Pulsed Laser Diodes

Pulsed laser diodes have their roots in military applications. They are ideally suited to rangefinding thanks to their short pulse widths and high output powers. Improvements in technology and cost-efficiency have opened up new areas of application in automotive, industrial safety scanner, metrology and medicine. Laser Components offers inexpensive laser diodes, which generate short but intense light pulses of up to 650 W.

Principle of Operation

Most laser diodes are designed to emit in continuous wave (cw) mode with powers from a few milliwatts to a few watts. Such diodes are not designed to be overdriven; if the specified maximum power is exceeded, even for a short time, the laser resonator may be damaged, after which laser output will cease.

Pulsed laser diodes, however, are designed to be overdriven for short periods. To achieve the high peak powers demanded by the application, the duty cycle must be kept very low, typically 0.1%. For example, a 100 ns pulse is followed by a pause of 100 µs, which means that very short pulses can be used with repetition rates in the kHz range. The maximum pulse lengths that can be achieved are therefore typically in the 200 ns range. Laser currents on the order of several tens of amperes are used to create these light pulses, which require fast switching transistors and appropriate circuit with all electrical connections as short as possible to diminish inductive losses.

Device Structure

The first semiconductor lasers were simple homojunctions produced by forming a p-n junction in a GaAs substrate. In the next evolution a single AlGaAs layer was grown on one side and a p-n junction again formed by diffusing Zn into the n-type substrate. Known as single heterostructure lasers, they suffered from the effects of self heating which reduced their efficiency due to significant non-radiative recombination of carriers. Operating effectively at room temperature they would emit at 904 nm, but would cease to function at 80 °C. Efficiency and laser threshold was improved with the introduction of double heterostructure devices, in which the active layer controlling the wavelength is enclosed within higher bandgap layers to confine the charged carriers.

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Nature is generous in providing this active layer with a higher refractive index to confine the photons and create a waveguide between the layers. Such a structure might employ GaAs in the active layer, typically in the sub micron range, sandwiched between two layers of AlGaAs. Adding controlled amounts of Al to the active layer allows the manufacturer to lower the emitting wavelength down to 800 nm.
In a quantum well structure, the active layer thickness is similar to the period of the charge carrier wave function. In such diodes, the potential well is so narrow (typically < 10 nm) that charge carriers are only active on one level, leading to a quantization of the energy levels that the charge carriers can occupy.

Quantum wells are usually achieved by using hetereostructures, for example GaInAsP/GaInAs or AlGaAs/GaAs. Structures with only one well are referred to as single quantum well (SQW); where several wells are present these are termed multiple quantum wells (MQW). Quantum well devices are typically highly efficient and can be designed to prevent thermalization of carriers allowing useful operation of the devices beyond 100 °C.

Characteristics

The emission wavelength of a laser diode depends primarily upon the materials used in the active and passive layers of the semiconductor.
Typical wavelengths for commercially available pulsed laser diodes are 850 – 870 nm, 905 nm, and 1550 nm. The AlGaAs structure of the 905 nm devices is well known for its reliability, beam characteristics and temperature stability. The high efficiency allows powers of up to 40 W to be reached with single emitters, and of up to 130 W for stacked devices, for typical pulse lengths of 150 ns.

Multi-junction pulsed laser diodes are similar to nanostack technology with multiple epitaxially stacked emitters. Single chips allows power up to 80 W, stacked one up to 650 W. Available packages include hermetic metal cans (e.g. TO-18, 5.6 mm, 9 mm or coaxial) and cost-effective plastic housings.

