# Better Test Systems Boost Laser Diode Performance

*by Larry Johnson and Jim Schreiner*

**As laser diodes continue their drive to the head of the class, instrumentation that provides test and measurement support is not far behind.**

Semiconductor laser diodes have taken the laser market by storm, in part because of their operating efficiency and compactness. They have several unique characteristics, though, that must be considered in their application (Figure 1). These include their physical packaging, low voltage, current-sensitive power supply requirements, temperature sensitivity, optical output power, spectral characteristics and beam divergence. Not surprisingly, as demand for the lasers grows, so does the need for instruments to support their test and measurement requirements.

Fundamentally, all laser diodes are semiconductor PN-junction devices with a gain region, an optical waveguide and a resonant cavity. A common edge-emitting structure has a planar optical waveguide consisting of multiple crystalline layers of controlled consistency and doping grown on a suitable substrate material (Figure 2). A Fabry-Perot laser structure has a resonant cavity formed by careful cleaving of the bulk material to create parallel end facets that act as mirrors. Optical gain results from passing electrical current through the PN junction. At high current densities, a large population of excited electrons become available to provide gain in the form of stimulated emission.

Electrically, edge-emitting laser diodes behave like other semiconductor diodes with a forward voltage of about 1.7 at room temperature. As the current increases in the laser junction, gain also grows until round-trip gain in the cavity exceeds round-trip loss, and lasing action begins. Manufacturers describe the most basic electrical and optical properties of these devices in a light-current-voltage plot (Figure 3). Many of these curves also include the output current of a monitor photodiode, which comes with most laser diode packages.

The optical spectrum of light emitted by laser diodes varies in center wavelength and in spectral distribution, depending on the type of device and its operating parameters. The output beam depends on the dimensions of the optical waveguide cavity. A typical 10-mW, 780-nm laser diode might have an effective cavity cross section of 2 × 10 µm, which gives rise to a highly divergent and asymmetrical beam pattern.

Demand for these lasers has fueled a new class of test instrumentation for both laboratory and production environments. Special fixtures securely hold laser diodes and provide necessary heat sinking. Current sources produce precision, low-noise transient-free power under all operating conditions. Temperature controllers work with Peltier coolers and thermistor temperature sensors to achieve a known, stable operating temperature. Optical power measurement sensors accurately measure the highly divergent free-space beam. When the diverging beam pat-

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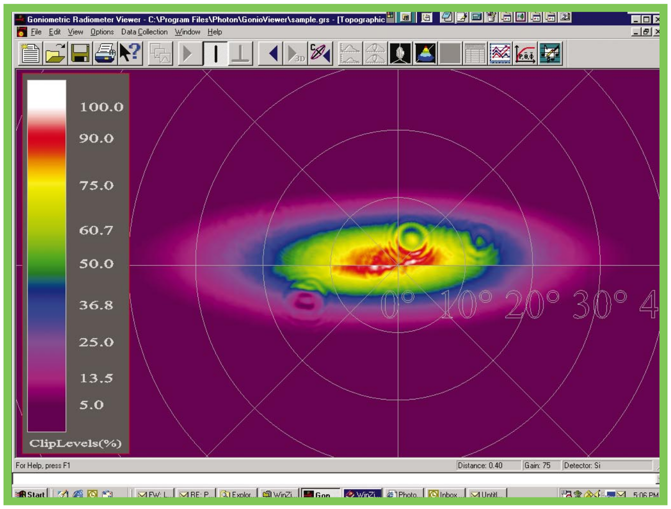


*Figure 1. The far-field pattern of a laser diode depicts light intensity as a function of angle. The highly asymmetric pattern of a typical edge-emitting laser is apparent. Courtesy of Photon Inc.*

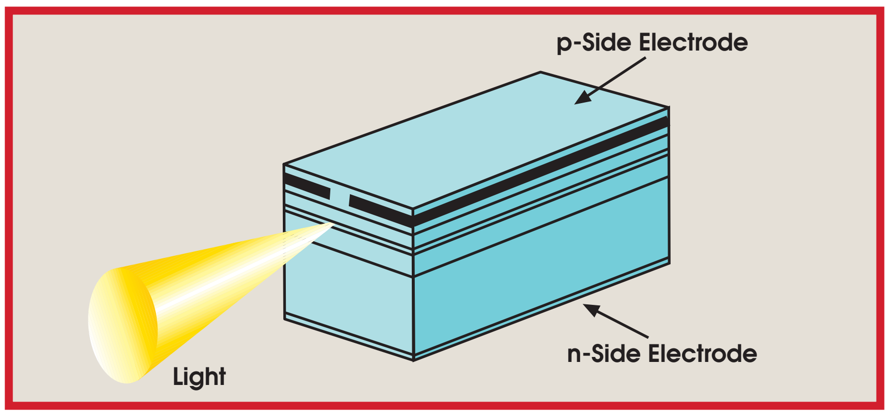


***Figure 2.*** *Typical edge-emitting laser diodes feature a planar optical waveguide fabricated in material combinations such as InGaAsP and InP.*

tern must be characterized, far-field scanners can map the emitted light intensity as a function of angle.

