Helium-neon lasers have a multicolored future

Despite competing technologies, new wavelengths and good performance make the HeNe laser the laser of choice for many applications.

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The market lifecycle of a high-technology product is typically quite short. Several types of gas lasers, however, including argon-ion, helium-neon (HeNe), and carbon dioxide lasers, continue to enjoy high sales volume in diverse applications even after many years in the marketplace (see Laser Focus World, January 1995, p. 54). This apparent anomaly results from the generally good cost/performance ratio of these products; either the performance is such that alternatives are not available or the cost-effectiveness of the lasers cannot be matched by a competing technology.

The HeNe laser, in particular, has withstood intense competition from laser diodes and continues to dominate many established applications while still being incorporated into new ones. The continuing market strength of HeNe lasers is mostly due to the unique combination of performance characteristics for traditional red-emitting lasers (632.8 nm) and to the advent of reliable devices with good performance at other wavelengths.

PERFORMANCE CHARACTERISTICS

In many applications, important laser-output parameters are not limited to output power and wavelength but also include coherence length, mode quality, beam divergence, beam-pointing stability, and output polarization. Additional factors, such as cost, reliability, lifetime, part-to-part consistency, physical size, and electrical requirements are often also significant, particularly to original equipment manufacturers (OEMs). Compared to other laser types, the overall performance of HeNe lasers in most of these areas is remarkably good, hence the long market lifetime of these lasers in many established applications and their continued attractiveness in several emerging ones.

The coherence length of HeNe lasers is typically 20-30 cm, while frequency-stabilized versions may exhibit a coherence length of several kilometers. The extended coherence length of HeNe lasers results directly from the gaseous lasing medium. Solid-state and semiconductor devices have a broader continuum of electronic states than do gas lasers, which results in an inherently larger bandwidth and consequent shorter coherence length (see Fig. 1). Typical coherence

In a typical commercial cytometer, the circular optic is a pickup lens used to collect scattered light and fluorescence excited by the laser beam at a 90° angle to the beam.
lengths of visible laser diodes, for example, are limited to a few millimeters. The very narrow linewidth and wavelength stability of HeNe lasers is why they are widely used as wavelength-calibration standards such as in Fourier-transform infrared spectrometers.

The rotationally symmetric cylindrical cavity of HeNe lasers allows the resonator and mirrors to be designed so the lasers produce a Gaussian beam with more than 95% TEM00 mode content. Because of this excellent mode structure, HeNe lasers can often be used without any spatial filtering. Conversely, even when numerous optical elements are used to improve the mode structure of a laser-diode output and spatial filters are incorporated (which reduces beam power), the beam quality of a laser diode still does not compare with the beam quality of a HeNe laser.

Beam divergence due to diffraction is an inescapable phenomenon, and laser beams that approach this theoretical limit—having the minimum possible divergence—are said to be diffraction-limited. Once again, the design of HeNe laser cavities, together with optical transformations made with the output coupler, yield a beam that is essentially diffraction-limited.

Good beam-pointing stability (angular drift) in HeNe lasers is a function of several design parameters. These parameters include optical-cavity design trade-offs between output power and pointing stability. Thermal-expansion effects are minimized with carefully chosen tube materials and a highly symmetrical mechanical design. A well-designed HeNe laser can easily achieve a long-term beam-pointing stability of less than 0.03 mrad, which means that at 100 m from the laser the beam will move less than 3 mm.

Even if a laser has ideal performance characteristics, it may still be useless for a given application if its output is not at the appropriate wavelength. The output wavelength determines whether or not a laser beam can transmit through a specific medium, if it will excite resonant absorption of a dye or fluorescent probe, or even if it will provide sufficient visible contrast against a particular background. Helium-neon lasers have a wider range of wavelengths than any other laser type. In addition to the ubiquitous red HeNe laser, other off-the-shelf wavelengths include green (543.5 nm), yellow (594.1 nm), orange (612.0 nm), near-infrared (1.523 µm), and mid-infrared (3.39 µm).

Primary concerns for OEMs are usually cost, reliability, lifetime, and product consistency. Usually OEMs want a zero-maintenance component that is simple to integrate into their systems. The HeNe laser meets these needs because of its inherent simplicity and product maturity. Typical HeNe-laser lifetimes are measured in years. Product consistency is similarly good; thus, most HeNe lasers exhibit <0.5% unit-to-unit variation in beam diameter. In fact, this tolerance can be made even tighter in custom lasers by using more closely tolerated mirrors. The beam-diameter variation found in many types of visible laser diodes is approximately 10%-20%.

APPLICATIONS

Cytometry. A growing biomedical application for green-emitting HeNe lasers is flow cytometry, which is now used in both basic research and clinical diagnosis to search for signs of cancer and leukemia and to follow the progress of diseases such as AIDS. Coulter Corp. (Hialeah, FL) is a supplier of both research and clinical diagnostic flow cytometers. The company’s instruments “rely on fluorescently labeled monoclonal antibodies—biological agents that bind to specific marker sites on the surface of the various cell types of interest,” explains Ron Porcelli, a scientist at Coulter. Adds principal scientist James Hudson, “By using various fluoroconjugates, we can label several cell types simultaneously. Each labeled cell type will fluoresce at a different wavelength or combination of wavelengths.”

