Photodigm

APPLICATIONS NOTE

Lifetime and Reliability

Photodigm 9xx-10xx nm Single Frequency DBR Laser Diodes…

…are designed and fabricated with mission-critical performance in mind. At mission end, no matter what the power, no matter what the beam quality, if the laser is not performing, nothing else matters. As a result of their proprietary design and process technology, Photodigm's 9xx-10xx single frequency DBR lasers are chalking up projected lifetimes approaching an industry-leading one million hours.

The reliability of semiconductor lasers depends on many factors. Elements contributing to failure include strains in the epitaxial material due to the design, defects introduced during the epitaxial growth, defects from the photolithographic process, strains induced by dielectric and metal layers deposited during the fabrication of the device, stresses introduced in packaging, and finally, the operating environment. The laser engineer must be aware of all of these factors and must design accordingly.

The three main types of failures are infant mortality, external hazards, and wear-out. Defects in manufacturing and intrinsic semiconductor defects result in infant mortality. The rate at which these failures occur diminishes quickly as the devices are used. Influences coming from outside of the device, such as electrostatic discharge are external hazards failures. The rate at which these failures occur is constant for an unchanging operating environment. Growth and propagation of non-radiative optical absorbing defects in the semiconductor result in device wear-out. The rate at which these failures occur increases with increasing operation time. The composition of these three failure types yields a general device failure characteristic, known as the "Composite Bathtub Curve," shown below.

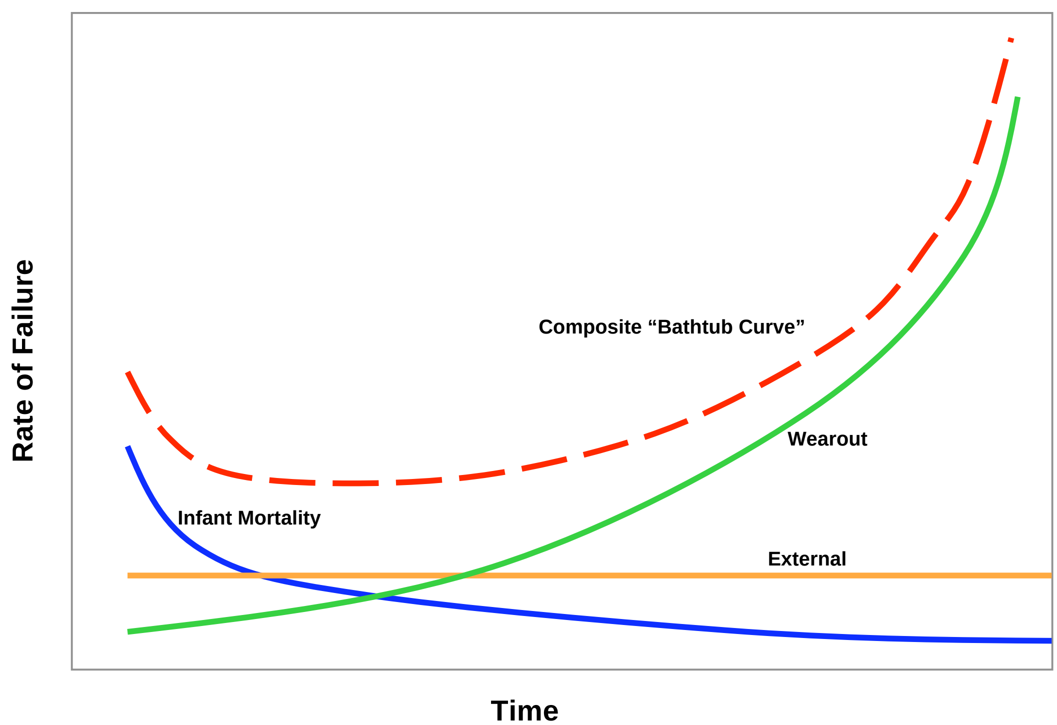


Figure 1. The "Bathtub Curve." typical of time dependent failure rates

Accelerated Life Testing

Theory

The degradation mechanisms that determine the lifetime of a semiconductor laser can be sped up by operating the device at elevated temperatures; this is known as accelerated lifetime testing. The time-to-failure of a device at a nominal operating temperature (T_2) can be projected from the time-to-failure (TTF) of a device operating under an elevated temperature (T_1) by using the Arrhenius equation

$$TTF_2 = TTF_1 \exp\left(\frac{E_a}{k}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right)$$

where k is Boltzmann's constant, and E_a is th activation energy, which is determined by the failure mechanism causing the degradation.

Semiconductor lasers degrade due to a variety of factors; these factors include imperfection in the wafer growth, unwanted strains induced by the epitaxial architecture, contaminations, imperfections, and stresses from the photolithographic processes performed at the wafer level, and imperfections from packaging of the individual laser chips. Despite the range of degradation mechanisms that can cause a semiconductor laser to fail, the majority of failure mechanisms have activation energies ranging from 0.2 to 0.7 eV.