Successful equipment specification requires careful consideration of a variety of characteristics unique to each support tool. Mounting fixtures, for example, are critical but undervalued elements needed for controlling a semiconductor laser.

## Mounting maneuvers

Commercial mounts provide convenient electrical connections, dependable thermal contact for temperature control, robust mechanical mounting and suitable coupling of the output light, whether fiber-coupled or free-space. Mounting fixtures are available for nearly all styles of laser diodes, including window-can, dual in-line and butterfly packages.

With nonfiber-coupled packages, end users must carefully evaluate the mount's mechanical stability, as well as ease of alignment with subsequent optical elements of the system. For diodes requiring high temperature stability, such as wavelength-division-multiplexing fiber-coupled devices, the mounting fixtures should support not only external or case temperature control and monitoring, but also control and monitoring of an internal Peltier cooler. For high-power laser diodes, the mounting fixture may include multiple stages of Peltier coolers, accommodations for water cooling, and mounting holes for mating to a larger thermal mass for improved stability and cooling capacity.

Many mounts also include an embedded temperature-sensing element, most commonly an NTC thermistor, for monitoring the heat sink temperature near the laser. The location of this sensor relative to the laser diode is important when considering the overall thermal performance of the temperature-control loop; too much distance between the diode and the sensor will introduce thermal delays, affecting the speed and stability of the control.

## Current and temperature

A variety of laser diode current sources are available, offering a range of output currents, operating modes and protection features tailored for semiconductor lasers. Controllers provide the convenience of current source and temperature control in a single instrument.

Semiconductor lasers are inherently current devices, and laser diode current sources deliver a stable, low-noise constant output with the protective features demanded by these electrically sensitive devices (Figure 4). Unstable or noisy injection current translates to unstable optical output power and shifts in output wavelength. Output noise and stability specifications should be carefully reviewed when selecting a laser diode driver.

Early users of semiconductor lasers would drive the device with a battery or other available voltage source, but these approaches offered none of the protective features of current laser diode instrumentation. Voltage sources may provide a smooth turn-on ramp-in voltage but, without current control, laser output can drift with temperature.

A laser diode current source offers selectable output current limits that clamp the output before damage can occur. This also provides a slow-start circuit to limit start-up transients, as well as adjustable overvoltage protection for changes in output impedance or intermittent electrical contacts. With the output off, it is important to short connection leads to the laser to prevent damaging surge current or discharge. Shorting field-effect transistors or adding relays on the output stage will provide this protection in most drivers. Finally, well-designed drivers protect against power line transients and ensure highly controlled turn-on and shutdown modes of operation.

Another device that requires careful control is the cooling module, because the performance of semiconductor laser diodes is highly dependent on a stable operating temperature. Thermoelectric cooling devices or Peltier elements are the most common ways of stabilizing temperatures of optoelectronic devices, whether the diode is externally mounted to a thermoelectrically cooled module or the cooling module is inside the diode package. Thermoelectric temperature controllers provide this level of control and have additional features tailored to the operational needs of semiconductor lasers.

The controller's output current should match the maximum current capacity of the cooling element, which should be selected based on the heat load. Modern temperature controllers deliver precision current using closed-loop control algorithms that achieve the desired temperature set point quickly, with little oscillation. One can adjust these proportional-integral-derivative control algorithms for optimal performance for varying load characteristics. Also, a stable, low-noise current to the thermoelectric cooler minimizes the impact of coupled noise and transients.

Many controllers support a wide variety of temperature sensors, including NTC thermistors and linear integrated circuit temperature sensors. NTC thermistors are more common because of their low cost, high accuracy and small size. Each sensor requires different control and sensing signals from the instrument and may require calibration constants for accurate readings. For instance, because the thermistor is a nonlinear device, the instrument must support constants for a nonlinear conversion. Many thermistor suppliers provide these constants with their devices, but the values are derivable using appropriate measurements of resistance vs. temperature and established curve-fit programs. Linear integrated circuit sensors depend on much simpler calibration constants.

