used.

WARNING: Use caution when removing the substrate from the chamber, it may be hot. Do not view the evaporation process without proper eye protection! This means that the use welderâĂŹs Shade 9 glass (at least Shade 9) should be used at all times to observe the heater. Eye damage can occur from looking at the Evaporation process without adequate eye protection.

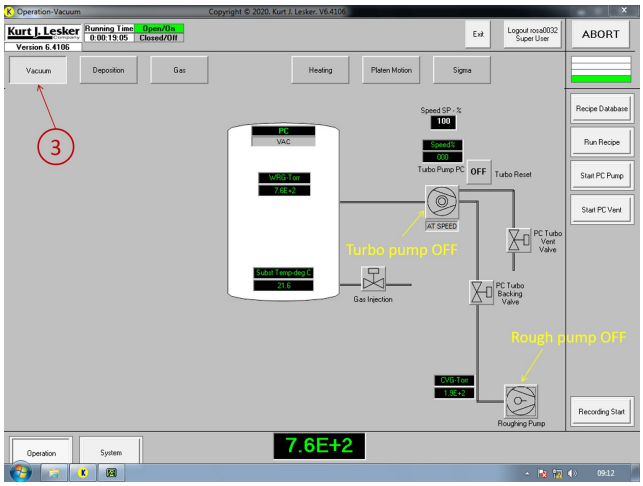
A : THERMAL EVAPORATION

Login and check system

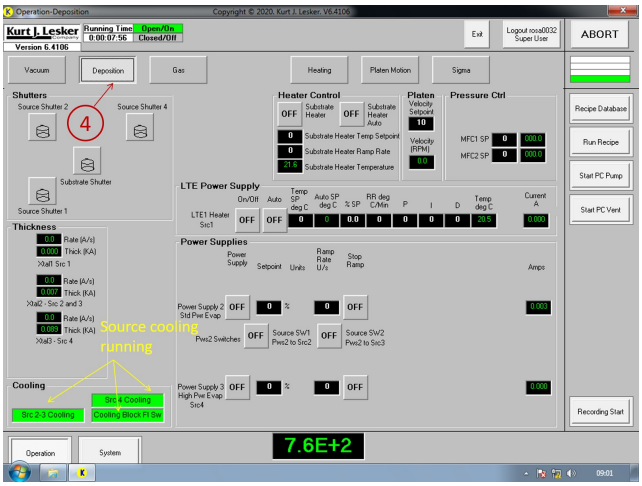
1. If it was not already ON? Start software "**CWare**" (found on the Desktop). In normal case you will find the software ready to use.
2. Log in using with your login name (CAS id) and your password. Key in your user name and press Enter, then key in your password and press Enter again. OK button appears, press "**OK**".



3. Check the pumps status in "**Vacuum**" software runtime screen. Green means ON, gray means OFF.



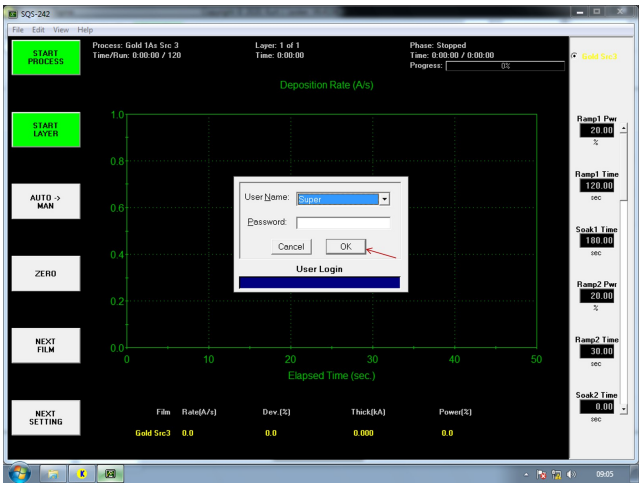
4. Turn ON cooling-water circulation switch on the right side on the wall.
   Check the water cooling status in "**Deposition**" software runtime screen. Green means OK, gray means no water circulation. The system will not operate if there are no water circulation.



5. Enter "**Sigma**" software runtime screen, and turn ON "**Sigma Launch 242**" button. Gray means OFF and green means ON.

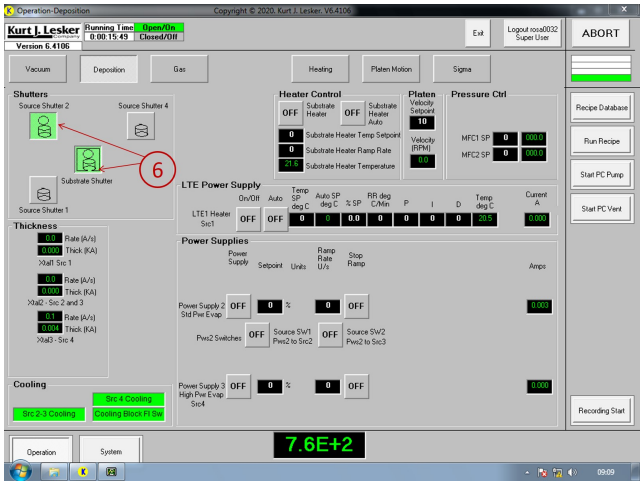
The deposition monitor software "**SQS-242**" will start, no password needed, press **OK**.

If Sigma was already ON (which should be the case), then do nothing, and go to point 6.

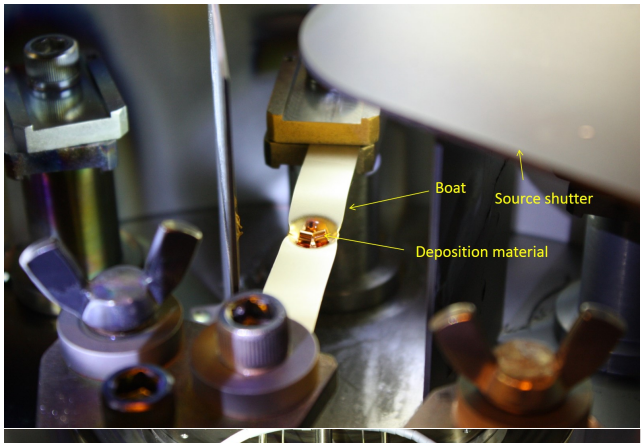


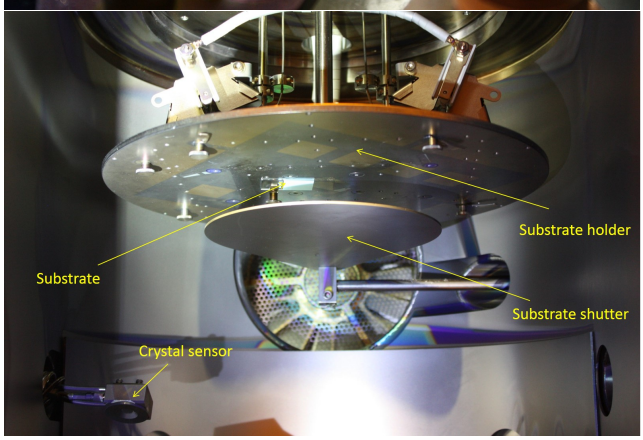
Install boat, load material & substrates

6. Enter "**Deposition**" software runtime screen. Open substrate shutter and the desired source(s) shutter(s). Each of source 1 and 4 has its own shutter. Sources 2 and 3 sharing one shutter.



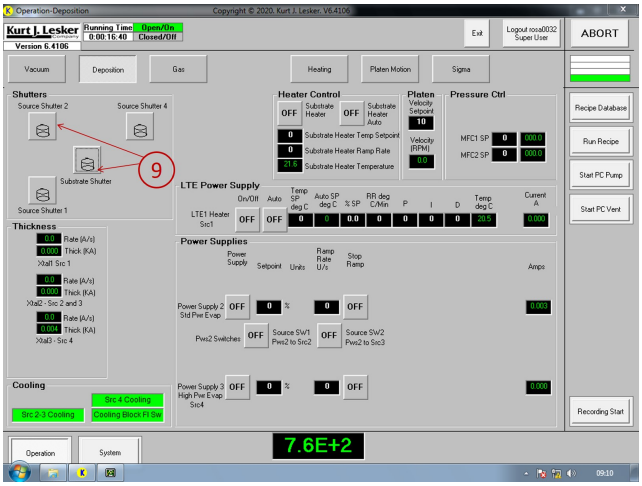
7. Install boat (chose correct boat), load deposition material (1-4 pellets) and your substrate. It is important that the boat be installed with as little loading torque as possible (do not use tools), and the boat is installed between the two washers with a central screw sandwiching these washers together. Avoid touching the crystal sensors.



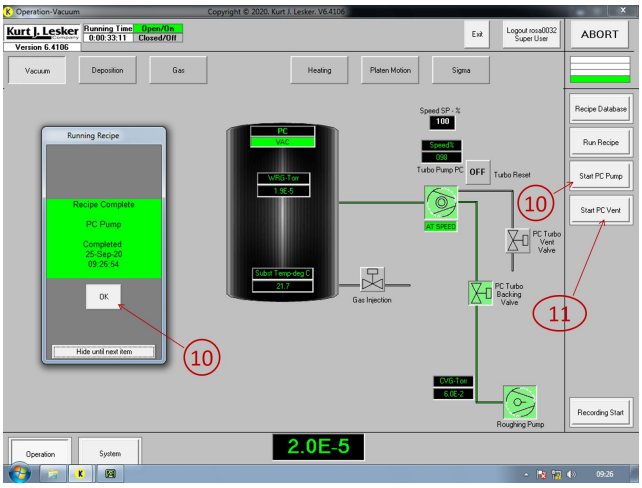


8. Fix your substrate(s) on the center of the substrate holder. Close substrate shutter and all source shutters.
The homogeneity and the thickness of the produced layer is dependent on where you fix the substrate. You have to gain your own experience on this point based on you evaporated material.

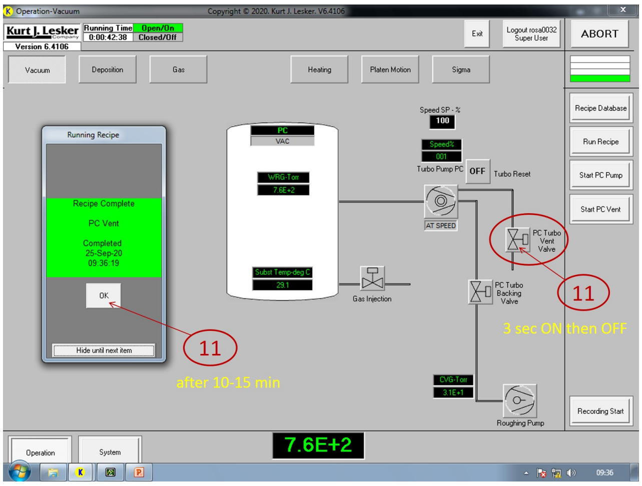
9. Close shutters.



10. Close chamber door and click on "**Start PC Pump**" button on the right hand side menu. Operation pressure (5.0E-5 Torr) will be reached in around 5-10 min. Finlay confirm completed recipe by pressing "**OK**".