The TTF of a device is also dependent on the drive current at which the device is operated. This relation is described mathematically by the equation

$$TTF_2 = TTF_1\left(\frac{I_2}{I_1}\right)^{-n}$$

where I_i is the drive current corresponding to TTF_i; and n is the current degradation factor, typically ranging from 1.5 to 2.0.

Methodology

The lifetime testing for our semiconductor lasers is performed under automatic power control (APC). Under APC operation, the optical power emitted from the laser is held constant by adjusting the drive current into the device. Because semiconductor lasers can have lifetimes in the range of decades, monitoring the slow increase of laser current over time as the laser degrades is the preferred way to measure laser lifetime. The current is recorded for several thousand hours and its rate of change is used to project the lifetime of an individual device.

The laser is deemed to have failed when the drive current has risen to 1.5 times its initial value. This is a fairly strict definition of failure as some failed devices are still capable of producing their rated optical power. Once the time to failure for each device is determined for a given set of operating conditions, the mean time-to-failure (MTTF) is calculated under the assumption that the failure times are statistically lognormal distributed.

Generally, the activation energy and the current degradation factor can be determined through a maximum-likelihood estimation. However, this requires a large sample size in order to obtain reasonable statistics. Three different operating temperatures and three different power levels, with at least 8 devices at each operation condition, would be required to make a reasonable estimate of the activation energy and current degradation factor. This determination of parameters could be carried out with a minimum of 40 devices in each batch. Due to our limited capabilities at present, we instead assume an activation energy of 0.5 eV and current degradation factor of 1.8; these are both "middle of the road" values, and fit well with our limited data.

Summary of Current Life Test Results

The 1064 nm and 1083 nm epitaxial materials are made from the same material system with some modifications to the active layers to achieve the desired wavelength. Due to the similarity of these epitaxial materials, the lifetime of devices in the 1064 nm and 1083 nm should be similar, given that processing and packaging are of good quality. One of the first samples of lasers tested included 1083 nm material, in order to qualify the entire laser fabrication process from the basic epitaxial structure, growth, and processing. The devices in this sample are still being tested at an output power of 100mW at several different temperatures. The drive currents as a function of time are shown in Figure 2. Note that as the devices began aging, the current first

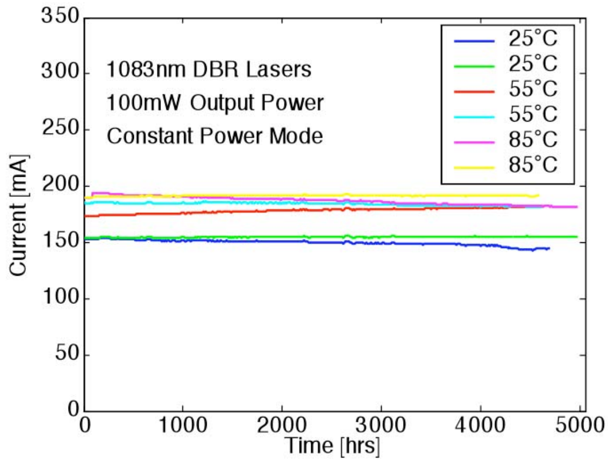


Figure 2. Lifetime testing of Photodigm 1083 nm DBR laser. Data shows current required to maintain constant 100 mW light output as a function of time

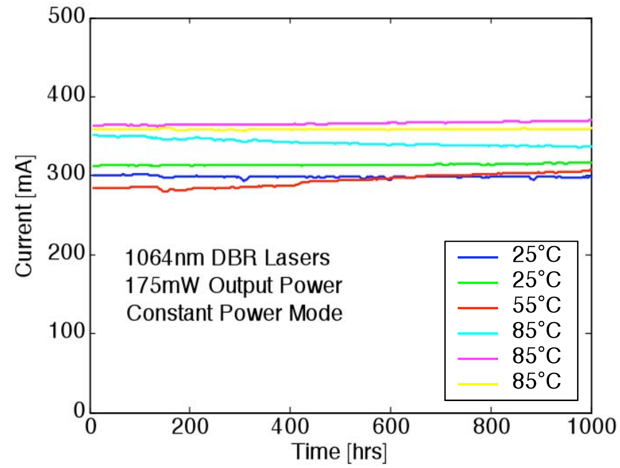


Figure 3. Lifetime testing of Photodigm 1064 nm DBR laser. Data shows current required to maintain constant 175 mW light output as a function of time.

started to increase and is currently decreasing. This type of phenomena can occur to devices that have a significant amount of tensile and/or compressive stresses incurred during the fabrication processes. As the device ages, these stresses are relieved and device performance can actually improve. Due to this "device improvement", no projections can be made on the TTF for specific devices showing thisbehavior. Devices that exhibit this behavior are. assigned a low TTF of 20,000 hrs so that some estimate is included in the log normal model. These devices are being driven at an output optical power of 100mW. The devices shown in Figure 2 have a projected lifetime or MTTF of 1,084,000 hrs at 100mW of optical output power and an operation temperature of 25°C.

