Optima Laser Diode Application Notes and Glossary

Terms Describing Laser Diode Absolute Maximum Ratings:

Commonly used abbreviations are shown in parentheses.

Case Temperature (Tc) – Device temperature measured at the base of the package.

Operating Temperature (Topr) – Range of case temperatures within which the device may be safely operated.

Optical Power Output (Po) – Maximum allowable instantaneous optical power output in either continuous (CW) or pulse operation. Up to this point, there are no kinks in the optical power output vs. forward current curve.

Important note: The optical power output specification is applicable to the bare laser diode – it does not allow for, or take into consideration, any optics that may be in the optical path, such as a collimating lens located between the laser diode and a power meter or other detector.

Caution: Do not exceed the specified optical power output — even an instantaneous (less than a nanosecond) application of excessive current or voltage may cause deterioration or catastrophic optical damage (COD) to the facets.

Reverse Voltage (VR) – Maximum allowable voltage when reverse bias is applied to the laser diode or photodiode. For laser diodes with an internal monitor photodiode, the reverse voltage is specified for the laser diode as VR (LD) and for the photodiode as VR (PD).

Storage Temperature (Tstg) – Range of case temperatures within which the device may be safely stored.

Terms Describing Laser Diode Electro-optical Characteristics:

Commonly used abbreviations are shown in parentheses.

Automatic Power Control (APC) – Laser diode drive circuit based on a photodiode feedback loop that monitors the optical output and provides a control signal for the laser diode which maintains the operation at a constant optical output level. See additional information below on Drive Circuits and Operating in Constant Power Mode vs. Constant Current Mode.

Automatic Current Control (ACC) or Constant Current – Laser diode drive circuit that operates the laser diode without a photodiode feedback loop, the laser diode is simply driven at constant current. The optical output will fluctuate as the laser diode temperature changes. See additional information below on Drive Circuits and Operating in Constant Power Mode vs. Constant Current Mode.

Fall Time – Time required for the optical output to fall from 90% to 10% of its maximum value.

Mode Hopping – As the temperature of the laser chip increases, the operating wavelength also increases. Rather than a smooth, continuous transition in the operating wavelength, the wavelength makes discrete jumps to the longer wavelength modes. The phenomenon is referred to as “mode hopping” or “mode jumps”.

Monitor Current (Im) – The current through the photodiode, at a specified reverse bias voltage, when the laser diode is producing its typical optical power output. Note: The manufacturers data may list specifications based on operation at lower optical output power than the devices absolute maximum rating. For example, the test condition might be 20mW for a diode with an absolute maximum optical output of 30mW.

Operating Current (Iop) – The amount of forward current through the laser diode necessary to produce the specified typical optical output at a specified operating temperature.

Operating Voltage (Vop) – The forward voltage across the laser diode when the device produces its specified typical optical output at a specified operating temperature.

Photodiode Dark Current ($ID_{(PD)}$) – The current through the reverse biased internal monitor photodiode when the laser diode is not emitting.

Optima Laser Diode Application Notes and Glossary

Positional Accuracy (Dx, Dy, Dz) – Also referred to as emission point accuracy. These specifications define the positional accuracy of the laser diode emitter with respect to the device package. Delta x and delta y are measured as the planer displacement of the chip from the physical axis of the package. Delta z is measured perpendicular to the reference surface. Specifications may list both angular error expressed in degrees and the linear error in microns.

Rise Time – Time required for the optical output to rise from 10% to 90% of its maximum value.

Slope Efficiency (SE) or (ηS) – Also referred to as differential efficiency. This is the mean value of the incremental change in optical power for an incremental change in forward current when the device is operating in the lasing region of the optical power output vs. forward current curve.

Threshold Current (Ith) – The boundary between spontaneous emission and the stimulated emission shown on the optical power output vs. forward current curve. Below the threshold current point, the output resembles the incoherent output from a LED; at or above the specified threshold current, the device begins to produce laser output. Once past the threshold point, stimulated emission is achieved and the optical output increases significantly for a small increase in forward current.

Wavelength (lp) – The wavelength of light emitted by the laser diode. For a single mode device, this is the wavelength of the single spectral line of the laser output. For a multi-mode device, this is the wavelength of the spectral line with the greatest intensity.

Terms Describing Laser Diode Optical Characteristics:

Commonly used abbreviations are shown in parentheses.

Aspect Ratio (AR) – The ratio of the laser diode's divergence angles, $\theta \perp$ (perpendicular) and θ // (parallel). A diode with a 27^{o} perpendicular divergence and a 9^{o} parallel divergence has an elliptical beam with an aspect ratio of 3:1.