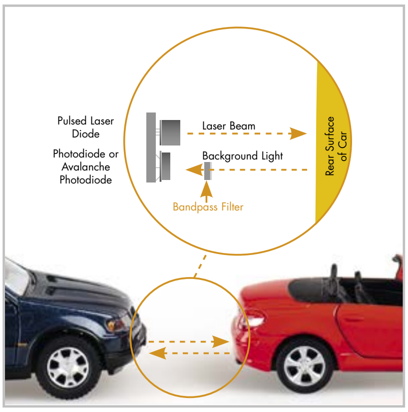
The 1550 nm devices available in the mid-IR can be operated at higher peak power than the 905 nm and still be regarded as eye safe since the laser radiation is not focused directly on the retina. These diodes are based on InP with additional InGaAsP layers, and can be manufactured either by molecular beam epitaxy (MBE) or metal-organic chemical vapor deposition (MOCVD). Peak output powers of up to 50 W can be reached using stacked devices thanks to the efficiency of 0.5 W/A.

Applications

Even at the speed of light, a photon needs a certain length of time to cover a given distance between a rangefinder and the object of interest. Since the speed of light is known for a given material with known refractive index (e.g. air) the time-of-flight can be used to accurately calculate the distance covered by a light pulse.
Laser speed guns are a typical application for pulsed laser diodes. Using pulse lengths of < 10 ns and powers of up to 50 W, vehicle speeds of up to 250 km/h may be easily measured at ranges of up to 1000 m. The accuracy of such measurements is typically 1 – 3%.
Hunters use eye-safe rangefinders to measure the distance to their targets. Neither the deer the hunter is aiming at, nor anyone else nearby, needs to worry about their eyesight. In this case, the class 1 laser device delivers accurate information within one second, with an accuracy of 2 m at distances of 600 m. In other applications, golfers use laser rangefinders to try to improve their handicaps, and car drivers are warned of approaching hazards.
Laser sensors are also widely used as navigational aids for ships, particularly in ports and harbors, and for cloud base measurement at airports, as well as in surveying and construction. Laser safety scanners, based on pulsed

laser diodes and highly sensitive avalanche photodiodes (APD) create a curtain of laser light which senses the presence of persons or objects in potentially dangerous areas e.g. in automated production lines. Finally, there is a range of medical applications including laser acupuncture and therapy.

Reliability



As with other light sources the life time of a pulsed laser diode is highly dependent on operating conditions. Without damage, the devices can be subjected to significant overdrive for short periods of time or when the pulse energy is reduced by employing pulse durations as short as 2 ns. The user should choose the appropriate device and drive conditions to suit the application and the operating lifetime required. Whereas lifetimes of less than an hour are enough for certain military applications such as thyristor ignition, industrial safety scanners in three-shift environments need to run reliably for tens of thousands of hours.

The following formula has been derived from many years of experience with pulsed laser diodes and gives an indication of mean time to failure (MTTF) as a function of a range of parameters:

$$MTTF = 3.9 \text{ x } 10^{20} \text{ x } \{P_o/L\}^{-6} \cdot t_w^{-2} \cdot F^{-1} \cdot f(T)$$

(Estimation for triple junction laser: $MTTF = 1 \cdot 11 \text{ x } 10^{21} \cdot \{P_o/L\}^{-6} \cdot t_w^{-2} \cdot F^{-1} \cdot f(T)$)

where

MTTF (hours) = Mean time to failure
Po (mW) = Optical peak power
L (µm) = Emitter length
tw (ns) = Pulse length
F (kHz) = Repetition rate
F(T) = Temperaturedependant multiplying factor (= 1 at 25°C)

Example: At room temperature the typical MTTF for a 4 W pulsed laser diode with 75 µm emitter, 100 ns pulse length and 10 kHz repetition rate would be approx. 170,000 hours. If the power is increased to 6 W with all other parameters unchanged the lifetime is reduced to 15,000 hours. Emitter length is equally important – if the power is halved, or the emitter length doubled, the lifetime is increased by a factor of sixty-four.

Summary

The short powerful pulses from pulsed laser diodes represent an enabling technology for a variety of applications in which cw-laser diodes can not be used for technical or economic reasons. Several manufacturers offer devices at 850 nm, 905 nm and 1550 nm for such applications. Single emitters and stacked devices offer a wide range of output powers and emitting areas.