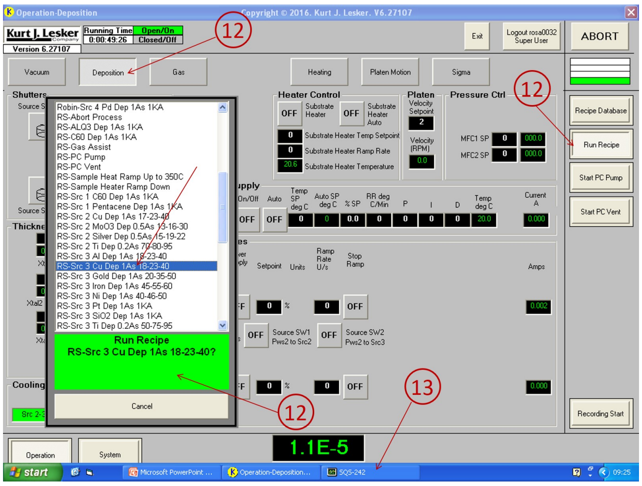


11. If needed to ventilate the chamber? otherwise skip this point. Click on "**Start PC Vent**" button. Ventilation takes around 10-15 min until the vent recipe is completed. Confirm by "**OK**". Open chamber door. If the chamber door dose not want to open? this is because of residual vacuum, then either run "**Start PC Vent**" recipe again, or turn ON the valve **PC Turbo Vent Valve**" for 3-5 sec then turn OFF.



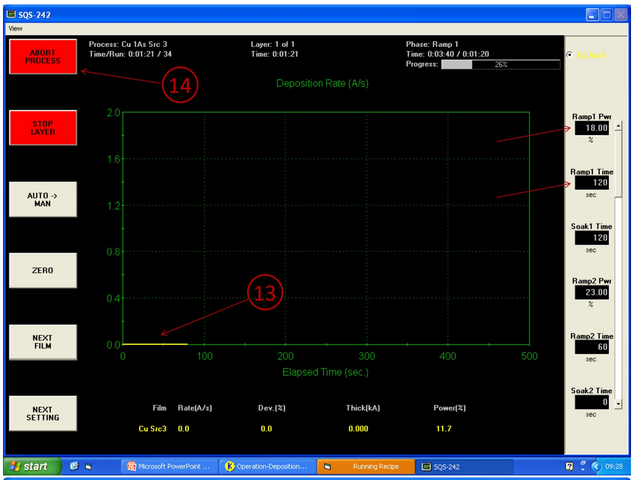
Evaporation

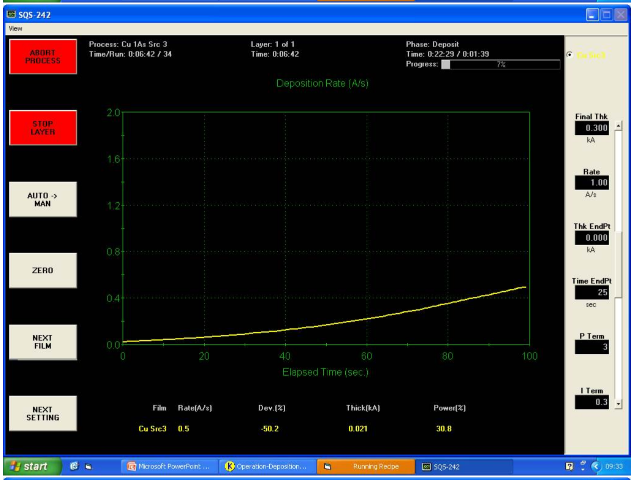
12. Enter "**Deposition**" software runtime screen. Click on "**Run Recipe**" button. Scroll to choose the recipe you want to run, will trun blue when clicking it, to run it click on the green field. The recipe is running now, do not interrupt.

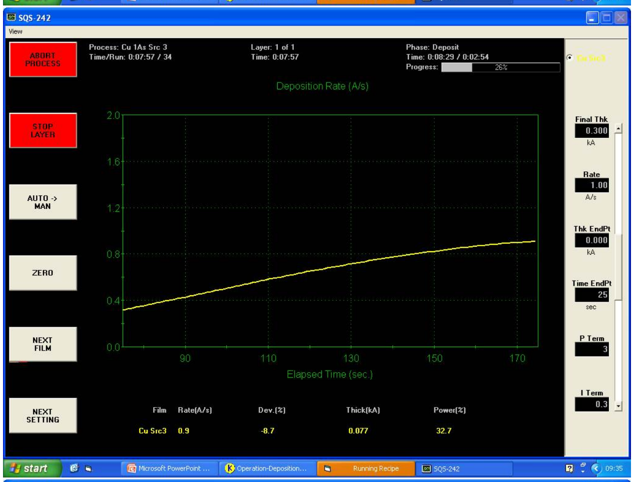


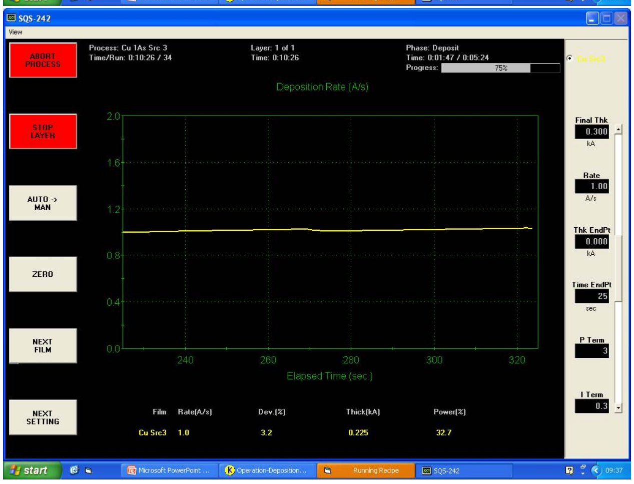
13. From Windows task-bar, go to sigma deposition monitor software (which is already running). Here you will see which recipe is running and all evaporation sequences. Besides you can control ramp power/time, layer thickness, deposition rate.
You can set and change these parameters during operation.

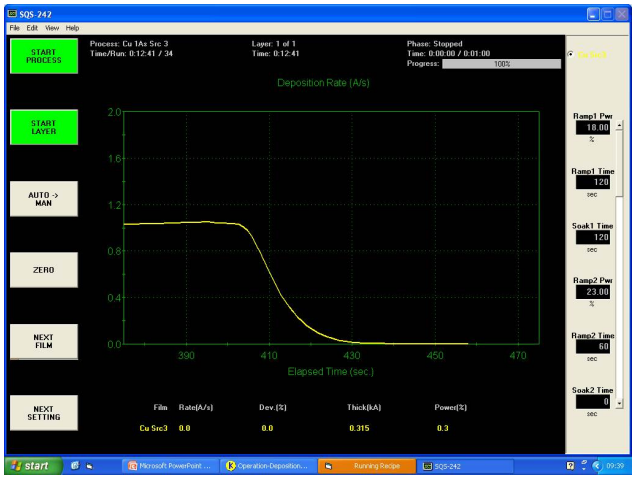
14. Only if you have problem with evaporation (broken boat, material finished, ... etc): press the red button "**ABORT PROCESS**" on the left-up corner to stop the recipe. Otherwise wait until the recipe is over.



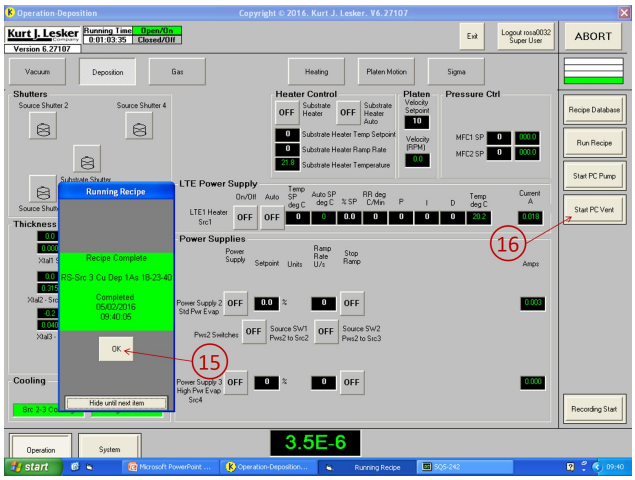






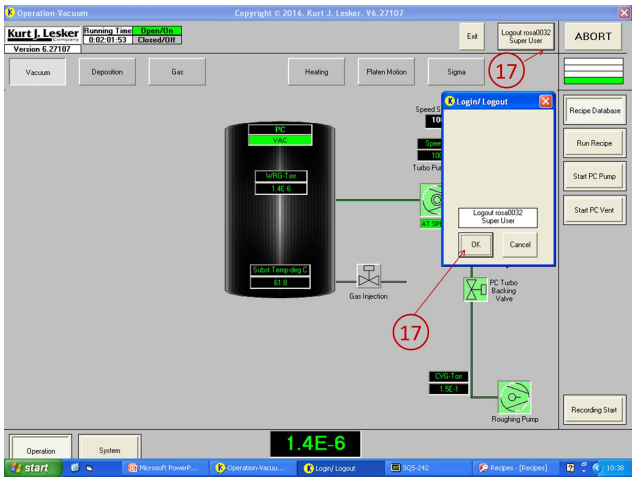


15. When evaporation is done and the desired thickness is reached? Confirm recipe complete by pressing "**OK**".



Un-load samples

16. Press "**Start PC Vent**" button on the right hand side of the screen for ventilating the chamber, and as described in point 11.
    Un-load sample, substrate, boat and then close the vakuum chamber. Leave the chamber under ambient pressure, do not start pumps.
17. Log off.

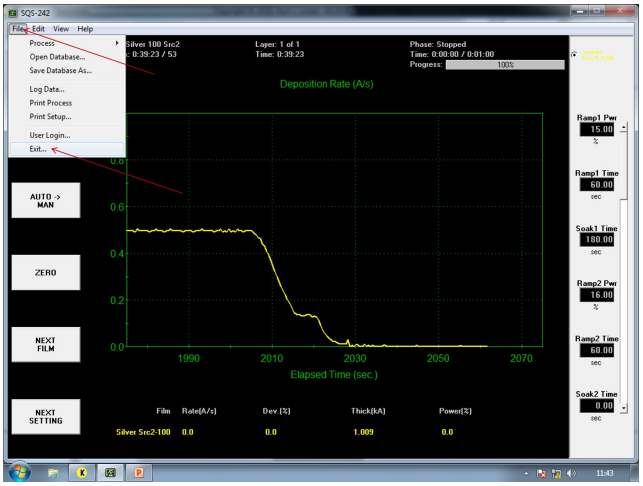


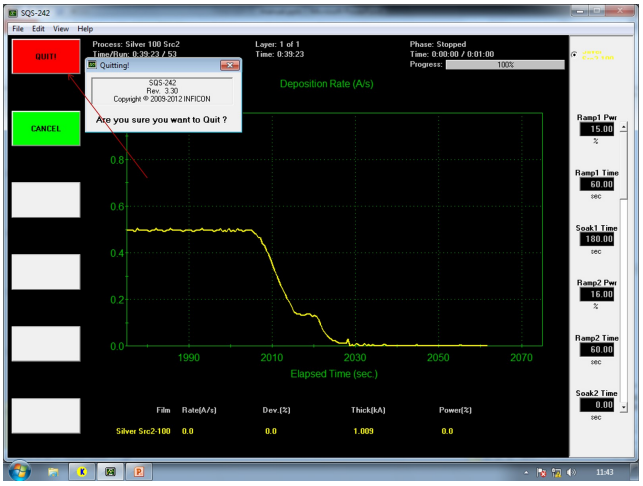
B : SHUTDOWN / RESTART SOFTWARE (if needed)

Usually we never shutdown software, computer or the PVD system.