## Beam characteristics

Two other components of interest for semiconductor laser users are optical power monitoring and far-field scanning. Selecting the best power meter depends on such factors as dynamic power range, operating wavelength range and output beam profile. Common power meters will satisfy a mixture of these factors, dependent upon which are most critical to the application, and the power and wavelength of interest (Figure 5).

Launch conditions of the laser also influence meter selection. When working with free-space or uncollimated edge-emitting laser diodes, end users will find the output beam divergent. Thus, to get reliable readings, the measurement head must be close enough to the device's output to capture all the output power. The sensor head should also be insensitive to beam divergence.

Telecommunications lasers in dual in-line or butterfly packages incorporate fiber pigtails, either with bare fiber terminations or with a standard connector. Fiber optic power meters have features that optimize power readings by reducing variability in the polarization dependencies, in the cleave angle and angle of insertion, and in the distance between the fiber end face and the detector. Those with an integrating sphere as the input port for the fiber usually minimize these variants and optimize the ac-

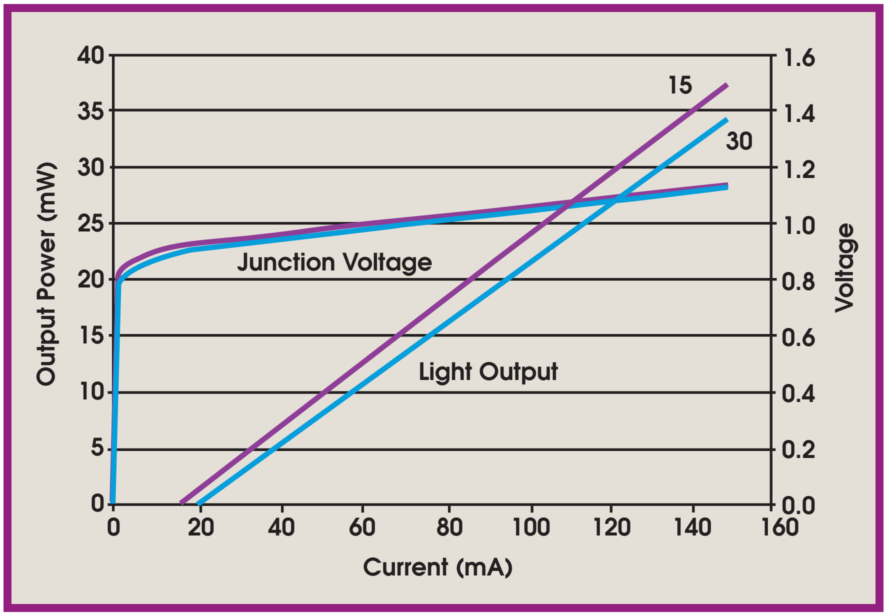


***Figure 3.*** *Light-current-voltage characteristics curves provide information on basic operating parameters of diodes.*

