Laser diodes provide high power for high-speed communications systems

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The trend to optical communications systems, "wired" with single fibers rather than bundles of fibers, puts a premium on the efficient coupling of source power into the fibers. The smaller optical aperture of the single fiber requires not only the higher source power of the laser diode but construction techniques that attach the fiber directly to a laser pellet. Meanwhile, laser diodes have their uses in high-speed, high-power systems using both fiber bundles and single fibers.

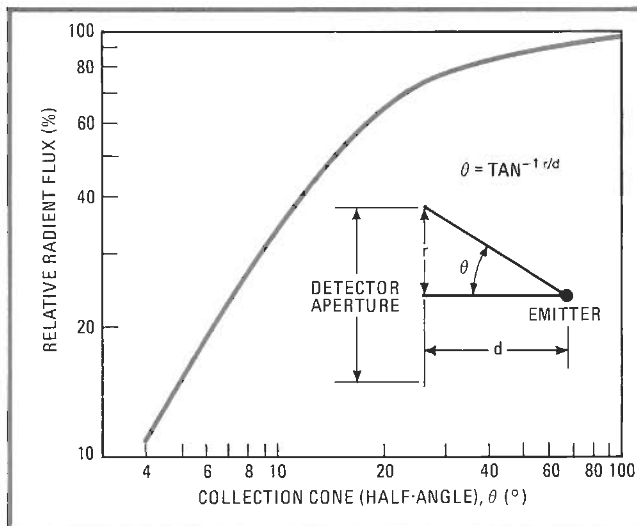
Two types

Gallium-arsenide and gallium-aluminum-arsenide laser diodes are available in single- and double-heterojunction structures. The double-heterojunction diode consists of a thin active layer of gallium arsenide, usually lightly doped with aluminum, sandwiched between two layers of GaAlAs. The single-heterojunction type has only one layer of GaAlAs along with the active layer of GaAs or GaAlAs. But the most important difference between them is the much higher data-rate capability of the double-heterojunction type (greater than 100 megahertz versus 100 kilohertz.).

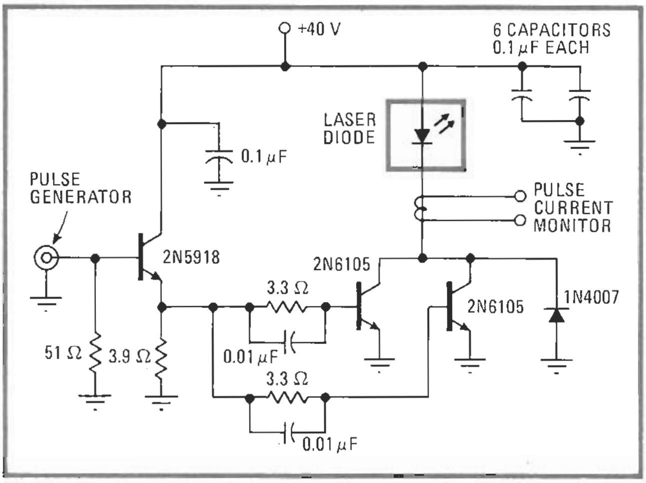
Single-heterojunction laser diodes are low-cost, off-the-shelf items used in low-duty-cycle applications requiring high output power. Peak radiant flux of these diodes is limited to approximately 1 watt per mil of emitting-junction width at a 200-nanosecond pulse width. For example, a diode with a 9-mil-wide junction, such as the RCA SG2007, is rated at a maximum of 10 W peak output. But because the diode's need to dissipate heat sets limits to its operation, a tradeoff between pulse width and pulse repetition rate must be made. Consequently, at a maximum pulse width of 20 ns and a maximum duty cycle of 0.1%, the repetition rate is limited to 5 kHz. At pulse widths on the order of 10 ns, repetition rates of 100 kHz are possible.

The double-heterojunction laser diode requires relatively low drive current and voltage (less than 400 milliamperes at 2 volts). Continuous or high-duty-cycle operation is possible at room temperature with power outputs in the 5-to-10 milliwatt range at less than 1-ns rise time. Analog or digital bandwidth capability exceeds 100 megahertz.