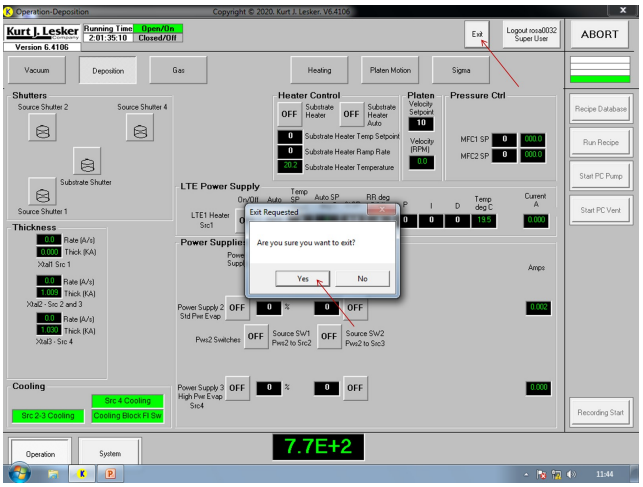
If need to shutdown, first Exit sigma software  .

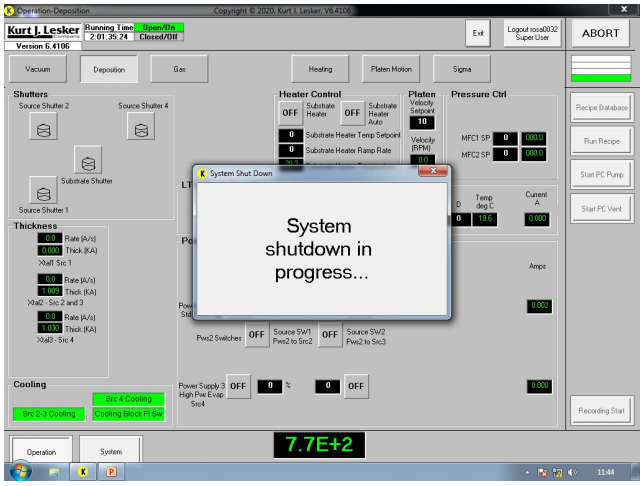
Flie $\Longrightarrow$ Exit $\Longrightarrow$ QUIT





Second Exit the Cware software  . Pressing the Exit button at the top right of any Runtime Software screen will close both the Runtime Software and the System Database. **Exit $\Longrightarrow$ Yes**

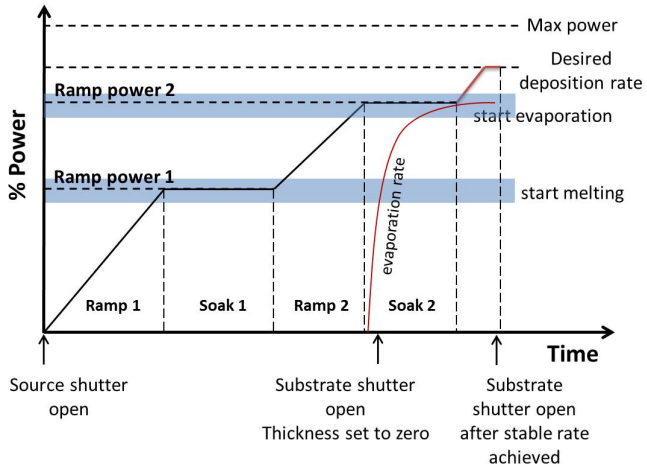




To restart software, see paragraph A points 1 and 5. You cannot start any process without logging in as in poit 2.

C : EVAPORATION PARAMETERS

Look up the material by alphabetic name in the deposition materials reference table and consider the melting point, the temperature required to reach 10^{-4} Torr. Compare your material melting temperature to previously used materials with almost the same melting temperature to estimate the power% needed for each ramp. It is a good idea to run a material for the first time to test the required ramp powers% as well as keeping an eye on the physical state of the material and the source being used in the vacuum chamber through the view port.
Both ramp 1 and 2 times can be set to 120 sec. Longer soak time 1 will prepare material for evaporation during soak time 2 much better. In soak time 1 the material should starts to melt and at the almost end of soak time 2 the material should starts to evaporate. Then the substrate shutter is opened.



It is possible to keep the substrate shutter closed until the required evaporation rate has been reached. This will mean more waiting time for the user and more spend of material. This option is never recommended for expensive materials. If the material sublimes and does not melt then the first ramp would be established at about 60% of the power.
You may set the final thickness to the required thickness even during running the recipe. The evaporation rate can also be reset during running the recipe. Set evaporation rate to 0.5 A/sec for hard evaporated materials and 1 A/sec for all others.
Setting Max power to lower than 100% will prevent rapid fluctuating in the evaporation rate curve. Only for very hard evaporated material use 100% power. Do not play with other parameters.

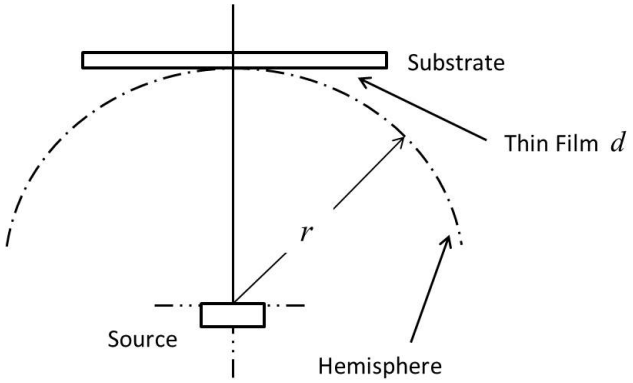
D : HOW MUCH MATERIAL DO YOU NEED?

The pellets are either 1/8" in diameter × 1/8" long or 1/4" diameter × 1/4" long. The volume of the 1/8"×1/8" pellets are 0.02512 cm^3/pellet and the volume of the 1/4"×1/4" pellets are 0.201 cm^3/pellet.

Usually used materials are **99.995% pure peletts, 1/8" diameter × 1/8" Long**.
Calculate the approximate volume of material needed to make a thin film of the specified thickness. This can be done by calculating the surface area of a hemisphere (cm^2) and multiplying that by the desired thickness of the thin film coating on the substrate.

$$V = 2\pi r^2 \times \frac{\text{tooling factor}}{100} \times 1.5 \times 10^{-7} \times d$$

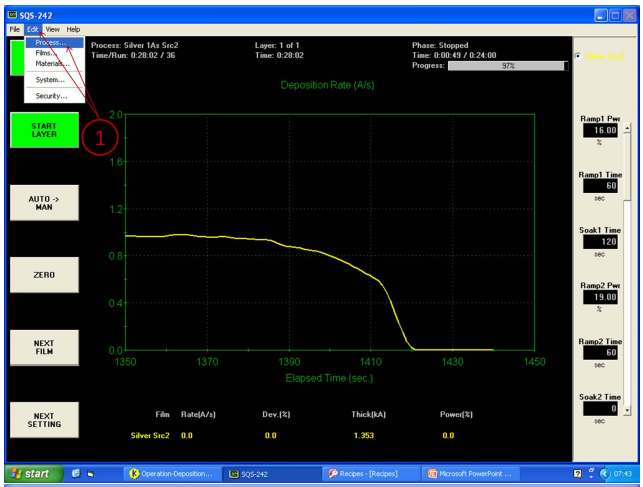
Where V is the volume of the evaporation material of one pellet in cm^3, r is the radius of the hemisphere in cm (source to substrate distance), r=40 cm and d is the desired thickness of the thin film on the substrate in nm.

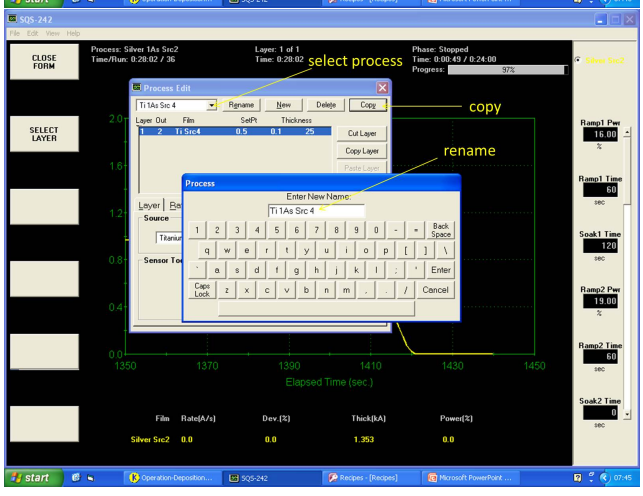


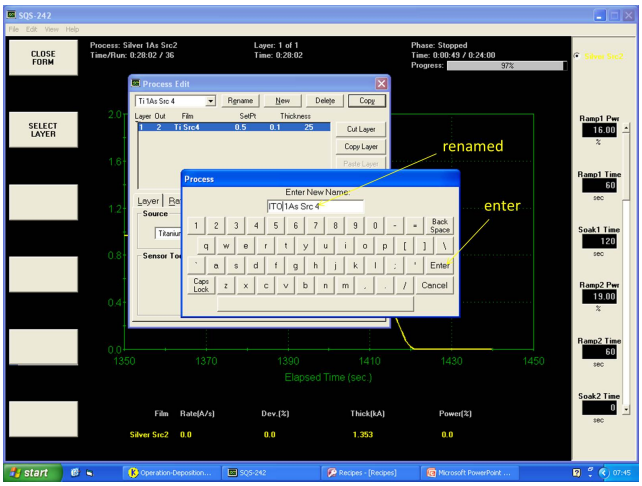
E : WRITE RECIPE

"Users are not permitted to write a recipe". Recipes for all common material are already written and tested. Ask PVD75 system administrator in advance to write a recipe for any new material which is not been used before.

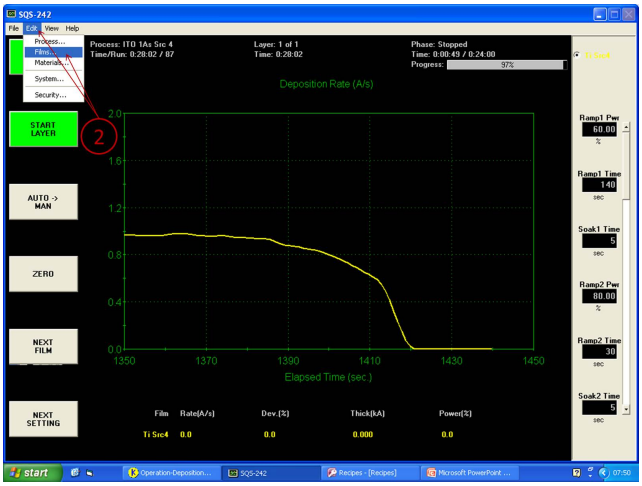
1. In sigma software SQS-242  , go to **Edit** $\Longrightarrow$ **Process** then select process (a process related to the source wants to evaporate the new material) to view or edit. Copy process and rename process, press Enter.