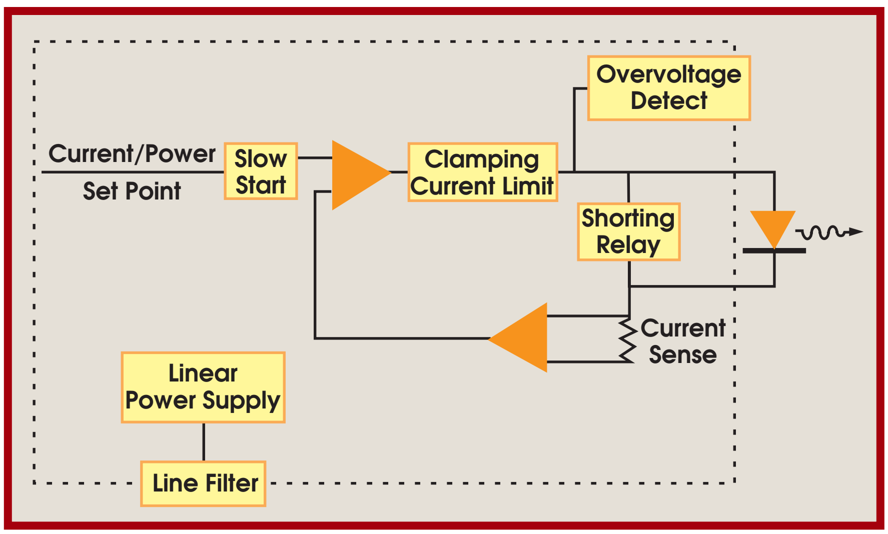


***Figure 4.*** *Instrument-grade current sources provide multiple laser protection features.*

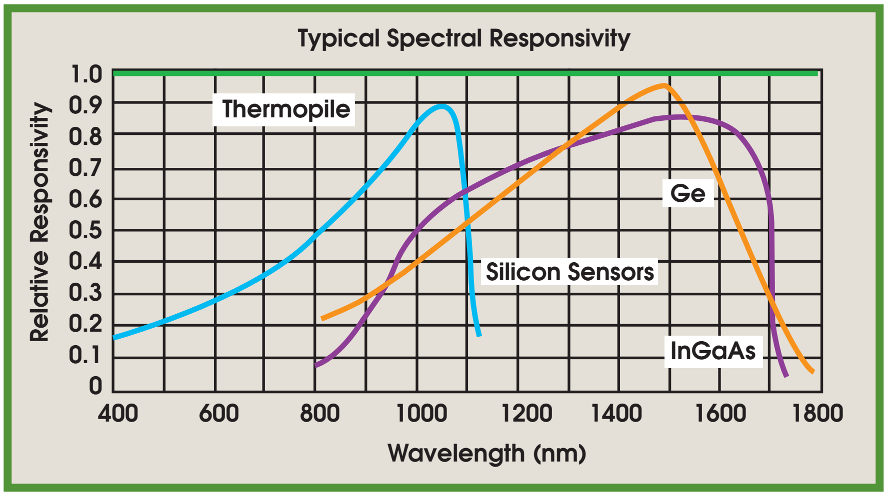


***Figure 5.*** *The spectral sensitivity of optical power measurement heads depends on the detector used.*

curacy and repeatability of fiber-based optical power measurements.

In a manufacturing environment, the measurement speed, accuracy and repeatability of these meters are important. They should have fast electronics and quick processing capability. Production requirements may also demand dual-channel capability to enable comparison with a reference signal or with support ratio measurements.

Beam divergence can be a critical parameter because the output beam of edge-emitting laser diodes is elliptical and highly divergent. This occurs because the laser's emission aperture is a narrow slit with a long and short axis, causing diffraction effects to be stronger in one direction than the other. The beam divergence characteristics are important in applications where the laser output couples into a fiber or other small aperture. It is often necessary to perform a far-field scan to measure and evaluate the spatial properties of the diode's output power.

Far-field scanning techniques exist for both free-space diodes and fiber output, with the conventional method involving the sweeping of a small-area detector through arcs in both output axes while measuring the optical power throughout the sweep. This information creates a map of the emitted light intensity vs. angle, essentially representing the cone of light from the diode at the chosen far-field reference hemisphere.

For free-space diodes, this is useful when coupling a fiber to the laser output or if collimating optics are required. Far-field information for single- or multimode fibers is useful in calculating mode-field diameter, effective area of the fiber and the numerical aperture, all in accordance with TIA/EIA standards.

Laser diodes typically come in 2- to 3-in. wafers produced via metallorganic chemical vapor deposition or molecular-beam-epitaxy processes. A good wafer can produce thousands of lasers. Between the wafer and the final product, the devices face many test and packaging steps. Unlike silicon-based devices, a high percentage of the final cost of a laser diode comes from these back-end steps, where process yields are frequently low and devices may require expensive packaging, including optical alignment.

Test systems used in laser diode manufacturing fall into three main categories:

• *Parametric and functional test systems* measure operating characteristics of diodes and modules at various processing steps. They incorporate one or more measurements, including facet light output, monitor photodiode current and laser voltage as a function of laser diode forward bias current; spectral properties; and far- or near-field pattern.

Later in the packaging process, engineers will take measurements at multiple temperatures. For lasers incorporated into modules that include thermoelectric coolers, tests to verify the operation of other module elements include the coolers' efficiency, and AC and thermistor resistance.

To reduce test time and cost, all parametric and functional systems incorporate test sequence automation. Many systems feature ganged or multiple test heads as well as some device-handling automation.

• *Burn-in systems* accelerate aging of lasers during production to weed out devices that suffer from infant mortality. A typical burn-in profile would be to operate a device in constant current mode at 1.2 times the normal operating current and 85 °C for 200 hours, with the laser-current-voltage characteristics measured before and after. Devices whose output drops by more than a few percentage points would be discarded.

• *Life-test systems* accelerate the aging of lasers to verify their useful life. These are similar to burn-in systems except that they involve more complex monitoring during test, and test times run from 3000 to 5000 hours. Although many burn-in systems simply supply a constant current to the laser during the test, life-test systems almost always monitor facet output, laser voltage and photodiode output (if present).

Instrumentation and test systems have come a long way over the past 20 years to support the applications of laser diodes. Understanding their characteristics and selecting the right equipment should increase productivity and help achieve desired results in manufacturing or in research. □

## Meet the authors

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