

LASER DIODE BURN-IN AND RELIABILITY TESTING

Lawrence A. Johnson
President, CEO, and Founder
ILX Lightwave

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Introduction

Over 99% of all lasers manufactured in the world today are semiconductor laser diodes. Reliability is a concern in every laser diode application whether it is a simple \$10 laser pointer or a space qualified optical transmitter link. The commercial success of a laser supplier rests largely on his ability to develop a robust manufacturing process that consistently produces reliable devices combined with the quantitative assurances he can provide to his customers proving the reliability of his devices. Over the past two decades laser diode reliability testing techniques and equipment have evolved to support the diverse development of laser diodes.

In comparison to other electronic devices, laser diode testing is complicated by the requirement to accurately measure both optical and electrical parameters and by the diverse package styles and power levels found in currently available laser diodes. Laser diode life testing is used for part qualification during product development as well as for lot testing throughout the production life of the laser. Life tests generally consist of high temperature accelerated aging of a sample group of lasers under carefully controlled conditions. Degradation is observed and recorded throughout the test by precise measurement of changes in the laser's operating characteristics. In contrast to life testing, burn in is applied to all lasers during their manufacturing process to identify and remove defective devices that would suffer from infant mortality.

Laser Diode Operating Characteristics and Reliability

At low forward currents gain in the active region of the laser diode is low and spontaneous emission is observed. As current is increased beyond a critical "threshold current" round trip gain in the laser cavity exceeds losses and lasing action begins. Beyond threshold current, the light emitted by the laser diode increases rapidly with increasing forward current as shown in Figure 1. Many laser diode packages incorporate an internal monitor photodiode which may be used in a feedback loop to maintain constant optical output power from the laser under varying temperature conditions and as its performance slowly degrades over time. If the monitor photodiode is properly biased, its current is proportional to laser light output power.

Basic laser diode operating characteristics are measured by increasing forward current (I) while measuring the device voltage (V), light output (L), and monitor photodiode current (I_{pd}). The resulting information is usually referred to as an LIV curve. Typical device optical and electrical characteristics are shown in Figure 1.

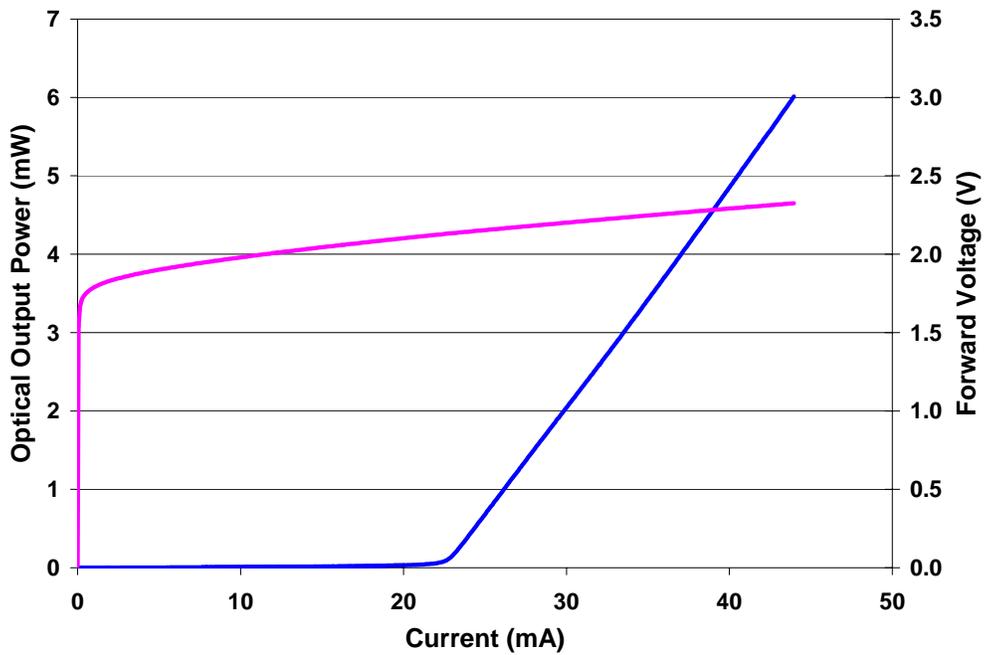


Figure 1- Laser Diode LIV Characteristic

Laser diode operating characteristics are quite sensitive to junction temperature. As temperature increases, threshold current increases while lasing efficiency decreases as shown in Figure 2.