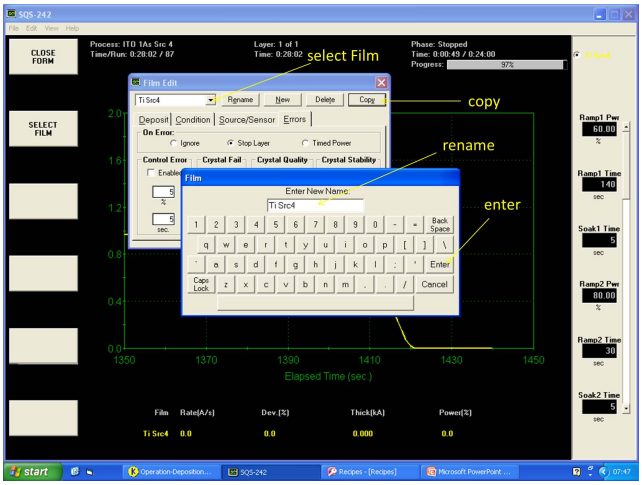


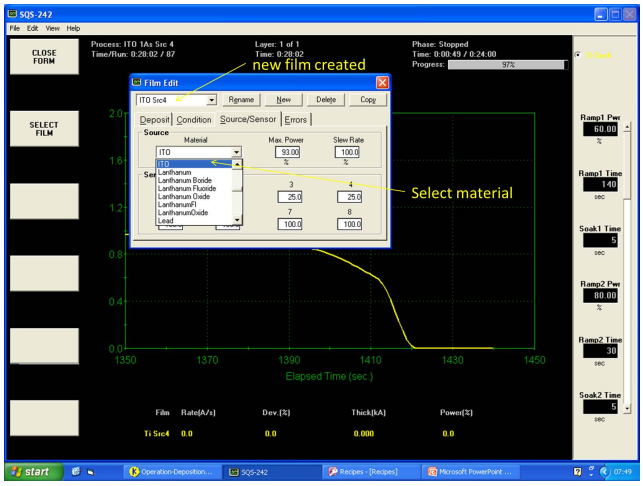


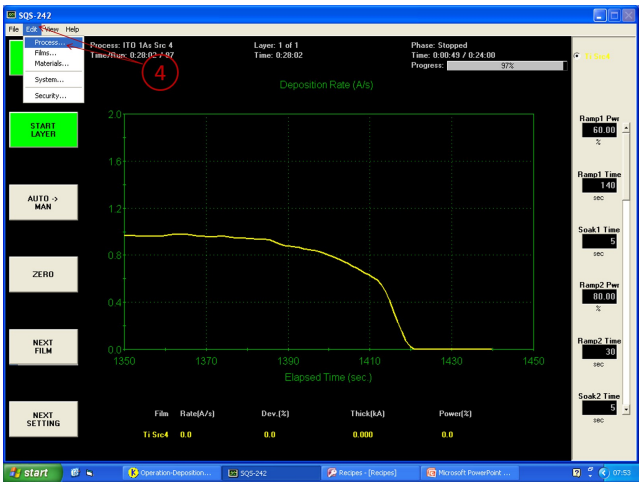


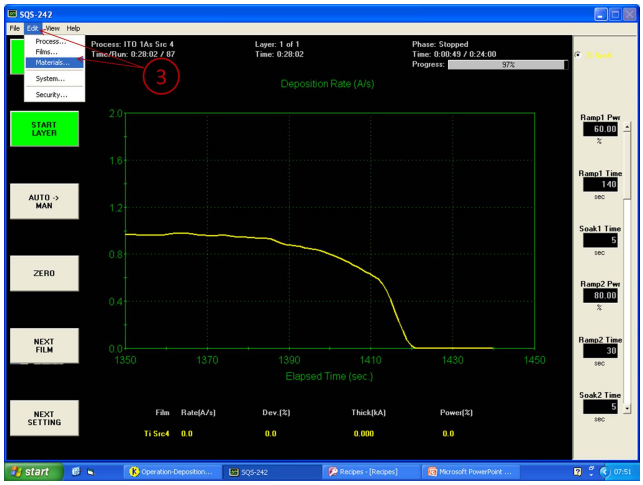
2. In sigma software SQS-242  , go to **Edit** $\Longrightarrow$ **Films** then select the film related to the process chosen in 1. Copy film and rename film, press Enter. The Film has been created. Press **Source**/**Sensor** and select Material.

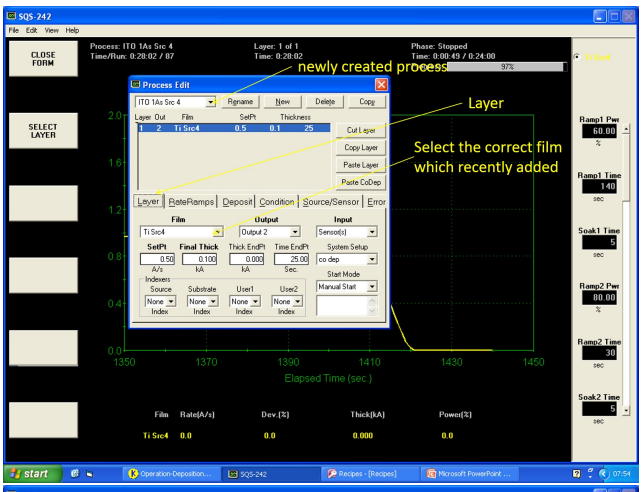


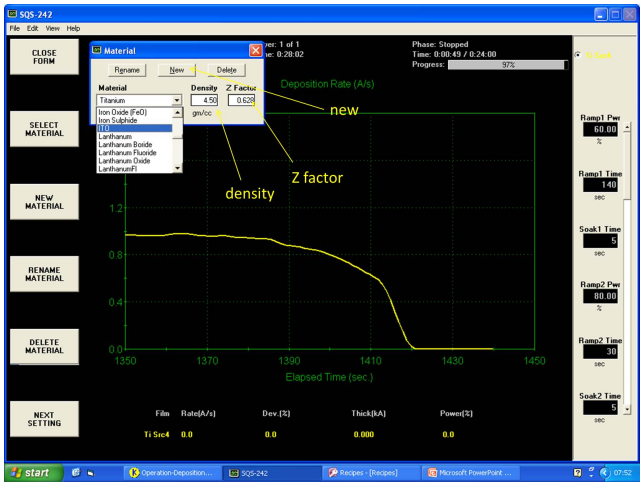


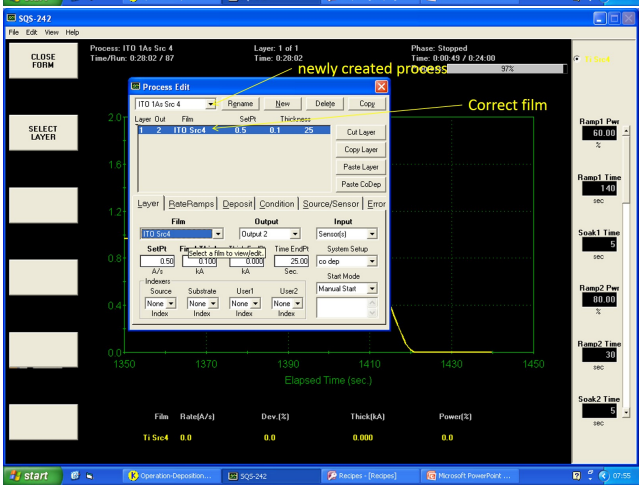




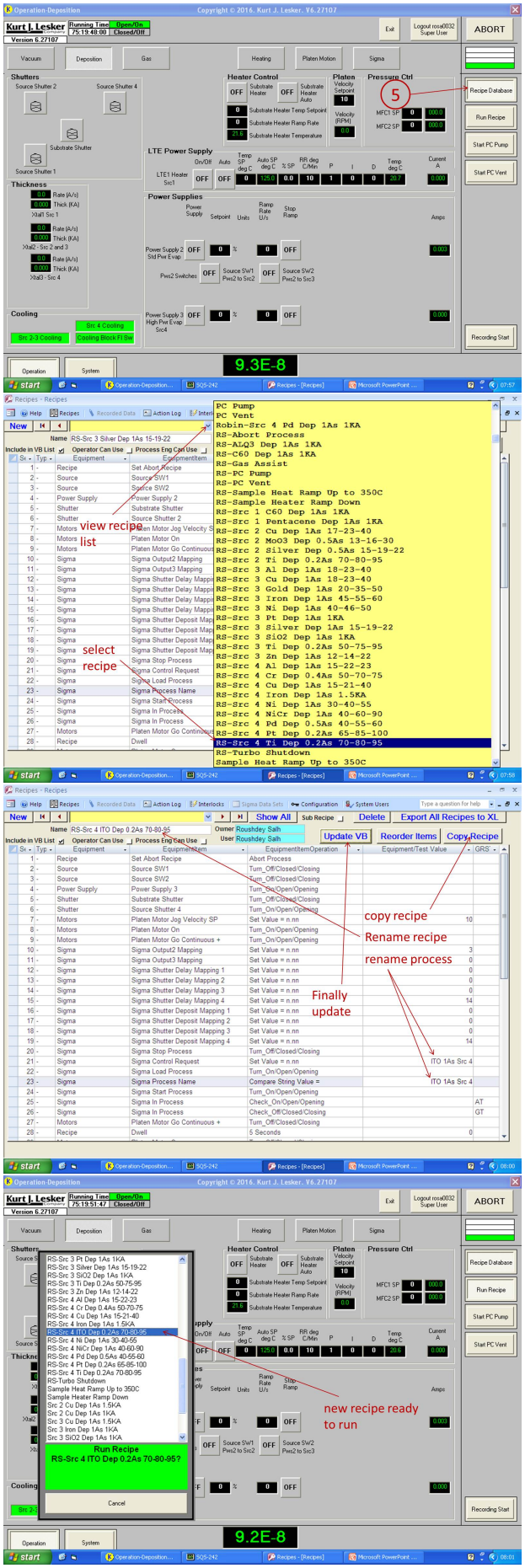


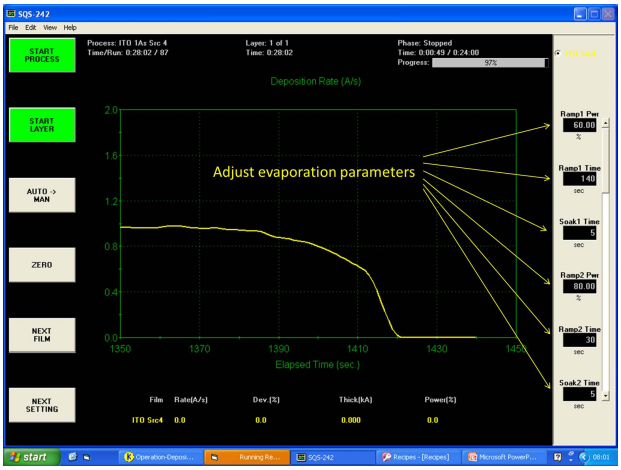






3. If wanted material is not found in the list; go to **Edit** $\Longrightarrow$ **Materials** $\Longrightarrow$ **New** then add material name and density and Z-factor. If Z-factor is unknown enter 1.
4. The process and the film must be combined. In âĂİSigmaâĂİ screen at SQS-242, go again to **Edit** $\Longrightarrow$ **Process** and select the newly created process then select the newly added film.
5. A recipe must be created. Go the main controlling software press **Recipe Database**, the recipe database will be opened. View the existing recipes and select any recipe related to the source wants to evaporate the new material. **Copy Recipe**$\Longrightarrow$ **Rename Process** (give the new created process name) $\Longrightarrow$ **rename recipe** $\Longrightarrow$ press **Update VB**. Now the new recipe to evaporate the desired material on the desired source is ready to use.