Astigmatism (As) or (DAs) – The laser beam appears to have different source points for the directions perpendicular and parallel to the junction plane. The astigmatic distance is defined as the distance between the two apparent sources. A laser diode with a large amount of astigmatism must have the astigmatism corrected (or reduced) if the laser diode output is to be accurately focused – otherwise, the resulting focused beam will be astigmatic.

Beam Divergence ($\theta\perp$) and (θ//) – Also referred to as radiation angles. The beam divergence is measured as the full angle and at the half-maximum intensity point, known as Full Width Half Maximum or FWHM. Angular specifications are provided for both the perpendicular axis and parallel axis.

Coupling Efficiency – The beam from the laser diode diverges as defined by the beam divergence specification. In coupling the laser diodes widely divergent beam into a lens or other device such as a fiber, the result is typically less than 100%. Coupling efficiency is defined as the percentage of total power output from the laser which effectively enters the external device (i.e. a lens or fiber).

Far Field Pattern (FFP) – Intensity profile of the beam when measured at a distance from the front facet of the laser diode chip.

Multimode Diodes – Laser diodes have either single or multiple longitudinal modes. For a multimode laser diode the emission spectrum consists of several individual spectral lines with a dominant line (line with the greatest intensity) occurring at the nominal wavelength of the device. Multimode laser diodes are often desirable as problems with mode hops are suppressed – consequently, multimode diodes generally have a better signal-to-noise ratio.

Near Field Pattern (NFP) – Intensity profile of the beam when measured at the front facet of the laser diode chip.

Numerical Aperture (NA) – The numerical aperture describes the ability of a lens to collect light from a source placed at its focal point. The maximum acceptance angle q, is measured from the center axis of the cone of light to the outside or surface of the cone.

Polarization Ratio – The output from a single cavity laser diode is linearly polarized parallel to the laser junction. Spontaneous emission with a random polarization and/or with a polarization perpendicular to the laser junction is also present. The polarization ratio is defined as the parallel component divided by the perpendicular component. For a diode operating near its maximum power the ratio is typically greater than 100:1. When operating near the threshold point, the ratio would be considerably lower as the spontaneous emission becomes more significant.

Optima Laser Diode Application Notes and Glossary

Single-mode Diodes – Laser diodes have either single or multiple longitudinal modes. For a single-mode laser diode the emission spectrum consists of a single spectral line occurring at the nominal wavelength of the device. At output levels near threshold, multiple spectral lines may be present in the emission spectrum however, these secondary lines decrease as the output increases.

FAQ's and Laser Diode Basics:

There are a number of precautions listed in the laser diode manufacturer's catalogs that should be observed when working with laser diodes. Below are a few points that might be helpful if you're new to this field:

Safety Considerations – The laser beam emitted by the laser diode is harmful if aimed directly into the human eye. Never look directly into the laser beam or at any specular reflections of the laser beam.

Electro-Static Discharge – Laser diodes are extremely sensitive devices and visible laser diodes (VLD's) tend to be the most sensitive type. The handling precautions outlined by the laser diode manufacturers are not overstated – good work habits require personal grounding straps and grounded equipment. ESD does damage laser diodes!

Drive Circuits – Laser diodes should always be driven by either a Constant Current or Automatic Power Control (APC) circuit (the APC circuit may also be referred to as a Constant Power Mode circuit). For simplicity, an APC circuit is generally preferred, especially if the ambient temperature fluctuates. Typical circuits include slow-start or soft-start circuitry and provisions to ensure that spikes, surges, and other switching transients are eliminated. Regardless of type of circuit used, the drive current must not overshoot the maximum operating level - exceeding the maximum optical output for even a nanosecond will damage the mirror coatings on the laser diode end facets.

A standard laboratory power supply is not suitable for driving a laser diode.

Examples of the recommended drive circuits can be found in most manufacturer's laser diode data books. Unless you have prior experience with laser diodes and/or their drive circuits, this is not a place to reinvent the wheel - it can be very frustrating and expensive.

Operating in Constant Power Mode vs. Constant Current Mode – The characteristics of a laser diode are highly dependent on the temperature of the laser chip. For instance, the wavelength of a typical GaAlAs diode will increase on the order of 0.25nm for a 1°C rise in temperature. With a single mode diode, the change in wavelength may produce an undesirable effect known as "mode hops or mode-hopping".