The semiconductor laser is essentially a line source with an emitting dimension of 0.08 mil times the emit-



1. Collecting flux. The amount of light output from a semiconductor laser incident on an optical fiber can be determined from the relative radiant flux emitted by the laser and the fiber collection angle. Data for a single-heterojunction laser is shown.



2. Switching sources. With the transistor circuit shown, pulses as short as 10 nanoseconds at repetition rates of 100 kilohertz are possible, but peak current is limited. Silicon controlled rectifier switches produce higher current but at lower repetition rates.

ting width. The wavelength of maximum intensity depends primarily on the bandgap energy of the material used and, to a much lesser extent, on junction doping. GaAs, for instance, has a center wavelength of 904 nanometers, which is temperature-sensitive. For a single-heterojunction type, the spectral bandwidth and half-angle beam spread at the 50% intensity points are 3.5 nm and 9° respectively. Both values are broad relative to other laser types and result in greater coupling loss to fibers.

The relative radiant flux collected at a detector depends on the collection angle of the laser diode. A typical curve is shown in Fig. 1.

For high peak output power, it is necessary to drive the laser with fast, high-amplitude current pulses. The pulse may be generated by discharging a capacitor through the laser using either a silicon controlled rectifier or a transistor. An SCR can switch higher peak currents than transistors, but at much lower speeds. Each has advantages and disadvantages, and the optimum drive circuit can be picked only in terms of overall system performance.

Drive circuits

In SCR driver circuits, transistors are used to regulate the level to which the storage capacitor is charged by the supply voltage. The SCR acts as the discharge switch and, when triggered, drives the laser diode. General-purpose SCRs, such as 40763 or 40555, can handle pulse repetition rates in the range of 5 – 10 kHz. The capacitance value is determined by the combination of current and pulse width desired.

Not many commercially available SCRs are fast enough to deliver narrow, high-current pulses at repetition rates in excess of 10 kHz. But a few, such as the Unitrode GA-201, can generate 25-ns pulses at repetition rates up to 25 kHz.

With a transistor switching circuit (Fig. 2), pulses as short as 10 ns at repetition rates greater than 100 kHz are possible. The maximum peak laser drive current, however, is limited to approximately 20 amperes.

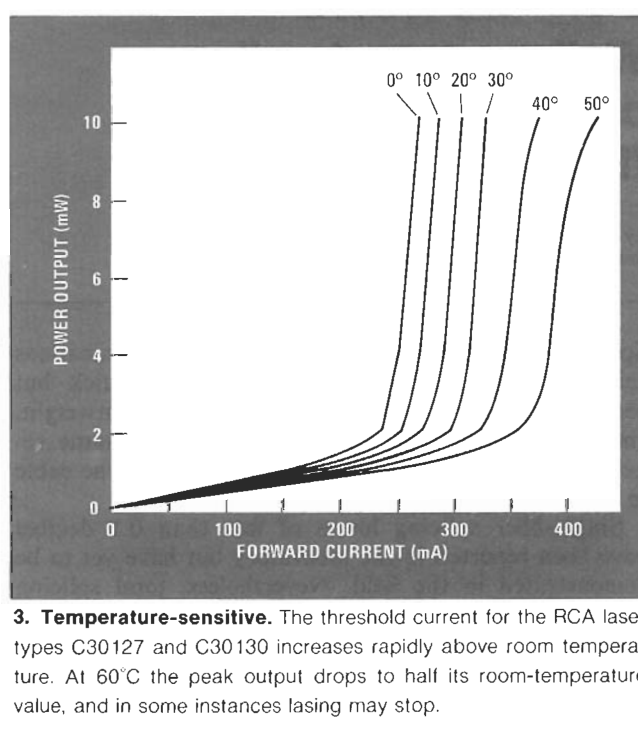
How much of the laser output actually enters a given optical fiber depends on cable as well as source parameters. From published data for a laser device, it's possible to determine what size gap there should be between it and the fiber face. The active diameter of the fiber and its numerical aperture, available on its data sheet, defines the emission angle the laser pellet should make with the fiber. The amount of laser output incident on the fiber bundle is found using the laser's relative radiant flux versus the fiber collection angle. A typical plot is shown in Fig. 1. Finally, from the bundle's packing fraction (the ratio of the useable core area to the over-all area of the bundle), the amount of power coupled into the fiber can be derived.