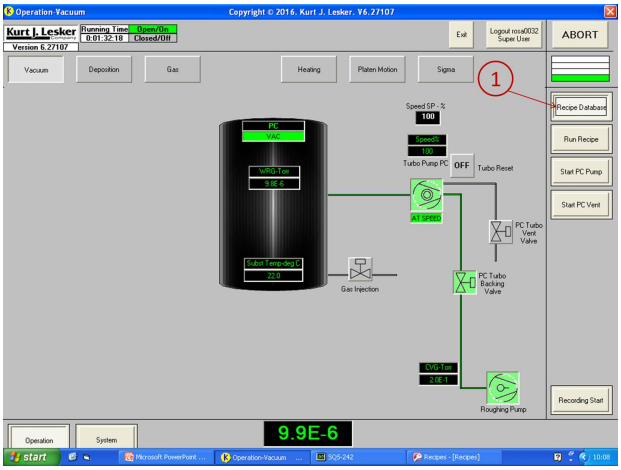




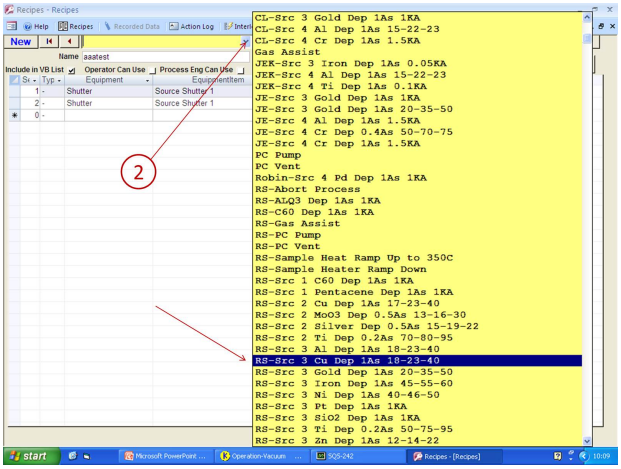
F : COPY RECIPE

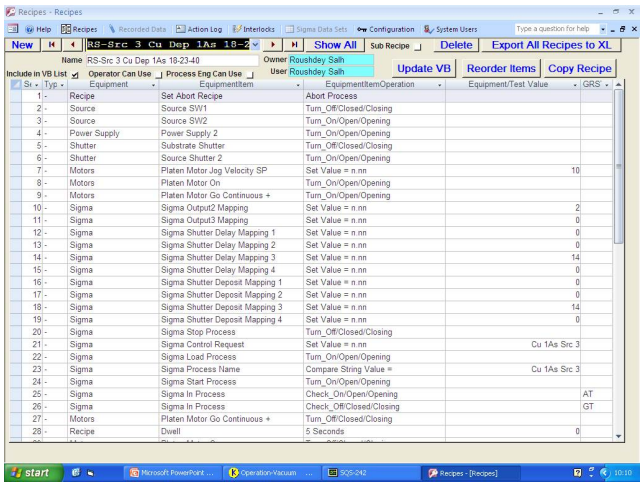
You are allowed to copy any recipe to your account and use it. All evaporation parameters, any changes even during running the recipe will automatically saved.

1. From Windows task-bar, go to "**CWare**" software. Click on "**Recipe database**" on the right hand side menu.

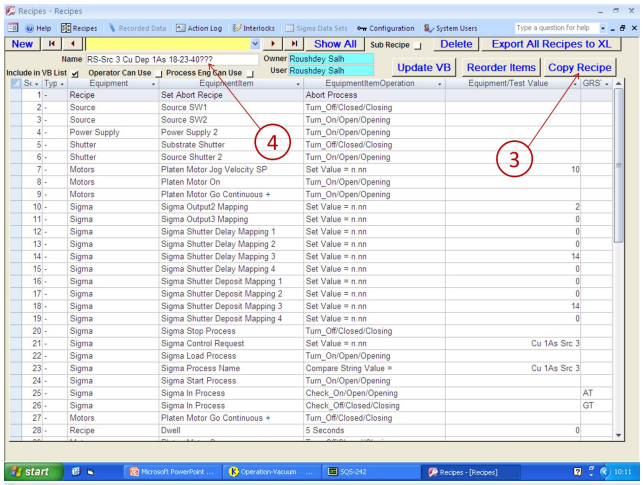


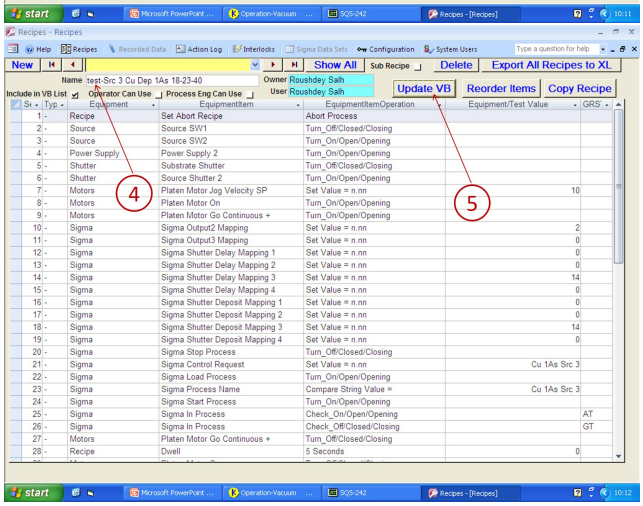
2. Open the recipe list. Select and click the one you want to copy.





3. Press "**Copy Recipe**". The recipe is copied now to your account under the same name with "**???**" on the end.
4. Remove "**???**" and rename recipe by changing only the first two letters to your own name first two letters.



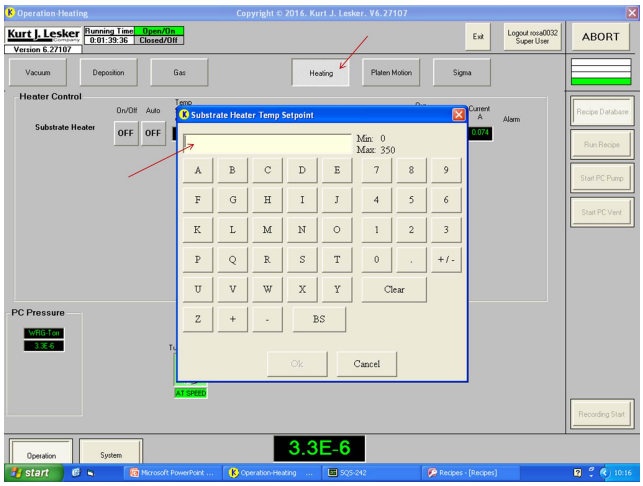


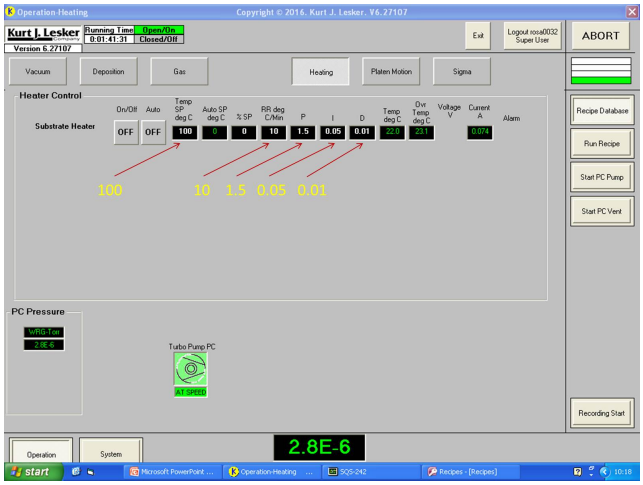
5. Press "**Update VB**". The recipe is now ready to run from "**Run Recipe**" on the right hand side menu as explained in "**EVAPORATION**" section.

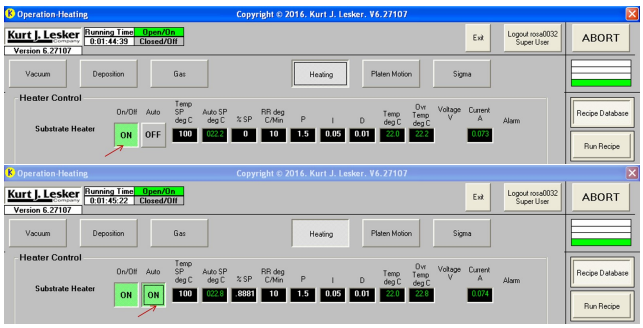
G : SUBSTRATE HEATING

The substrate can be heated up to 350 °C. Substrate heating is not embedded in any recipe (it operates independently). It should turned ON or OFF manually.

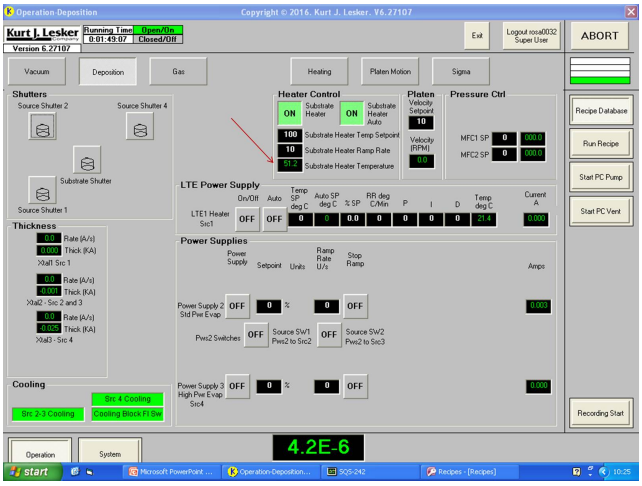
Set the desired temperature (example: "**Temp SP deg C=100**") , and set "**RR deg C/min=10**". The auto sequence runs on the PID values, if there is no value for P the power supply will not even try to push any current or power. You should set the PID values to: "**P=1.5**", "**I=0.05**", "**D=0.01**". Turn ON the "**On/Off**" first (this must be first otherwise you get an error) and then the "**Auto**".







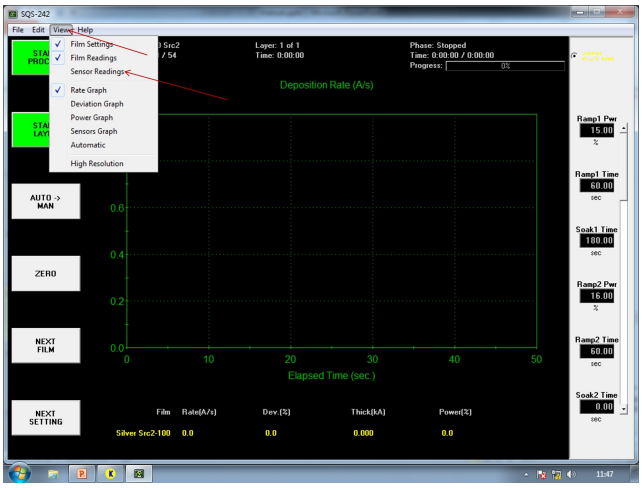
Heater controll can be observed in "**Deposition**" window too.