Other characteristics directly related to laser diode's operating temperature are; threshold current, slope efficiency, wavelength, and lifetime. Perhaps the most important characteristic is the effect of temperature on the relationship between the diode's optical output and the injection current. In this case, the optical output decreases as the operating temperature increases or, conversely the optical output increases as the operating temperature decreases. Without limits and safeguards built into the laser drive circuit, a wide swing in operating temperature could be catastrophic. However, there are two techniques commonly used to achieve a stable optical output from a laser diode:

Constant Current mode combined with precise control of the diode's operating temperature is generally the preferred operating method. The constant current mode provides a faster control loop and a precision current reference for accurately monitoring the laser current. Fur ther, in many cases the laser diode's internal photodiode may exhibit drift and have poor noise characteristics. If performance of the internal photodiode is inferior, the diode's optical output is likely to be noisy and unstable as well.

Constant Current operation without temperature control is generally not desirable – if the operating temperature of the laser diode decreases significantly, the optical power output will increase and could easily exceed the absolute maximum.

Constant Power or APC mode precludes the possibility of the optical power output increasing as the laser diode's temperature decreases. However, when operating in the constant power mode and without temperature control, mode hops and changes in wavelength will still occur. Further, if the diode's heat sink is inadequate and the temperature is allowed to increase, the optical power will decrease. In turn, the drive circuit will increase the injection current, attempting to maintain the optical power at a constant level. Without an absolute current limit thermal runaway is possible and the laser may be damaged and/or destroyed.

Summary – for stable operation and maximum laser lifetime – temperature control and constant current operation is generally the best solution. However, if precise temperature control of the laser diode is not practical, then an APC circuit should be used.

Revised 02DEC98

Optima Laser Diode Application Notes and Glossary

Drive Circuit Precautions – Even when a laser diode is driven by a suitable drive circuit, watch for possible intermittent or unreliable connections between the laser diode and the drive circuit. An intermittent contact in the photodiode feedback circuit will very likely destroy the laser diode. One not-so-obvious component to consider is the power control. If a potentiometer is used for setting the laser diode's power, evaluate the circuit design to determine the failure mode if the potentiometer's wiper breaks contact with the resistive element. Also, never use a switch or relay to make or break the connection between the drive circuit and the laser diode.

Power Measurements – The output from a laser diode must be measured with an optical power meter or a calibrated, large area photodiode. It's not practical or safe to estimate a laser diode's output power based on the diode manufacturers minimum-maximum data as each diode has unique operating characteristics and manufacturing tolerances.

Remember, once the laser diode is past the threshold point, stimulated emission is achieved and the optical output increases significantly for a small increase in forward current. Therefore, a very slight increase in drive current may cause the optical output to exceed the absolute maximum. Even with a visible diode, it's not feasible to judge the laser output by eye, an optical power meter or calibrated photodetector must be used.

Also, be sure to include optical losses through any lenses or other components when making measurements or calculations.

Operating Temperature and Heat Sinks – In most applications, laser diodes require heat sinks especially when operated continuously (CW). Without a heat sink the laser diode junction temperature will quickly increase causing the optical output to degrade. If the laser diode temperature continues to rise, exceeding the maximum operating temperature, the diode can be catastrophically damaged or the long term performance may degrade significantly. Generally, a lower operating temperature will help extend the diode's lifetime as the laser diode's reliability and MTTF are directly related to the junction temperature during operation. VLD's with lower wavelengths, i.e. ~635nm, appear to be more sensitive to temperature and users might consider thermoelectric cooling if operating in an environment with elevated ambient temperatures or if operational stability is a prerequisite. Also, using a small amount of a non-silicone type heat sink compound will improve thermal conductivity between the diode and heat sink.

Lifetime note: If the laser diode's operating temperature is reduced by about 10 degrees, the lifetime will statistically double.

Windows – Keep the laser diode window, and any other optics in the path, clean. Dust or fingerprints will cause diffraction or interference in the laser output that can result in lower output or anomalies in the far-field pattern. The window should be cleaned using a cotton swab and ethanol when necessary.

Cyanoacrylate Adhesive Precaution – "Super glue" should not be used anywhere near laser diodes - or near any other optical component - outgassing may fog windows and other optical surfaces. The amount of fogging, or the time required to observe the fogging, varies with different products. If you're in doubt, test the adhesive over time at an elevated temperature and in a sealed container. For example, place a drop of the adhesive in question on a piece of glass, something like a microscope slide, then place the sample in a plastic bag and seal the bag.

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