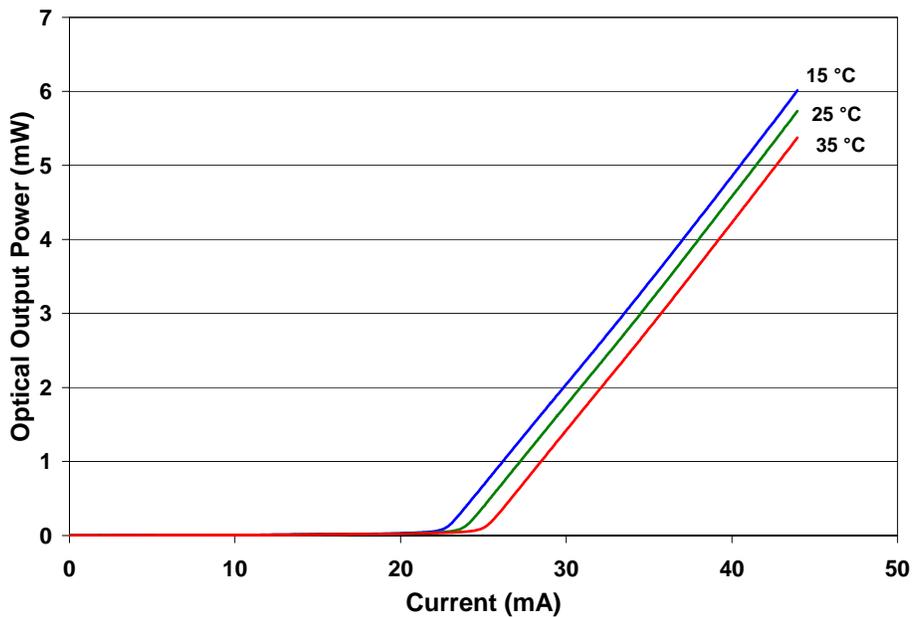


Figure 2 - Temperature Dependence of Light vs Current

Degradation in laser diodes is substantially different from that in other electronic devices due to the radiative recombination process of electron-hole pairs and the presence of high optical power densities within the active region and at the output facets of the laser (reference 1). The primary degradation modes in laser diodes arise from (1) defects in the active inner region of the laser due to the growth of dislocations, (2) facet degradation due to oxidation, (3) electrode degradation due to metal diffusion into the inner region, (4) bond degradation, and (5) heat sink degradation. Degradation may be enhanced by increased current, temperature, light output, and moisture. Additionally, laser lifetimes may be shortened by electrical surges.

From an external perspective, failures of laser diodes are generally classified as wearout or random failures. Wearout failures are generally the result of the growth of defects in the inner active region of the laser and are exhibited by a slow degradation in the performance of the laser. Random failures are usually caused by catastrophic optical damage of the output facet or degradation of the heat sink or bonds. Random failures are characterized by rapid degradation in the performance of the laser.

In general, laser diode reliability may be defined as the ability to operate the device satisfactorily in a defined environment for a specified period of time. From a laser user's point of view, many of the issues related to laser diode reliability are revealed by the hazard rate characteristic curve for a population of lasers as shown in Figure 3. Hazard rate is defined as the probability of failure per unit time, at time t , given that the device has survived until time t (reference 2). Infant mortality failures are often caused by defects introduced during the manufacturing process or intrinsic semiconductor defects. External factors such as current surges and ESD events create a constant hazard rate over the life of the device, and finally, wear out failures in lasers are generally found to be caused by the growth of non-radiative, optically absorbing defects within the active region of the laser.