Usually the measured value of a laser's emitted power is slightly lower than indicated in the available specifications. However, data sheet numbers do provide a starting point.

One example

For example, from published data on the RCA C30130 double-heterojunction laser diode it can be determined that a fiber-bundle cable with an active area of 0.015 inch can be positioned approximately 0.120 in. from the laser chip. This defines an acceptance angle of about 4° with the emitting surface of the laser pellet. From a plot of radiant flux as a function of collection angle, it is determined that about 4% of the emitted flux from the diode is incident on the active diameter of the bundle. Using a value of 40% to represent the area occupied by individual fibers in the bundle indicates that a total of only 1.6% of the laser output is coupled into the fibers.

More efficient coupling is possible using a laser with the glass window removed, so that the fiber can be placed closer to the laser pellet. Measurements taken with such a nonhermetic diode and the same fiber bundle show coupling efficiencies of 35%—which is a really



3. Temperature-sensitive. The threshold current for the RCA laser types C30127 and C30130 increases rapidly above room temperature. At 60°C the peak output drops to half its room-temperature value, and in some instances lasing may stop.

dramatic improvement.

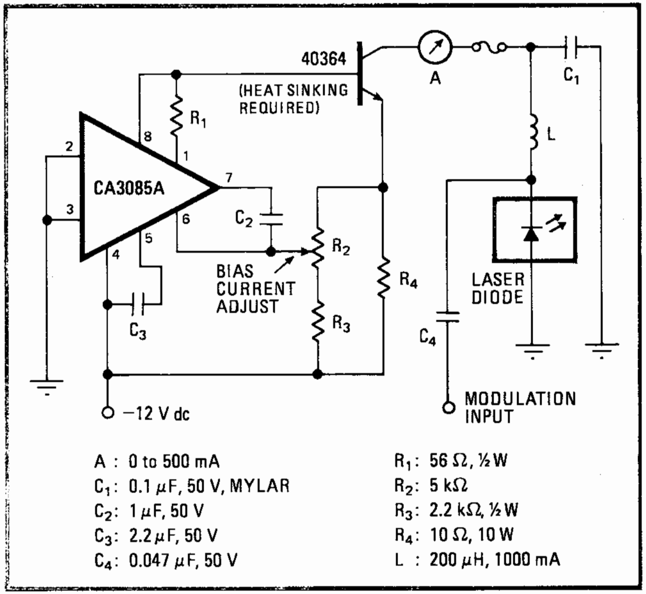
One problem with laser diodes is that relatively small changes in temperature can change their output significantly. As shown in Fig. 3, threshold current for RCA types C30127 and C30130 increases at temperatures above 27°C and doubles at about 70°C, while with constant current drive applied, the peak radiant flux at 60° drops to 50% of its room-temperature value. In fact, threshold current of the drive may increase sufficiently to prevent lasing.

Because of this heavy dependence of threshold current on temperature, the laser should be operated at some fixed temperature within its operating range temperature. A small thermoelectric heat pump will maintain the laser heat-sink temperature to within a few tenths of a degree over the expected ambient temperature range.

For analog systems, it is necessary to bias the device well above the threshold point and then superimpose the analog modulating signal on the dc drive current. Figure 4 shows a typical circuit used to measure the linearity and harmonic content of a laser diode when operated in the analog mode at 10 MHz. Approximately 350 mA of bias current is sufficient to provide a continuous output of 7 mW. A 30-mA peak-to-peak 10-MHz sine wave is coupled through capacitor C_4 and the laser output measured with a silicon photodiode. The first harmonic at 20 MHz is 40 dB below the fundamental with an ac drive current.

Laser lifetime remains another problem. It must be increased to well beyond 10^5 hours if the diodes are to find use in systems where 20-year reliability is essential. Actual laser-lifetime data isn't yet available, but data extrapolated from selected samples translates into a mean time between failures of 10 hours for some lasers with a heat-sink temperature of 22°C.

The third big problem area—efficient coupling of laser to fiber—should be alleviated with construction techniques that attach a short length of fiber directly to the laser pellet.



4. Measuring linearity. A 30-milliampere peak-to-peak 10-megahertz sine wave was coupled through capacitor C_4 to modulate the laser diode. The light output was measured, and the first harmonic was 40 dB below the fundamental.