Figure 3 shows a set of 1064 nm DBR lasers that are currently under lifetime testing. These devices are being driven at an output optical power of 175mW. These devices have a projected lifetime or MTTF of 868,000hrs at 175mW of optical output power and an operation temperature of 25°C. Note that devices lagging in time are replacements for devices that died due to infant mortality, and therefore lag by an allotted burn-in time.

A basic summary of current lifetime projections for Photodigm's 9xx and 10xx nm DBR lasers is presented in Table 1.

Wavelength (nm)	Operating Power (mW)	Operating Temperature	MTTF (hrs)
1083	100	25° C	1,084,000
1064	175	25° C	868,000
920	60	25°C	504,000

Table 1. Summary of 10xx DBR laser lifetime data

References:

[1] M. Fukuda, Reliability and Degradation of Semiconductor Lasers and LEDs, Artech House, Inc., Norwood, MA 1991.

[2] O. Ueda, Reliability and Degradation of III-V Optical Devices, Artech House, Inc., Norwood, MA 1996.

[3] M. Ott, "Capabilities and Reliability of LEDs and Laser Diodes," http://nepp.nasa.gov/photonics/pdf/sources1.pdf

Photodigm Product Line

Photodigm DBR Lasers These high-power single-frequency, diffraction limited devices are available at the following technologically important wavelengths:

780 nm certified for optically pumping the $5^2S \rightarrow 5^2P$ transition of Rb. Applications include cold atom physics, magnetometers, atomic clocks, and quantum encryption

920 nm for frequency doubling to blue

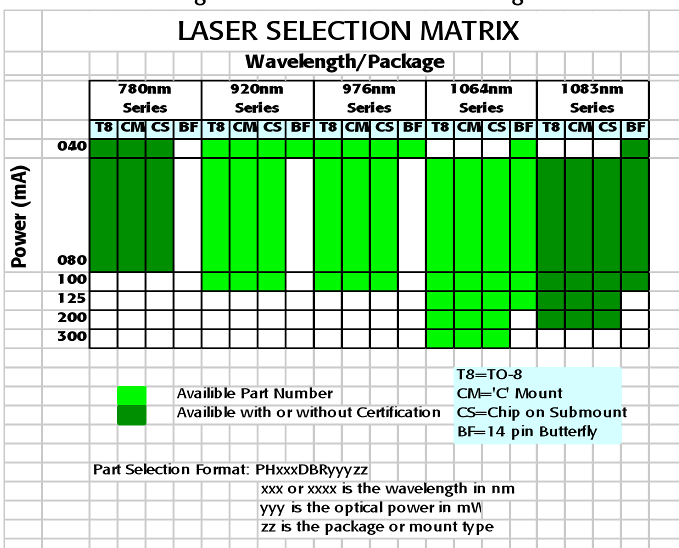
976 nm for frequency doubling to blue-green; narrow band pumping of Yb fiber

1064 nm for DPSS replacement, fiber amplifier seeding, difference-frequency, and frequency doubling

1083 nm certified for the optical pumping of the He $2^3S \rightarrow 2^3P$ transition for sensitive magnetometry

Custom wavelengths available. Contact Photodigm for more information

Photodigm lasers are available in several configurations. Our standard configurations are as follows:



See individual Product Bulletin for detailed information.

Photodigm Laser Diode Driver The LD1 is designed to provide current drive for laser diodes with modulation from DC to typically greater than 100MHz.

Photodigm PIN Photodiode The PHT1550-SEN is a family of InGaAs/InP pin photodiodes possessing low capacitance and bandwidths exceeding 40GHz.

Photodigm 1064 nm 10W Diffraction-Limited CW Laser The PH1064-10-MOD is a high-power CW laser module based on Photodigm's advanced single-frequency laser technology.

Photodigm 1064 nm Surface Emitting LED The PHT1064-LED is a surface emitting LED with junction oriented with 'p' side down for optimum heat transfer. Die surface size is 500x500 microns coupled to a truncated sphere lens for optimum light emission. Multiple connections within the package allows for pulsed currents as high as 15 Amps. Applications include eye safe light source for 1064nm detector test systems, IR surveillance, and low cost alternative to laser source.

Photodigm 1550nm 100W Pulse Laser Module The PH1550-100-MOD is a high-power Pulse laser module based on Photodigm's advanced single-frequency laser technology. Applications include sensing and range finding.

Photodigm 3W Diffraction-Limited Green Laser The PH532-3-MOD is a high-power CW laser module at 532 nm based on Photodigm's advanced single-frequency laser technology. Applications include medical, display applications, and spectroscopy.