To turn OFF heater, trun OFF the "**Auto**" first then "**On/Off**".
If heating process intrupted by user or incorrect parameters will lead to activating the interlock, alarm and heater power cut. To reset the process press "**Reset**" on the main bord.

H : CHECK SENSOR LIFE TIME

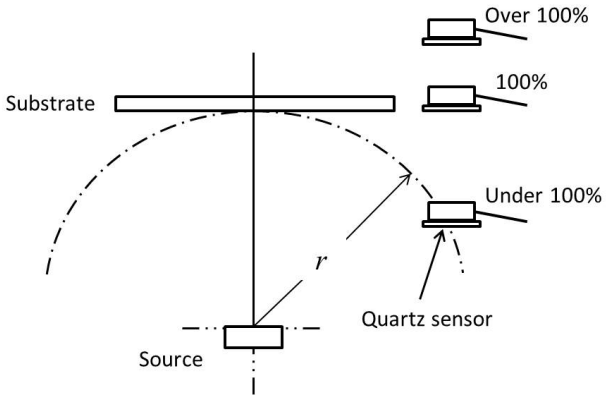
Crystal sensor lifetime must be checked regularly. Crystal sensor must be replaced when lifetime is between 50% and 55%.
View $\Longrightarrow$ Sensor Readings



Recommended crystal sensors used in the PVD75 are: **Crystals, Economy, 6MHZ, Gold coated, Part no. KJLCRYSTAL6âĹŠG10**.

I : TOOLING FACTOR

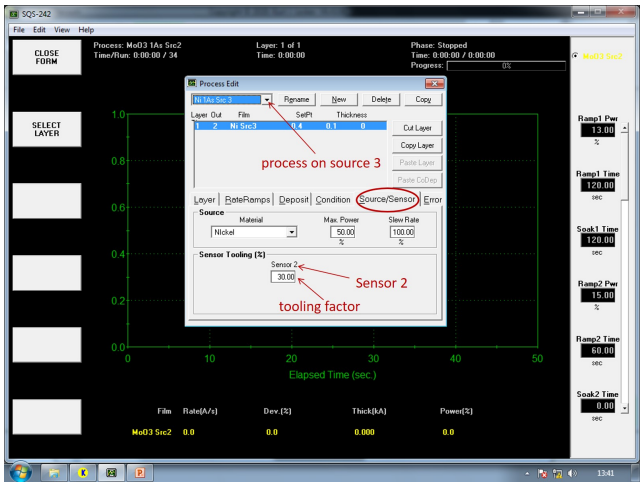
Tooling Factor adjusts for the difference in material deposited on the quartz sensor versus the substrate. Tooling calibration must be done for each source and material. Tooling may be 100%, less than 100% or greater than 100% depending where it is positioned.

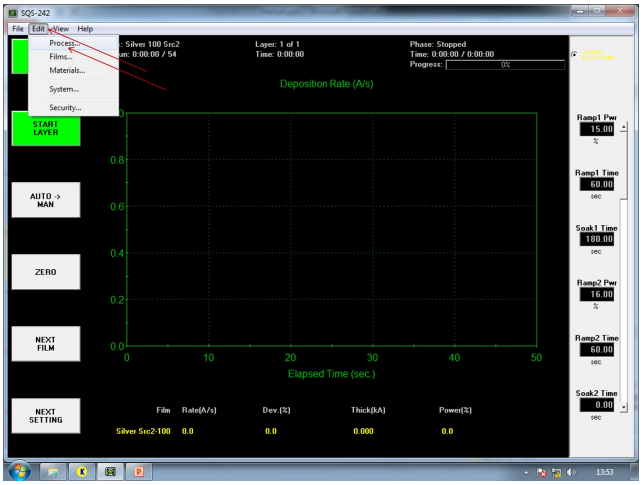


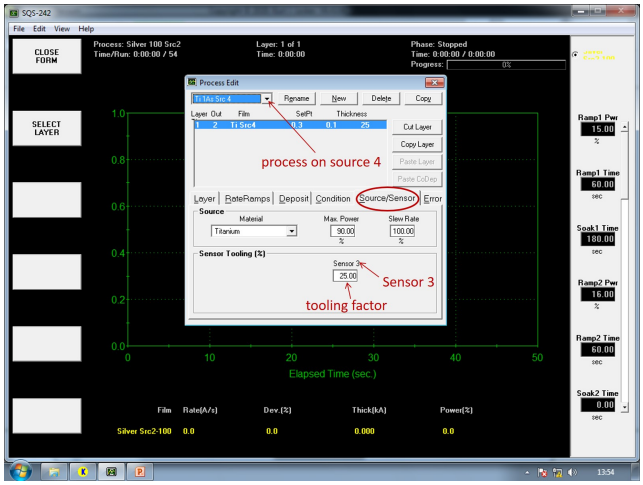
The correct Tooling Factor is calculated by:

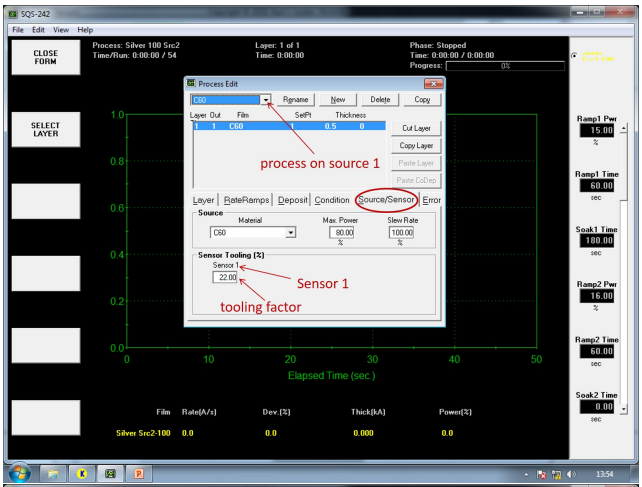
$$T_r = T_s \times \frac{d_m}{d_s}$$

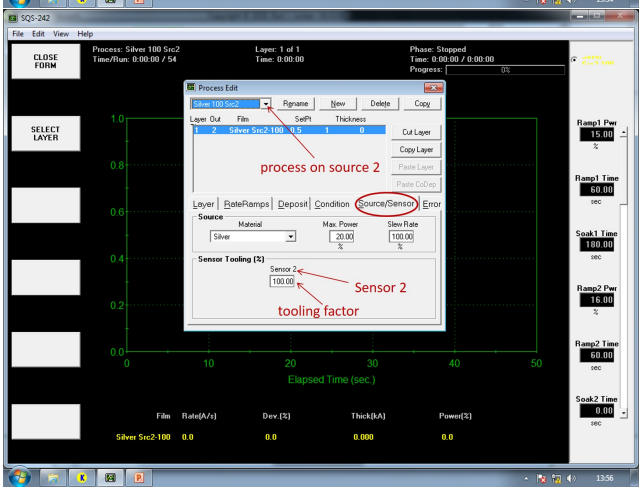
T_r is the correct tooling factor, T_s is the approximate tooling factor which is already in the software, d_m is the correct measured thickness, and d_s is the thickness you see in the screen.
Round off percent tooling to the nearest 0.1%. When entering this new value for tooling into the software, d_m will equal d_s if calculations are done properly.
To enter the new value for the tooling factor into the software: **Edit** $\Longrightarrow$ **Process** $\Longrightarrow$ **Source/Sensor** then select the correct process.





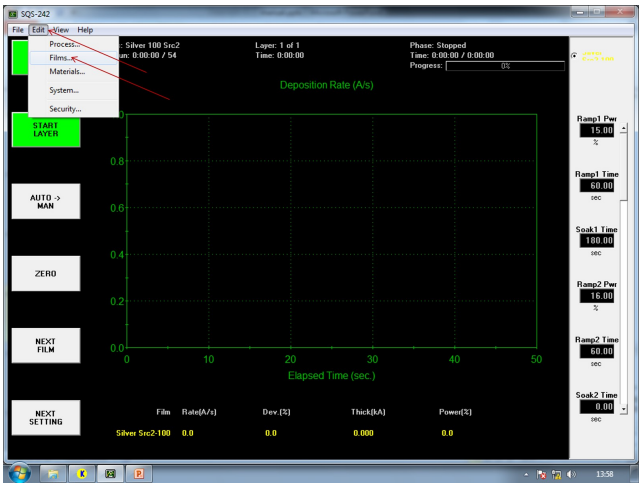


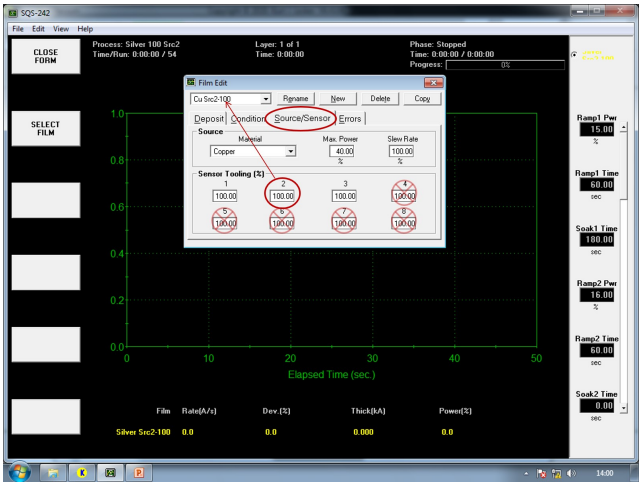


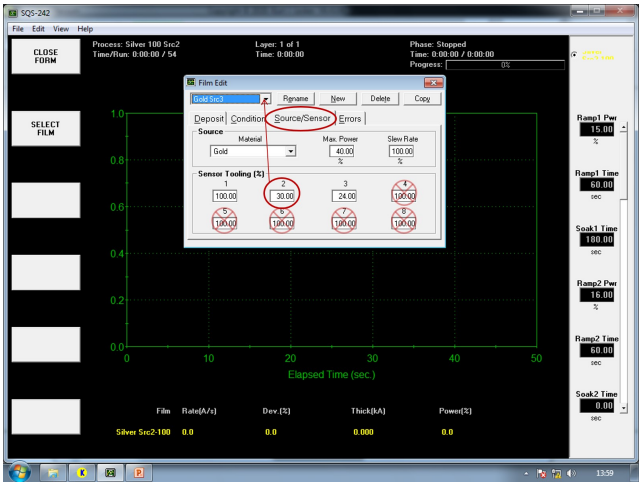


Replace the existence tooling factor with the new calculated one, it will be automatically saved.

Another way to check and replace the tooling factor is: **Edit** $\Longrightarrow$ **Films** $\Longrightarrow$ **Source**/**Sensor** then select the correct process.
Only sensor tooling 1, 2 and 3 are active. All other sensor tooling (4-8) have no meaning because we have only 3 sensors for 4 sources in the PVD7. Source 2 and 3 sharing one power supply, one shutter and one sensor (sensor 2). Sensor 3 belongs to source 4.