In the flow cytometer, treated blood-cell mixture flows through a narrow laser-interaction region, forcing the cells to flow in single file. As each labeled cell passes through a focused laser beam, it produces a characteristic fluorescence emission that is detected by several photomultiplier tubes, each shielded by different spectral filters (see photo on p. 1). In addition to being characterized, specific subpopulations of cells can be sorted out of the main stream, based on
their fluorescence signature (see Laser Focus World, Sept. 1994, p. 18).

The speed and efficiency of a flow cytometer are limited because the cells are counted one at a time. Efficient excitation and fluorescence detection of labeled cells, however, can help maximize the cytometer throughput. Many of the important probes (fluorescent labels) have absorption maxima in the 520-550-nm range, so optimal laser excitation requires a laser with output in this region. The green HeNe laser is preferred because it is less expensive and/or technically simpler than alternatives such as a diode-pumped Nd:YAG laser (frequency-doubled to 532 nm) or an air-cooled argon-ion laser operating at 514 nm.

An argon-ion laser is about four times more expensive than a green HeNe laser; it is also bulky and uses more electrical power. Furthermore, argon-ion laser excitation of probes such as phycoerythrin can cause Raman scattering within the bandpass of the fluorescence detector, which reduces the overall signal-to-noise ratio of the instrument. One of Coulter’s instruments, the EPICS Elite flow cytometer, also uses the green HeNe to assay cells for DNA content, allowing blood to be screened for abnormal cell activity.

Becton Dickinson (San Jose, CA) is another primary manufacturer in the cytometry market. The company recently received FDA clearance to market a low-cost instrument that uses a single green HeNe laser as its light source. Explains Bill Treytl, senior project optical engineer, “The bulk of clinical testing involves a limited number of cell types. We set out, therefore, to build a streamlined instrument that would perform these tests for a minimum cost.” Until now, clinical tests have been performed in a specialized laboratory because of instrument costs and the low test volumes at any given medical practice. Such tests include, for example, T-cell measurement in patients infected with the HIV virus.

Because the new system uses one green HeNe laser, Becton Dickinson has been able to market it for less than $35,000. The instrument is aimed at the medical practice/small hospital market, allowing these users to perform tests themselves.

Both cytometer manufacturers cite the low noise, good beam-pointing stability, and excellent mode quality of the green HeNe laser as critical characteristics. Unit-to-unit consistency, particularly for beam diameter, is also important because the dimensions of the focused spot are often used to determine cell size, thereby eliminating spurious cell counts.

**Interferometry.** Many industries rely on laser-based interferometry for precision metrology. This includes checking for eccentricity on rotating shafts and turbines, measuring fluid flow rates, and closed-loop micropositioning in semiconductor fabrication.

Interferometry measures the position of an object in the path of a beam by computing the phase of the laser light reflected from it. Interference between the object beam and a reference beam (split off from the same laser before reflection) provides measurable intensity variations that yield the phase information. The technique allows both the position and velocity of an object or surface to be accurately determined. The wavelength of the laser is essentially used as a fine optical ruler; narrow linewidth translates directly into increased accuracy and enhanced measurement range.

Helium-neon lasers, with their long coherence length, dominate such applications. Recently, we have seen a growing interest in stabilizing green and yellow HeNe lasers for applications for which the beam is required to pass through a medium, such as seawater, that would severely attenuate a red beam.

**Industrial alignment.** The alignment of objects relative to a projected line or plane, either by eye or using machine vision, is typical of most industrial alignment applications. Examples range from aligning raw lumber in saw mills to assembling airframes and ship hulls. Low cost, reliability, diffraction-limited beam divergence, and good beam-pointing stability have long made HeNe lasers popular for these types of alignment.

In many cases a low-power red-emitting HeNe laser does not provide optimal visible contrast between the beam and the item being illuminated by it. Hence, a growing market for yellow and green HeNe lasers has developed for applications where the higher visible contrast of a non-red HeNe laser allows the use of a lower-power yellow or green laser. Line generation for cutting marble and granite and aligning the head and shaft during golf-club assembly are both examples of such applications. A higher-power (>10 mW) red laser could work equally well, but this would involve additional safety measures and other restrictions due to CDRH regulations.

**X-ray film scanning.** High-power (10-35 mW) red-emitting HeNe lasers are now finding use in the digitization, storage, and reprinting of medical x-ray images. In the USA, where medical x-ray films must be retained for five years, digitizing these images provides large medical
facilities with an archiving method that is far more convenient than simply retaining the bulky films. This application uses low-noise lasers (about 0.5% peak to peak) to ensure that all the image subtleties (gray-scale detail) are accurately and linearly recorded. High power is necessary to minimize scan time. Stored images can then be reprinted onto film when needed, using a low-power, low-amplitude-noise HeNe laser.

**Industrial barcodes.** Visible laser diodes have been taking an increasing market share from HeNe lasers for hand-held barcode readers. The HeNe laser, however, still dominates other barcode applications because its superior collimation (low divergence) provides such scanners with a greater depth of field (see Fig. 2). Thus, a single HeNe-laser-based industrial barcode reader on a conveyor system can read a variety of items that differ in size and shape. Also, most supermarket scanners still rely on HeNe lasers to provide the depth of field needed for rapid, error-free operation. Tens of thousands of HeNe lasers are sold each year for this application alone.

Figure 2. Well-collimated laser beam provides greater depth of field for reading industrial barcodes.

Notwithstanding a significant challenge from diode lasers, the market for HeNe lasers remains strong, due in part to the nearly ideal output characteristics of this gas laser. Another factor in the continuing success of HeNe lasers, especially for OEMs, is the ability of laser manufacturers to customize and optimize their products for specific applications.