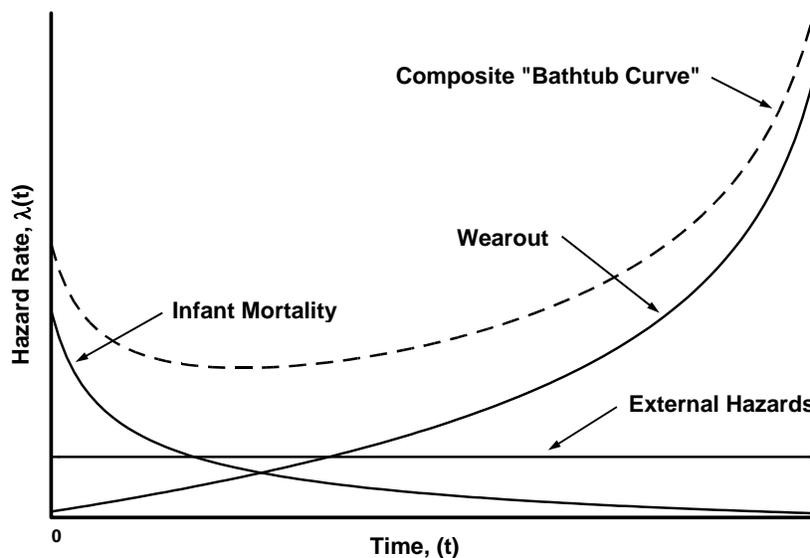


Figure 3 - Hazard Rate Characteristic Curve for Unscreened Laser Diodes

Laser lifetime is affected by operating conditions including injection current, optical output power, and temperature. Aging is empirically related to temperature through the Arrhenius equation (reference 1):

$$\text{Life} = A_t \exp(E_a/kT)$$

where A_t is a constant, E_a is the activation energy, and k and T are Boltzman's constant and temperature respectively. Depending on the type of laser, typical activation energies range from 0.2 eV to 0.7 eV. Laser aging can be significantly accelerated at high temperatures as shown in Figure 4. As can be seen in the figure, a laser diode with an activation energy of 0.7 eV and median lifetime of 100,000 hours at room temperature has a lifetime of only 2,300 hours when the device is operated at 70°C. This effect is used to advantage in accelerated life test studies.

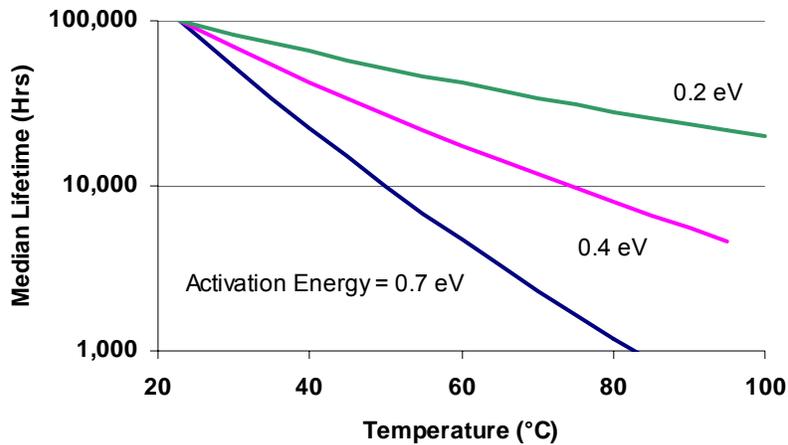


Figure 4 - Laser Lifetime Variation with Temperature

Laser Diode Manufacturing Test

Laser diode manufacturing test processes vary considerably depending on the materials and structure of the laser, package style and output power level. Telecommunication lasers in butterfly packages require relatively complex and costly testing due to the presence of ancillary components such as thermoelectric coolers, thermistors, and modulators. On the other hand, low power lasers mounted in TO-can packages can be produced with much simpler and less costly test systems. For simplicity this article focuses on low power lasers in TO-can packages.