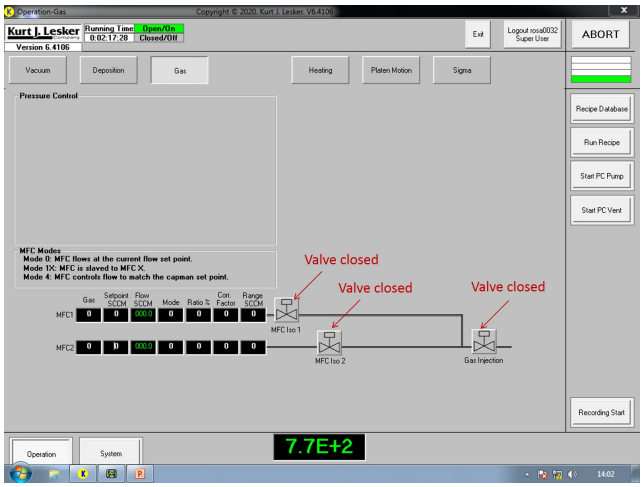


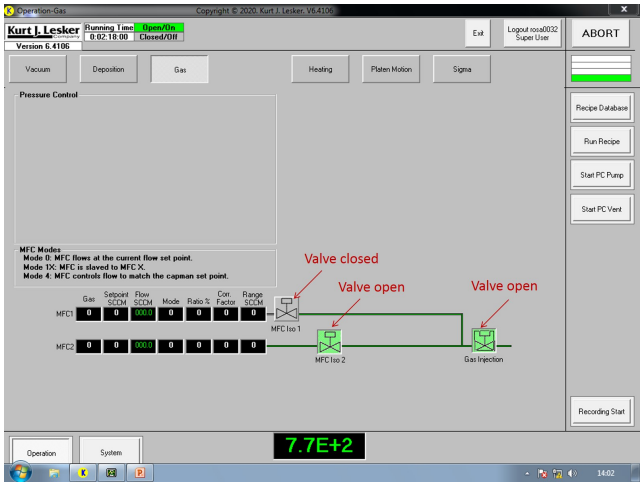




J : Gas

It is possible to evaporate under ambient gases, the flow can be set in **Gas** software runtime screen and the valve can be opened or closed manually on the screen.
In **Gas** software runtime screen; set MFC1 gas to O_2, Setpoint SCCM to 5, Flow SCCM to 000.5, Mode to 4, Ratio % to 100, Corr. Factor to 1.39, Range SCCM to 100.
Open source gas valve and gas injection valve, wait for chamber pressure to stabilize.Go to **Deposition** software runtime screen and run recipe as described in A.



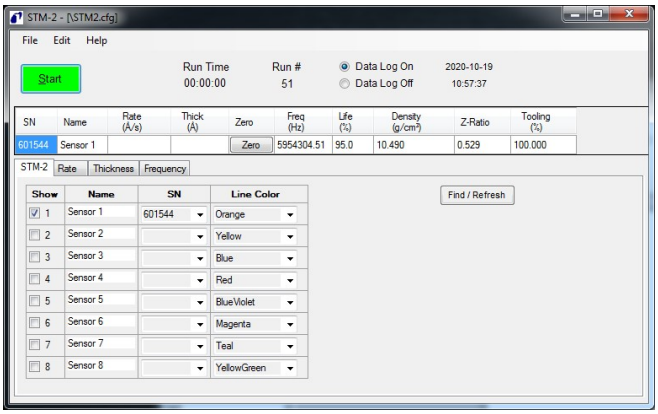


SCCM is Standard Cubic Centimeters per Minute, a flow measurement term indicating cm^3/min at a standard temperature and pressure.

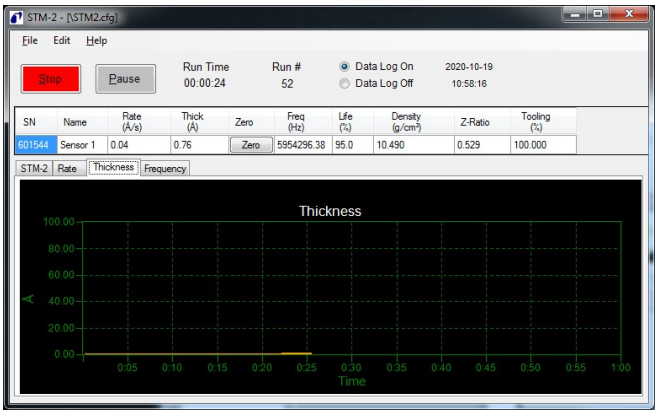
K : INFICON STM-2

The INFICON STM-2 is already connected to the computer, only switch ON the USB connection and run the software STM-2  (found on taskbar).

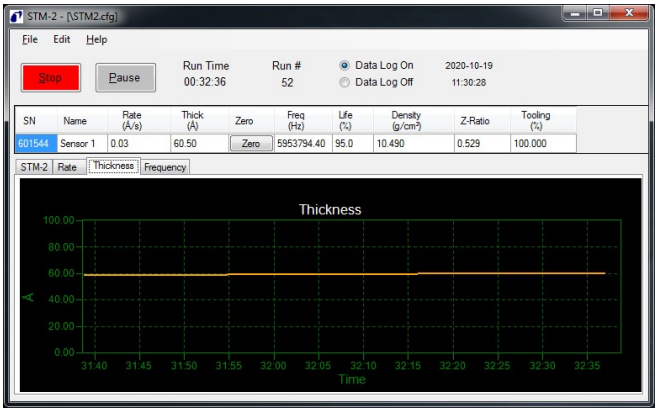
Input mass density, Z-Ratio and the tooling % for the related material (found on desktop). Press Strat button  .



Switch to thickness screen and watch the thickness development. The software will accumulate thickness from the start time.



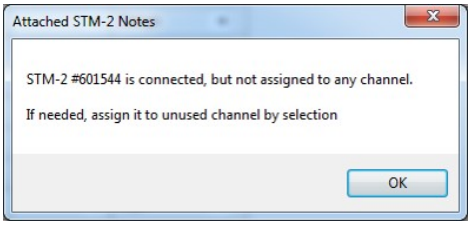
When the desired thickness is reached? Stop the running CWare  recipe, then press Stop button  in STM-2 software  .



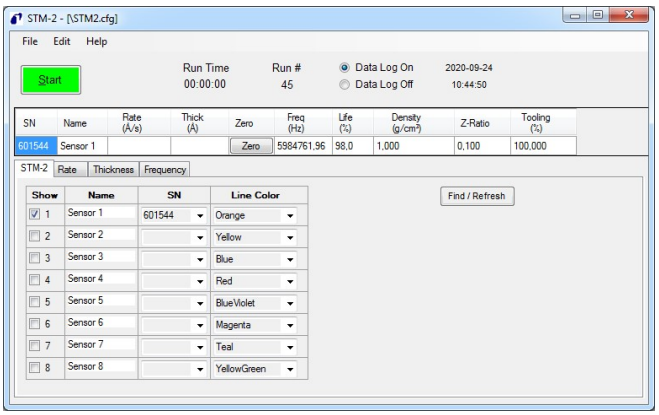
Remember the STM-2 software only monitor the thickness and not controlling it.

Installing INFICON STM-2 software (only for system administrator

In this configuration the INFICON STM-2 is set for internal oscillator operation. **Installing INFICON STM-2 software (only for system administrator)** First you have to install the protocol server: Open âĂİCommon SoftwareâĂİ folder, double click setup_smd_svr_lv.exe, follow the installation instruction (agree license, and next) until the installation complete, press close and Restart computer. Second: install STM-2 v1.4.0 Setup, follow the installation instruction (agree license(s), next, and three times Finish) until the installation complete. Restart computer.



Select the sensor to be displayed on the STM-2 window (Sensor 1) inter correct SN number for the sensor (601544), click Find/Refresh.



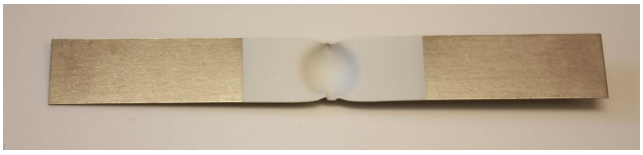
The INFICON STM-2 is ready to use.

L : BOAT SOURCE SELECTION FOR METALS

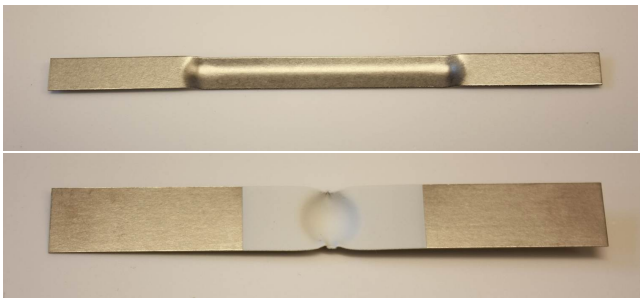
Aluminum has the ability to wet to and creep over a wide variety of materials. This makes it very hard to contain Al in crucibles and boats. In addition Al reacts with all of the refractory metals evaporation sources are made from causing them to become very brittle. Al will not dissolve the boat/filament but it will make the boat/filament extremely brittle.
Recommended boat for Aluminum in PVD75 is:
Tungsten boat source, 4"L X 1/2" W X 1 1/2"âĹŠ1/8" deep, Part no. EVS20A015W

Titanium is very difficult to thermally evaporate because Ti will melt (1660 °C) at the same time that it reaches a temperature high enough to yield reasonable deposition rates. Molten Ti will react with most materials as it is a very corrosive material. Therefore the boats can be used only for one evaporation in most cases.
Recommended boat for Titanium in PVD75 is:
Tungsten boat source, 3 7/8"L X 1/4"W X 1/16" DâĹŠ2", S48âĹŠ.015W Modified width, Part no. EVS48015WSPL01
Uses always evaporation source 4 for Ti evaporation.

Nickel is similar to titanium in that when it is in liquid form (melts at 1453 °C) it is extremely reactive with the boat source materials. The Ni melts at a low enough temperature (1453 °C compared to 1660 °C for titanium) so as not to interact with the Al_2O_3 coating. The Ni does not wet to the Al_2O_3 coated boat but does form a ball on top of the Al_2O_3 coating. The boat can be used multiple times for Ni evaporation.
Recommended boat for Nickel in PVD75 is:
Tungsten boat source, Alumina coated 4"L X 1/2"W X 1/8"deep, Part no. EVS9AAOW

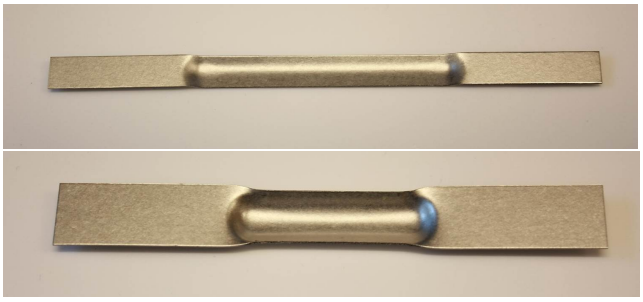


Palladium is similar to nickel in that when it is in liquid form (melts at 1554 °C) it is extremely reactive with the boat source materials and will destroy an Al_2O_3 coated boat as soon as the Pd melts into a liquid. The Pd does attack and usually breaks the Al_2O_3 coated boat when a second run is attempted.
Recommended boats for Palladium in PVD75 are:
Tungsten boat source, 3 7/8"L X 1/4"W X 1/16" DâĹŠ2", S48âĹŠ.015W Modified width, Part no. EVS48015WSPL01
Tungsten boat source, Alumina coated 4"L X 1/2"W X 1/8"deep, Part no. EVS9AAOW

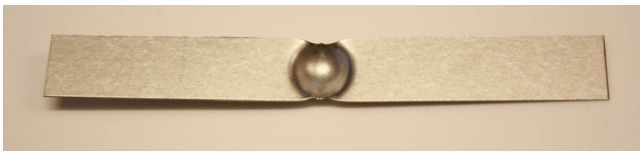


Chromium evaporation is more of a conceptual problem than a real problem. Chromium full sublimes and will not melt when thermally evaporated. It comes in irregularly shaped pieces. The Cr pieces do not react with the boat material and the boat can be reused many times. Use source 4.
Recommended boat for Chromium in PVD75 is:
Tungsten boat source, 3 7/8"L X 1/4"W X 1/16" DâĹŠ2", S48âĹŠ.015W Modified width, Part no. EVS48015WSPL01
Uses always evaporation source 4 for Cr evaporation.

Iron is similar to titanium but less reactive with the boat source materials. the boats can be used for one or two evaporations. Recommended boats for Iron in PVD75 are:
Tungsten boat source, 3 7/8"L X 1/4"W X 1/16" DâĹŠ2", S48âĹŠ.015W Modified width, Part no. EVS48015WSPL01
Tungsten boat source, 4"L X 1/2" W X 1 1/2"âĹŠ1/8" deep, Part no. EVS20A015W

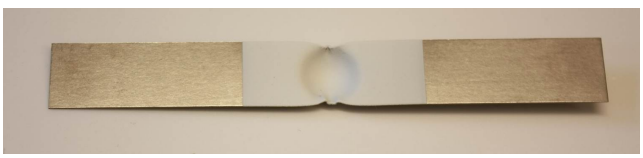


Gold, Silver, Copper are very gentle materials, they evaporate in moderate temperatures and relatively low powers. The boat can be reused many times.
Recommended boat for Gold, Silver, Copper in PVD75 is:
Tungsten boat source, Dimple, 4"L X 1/2"W X 1/8" deepâĹŠ7/16", Part no. EVS9A015W



Platinum is a very hard evaporating material but it is not reactive with the boat source materials. Uses always evaporation source 4 for Pt evaporation.
Recommended boat for Platinum in PVD75 is:
Tungsten boat source, 3 7/8"L X 1/4"W X 1/16" DâĹŠ2", S48âĹŠ.015W Modified width, Part no. EVS48015WSPL01

Nichrome (80%Nickel/20%Chromium) is a very hard evaporating material and it is reactive with the boat source materials.
Recommended boat for Nickel in PVD75 is:
Tungsten boat source, Alumina coated 4"L X 1/2"W X 1/8"deep, Part no. EVS9AAOW

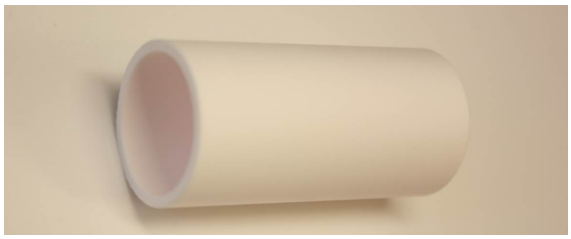


Indium Tin oxide ITO (In_2O_3/SnO_2 90/10 WT%) ITO full sublimes, it deposited by thermal evaporation using Mo-boats.
Recommended boat for ITO in PVD75 is:
Moly boat source, Isol.Htzon Dmpl 4"L X 3/4"W X 5/8"DIA, Part no. EVS8B005MO

Molybdenoxid MoO_3 Recommended boat for MoO_3 in PVD75 is:
Moly boat source, Isol.Htzon Dmpl 4"L X 3/4"W X 5/8"DIA, Part no. EVS8B005MO

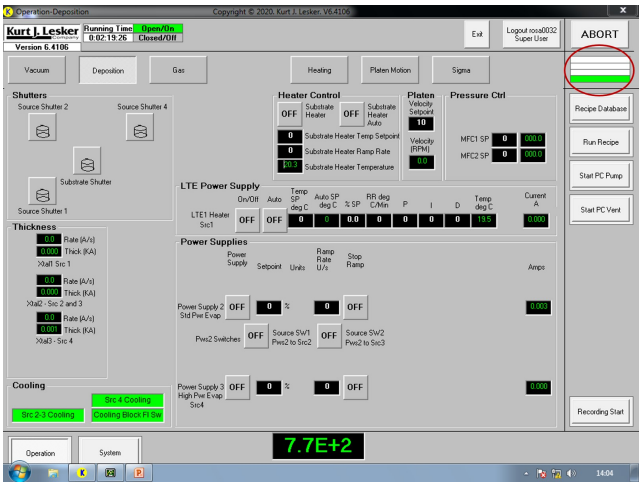
M : CRUCIBLE SELECTION FOR ORGANIC MATERIALS

Markings on the crucibles are not acceptable.
Recommended crucibles for the PVD75 is:
OXIDE CRUCIBLE FOR 10CC LTE & HTE, 0.98" TOD X2.03" H, 0.070" THICK WALL, STRAIGHT WALL.Part no. EVCE-FâĹŠ10AO.



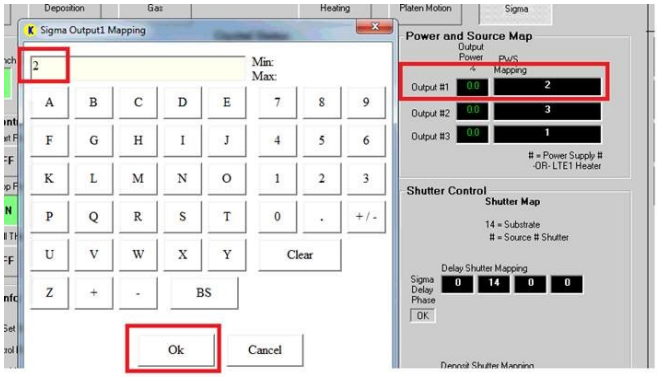
N : NOTES

The Light Tower appears in the top right corner of all screens. When the topmost bar is illuminated red, a red alarm condition is present. The second bar will light yellow to indicate a yellow alarm. The third bar will light green to indicate that a recipe is running. The bottom bar will light blue to indicate a âĂIJnormalâĂİ status, no alarms are present and no recipes are running.

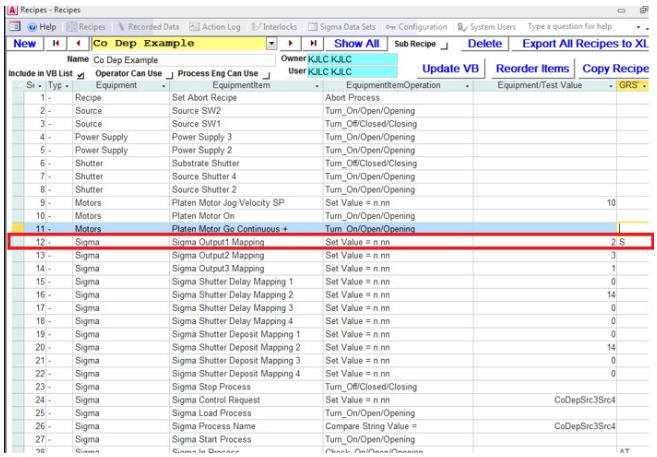


O : PVD co-deposition

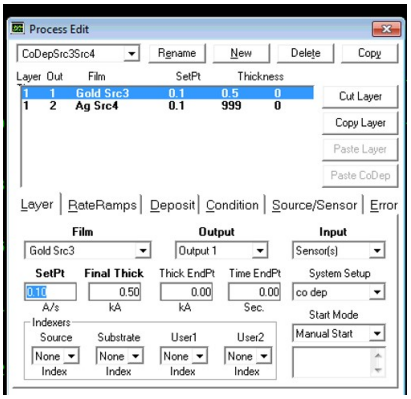
This system only have 2 outputs available from the Sigma card. Setting up a co-deposition process in Sigma and via recipe control a third output from Sigma is needed to allow the mapping for the power supplies in Cware to map:
Sigma output #2 = Cware power supply 2 and
Sigma output #3 = Cware power supply 3
The problem is that the Recipe control does not allow the mapping for Sigma output #1 to be used for anything other than LTE1 Heater. The system has somehow locked in and reserved Output #1 mapping for the LTE power supply.
But this is possible to overcome manually. Each time when co-deposition is needed you have to set the Output #1 = 2 before you want to run a co-depostion process (just like in the above screenshot).
When the recipe is complete you can set Output #1 manually back to LTE1 Heater.
This system only has outputs 1 and 2, so I had to use:
Sigma output #1 = Cware power supply 2
Sigma output #2 = Cware power supply 3



In the co-deposition Example, the step that does not work for mapping Output #1 is skipped. You will need to leave this step skipped and set it manually before running the recipe as described below.



I created a new Sigma process called CoDepSrc3Src4, which the recipe calls out. You will need to calibrate the tooling on the films and the soaks/ramps. I just used some pre entered values from existing layers. Gold is set to be the host material and Ag as the dopant



MATERIAL PARAMETERS

Material	Symbol	Density g/cm^3	Z-Ratio	Melting T (°C)	Melting Power %	Evaporation Power %	Max Power %	Evaporation Rate Å/s	KJL Tooling % Src 2	KJL Tooling % Src 3	KJL Tooling % Src 4	INFICON Tooling %
Aluminum	Al	2.7	1.08	660								
Gold	Au	19.3	0.381	1063								
Silver	Ag	10.49	0.529	961								
Copper	Cu	8.93	0.437	1100								
Chromium	Cr	7.2	0.305	1857								
Iron	Fe	7.86	0.349	1536								
Nickel	Ni	8.85	0.331	1453								
Nichrome	NiCr	8.5	1.000	1400								
Titanium	Ti	4.5	0.628	1670								
Platinum	Pt	21.37	0.245	1770								
Calcium	Ca	1.55	2.62	839								
Cadmium	Cd	8.64	0.682	321								
Cobalt	Co	8.9	0.343	1495								
Indium	In	7.24	0.769	157								
Indium Tin oxide	ITO	7.14	1.000	1800								
Palladium	Pd	12.16	0.352	1552								
Silicon	Si	2.32	0.712	1412								
Silicon dioxide	SiO_2	2.648	1.07	1610								
Silicon monoxide	SiO	2.13	0.87	1702								
Tin	Sn	7.3	0.724	232								
Tin oxide	SnO_2	6.95	1.000	1630								
Zinc	Zn	7.04	0.514	420								
Zirconium	Zr	6.49	0.6	1852								
Zirconium oxide	ZrO_2	5.6	1.000	2715								
Molybdenum Oxide	MoO_3	4.69	1.000	795								

Z-factor is used to match the acoustic properties of the material being deposited to the acoustic properties of the base quartz material of the sensor crystal. To measure Z-factor experimentally is a challenge, due to this 1.000 is used for some materials, which indicates that the materialâĂŹs Z-factor is not known.