A flow chart for a typical TO-can laser diode packaging and test production line is shown in Figure 5. Wafers enter at the upper left-hand side of the diagram and undergo various processing and test steps before ending up as finished products. Not shown in the production flow chart are life-test studies used during the development of new devices, wafer qualification, and sample audit testing. These tests along with production burn-in

tests deserve special mention due to their relatively high cost impact on the overall cost of laser diode development and manufacturing.

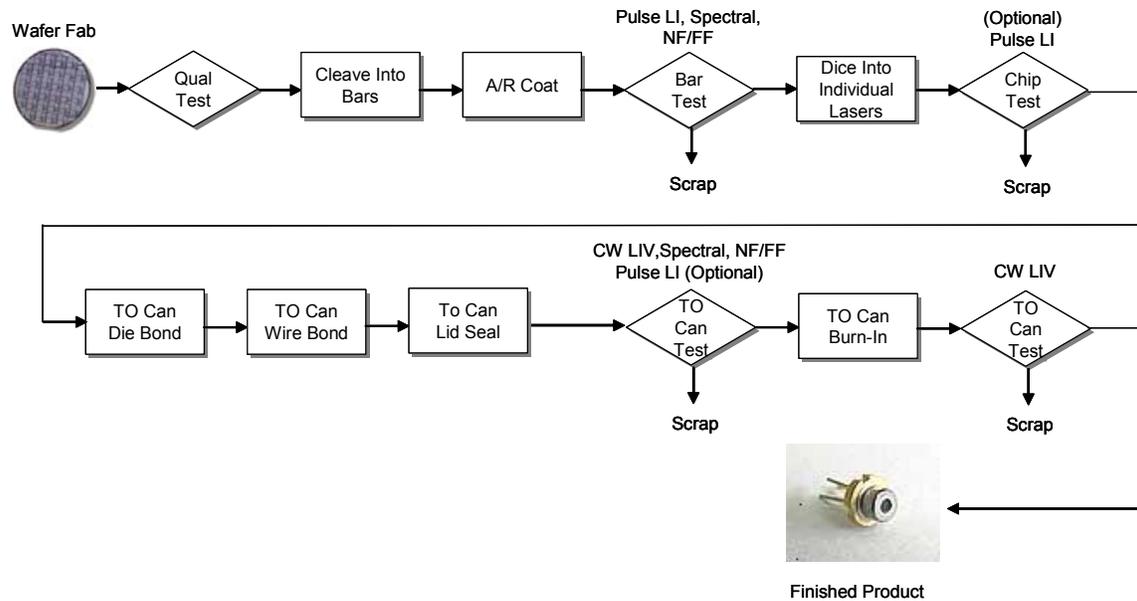


Figure 5 - Laser Diode TO-Can Packaging Line

Life Test Studies

Life test studies are used to collect laser life time data under carefully controlled operating conditions in order to develop statistical models that can then be used to predict laser life time under intended operating conditions. In order to obtain statistically meaningful data, life test studies normally involve dozens of lasers monitored for periods of at least 1,000 hours and often these test studies extend to over a year in length. Within the telecommunications industry, standards for life test studies have been developed and promulgated by Telcordia Technologies (references 3 and 4). These standards specify the sample size as well as the length of testing.

Depending on the type and application of the laser diode, life test studies involve the periodic measurement of a variety of device parameters including operating current, optical output power, threshold current, and forward voltage under accelerated aging conditions. Accelerated aging may be implemented through high temperature, injection current, or optical power; however temperature acceleration is the most common.

Aging studies are conducted in one of the following three modes of operation:

Constant Current Aging - Often referred to as ACC mode (automatic current control). In this mode laser current is held constant for the duration of the test.

Constant Power Aging - Often referred to as APC mode (automatic power control). In this mode laser output power is held constant by continuously adjusting current as required to maintain constant output power. Optical output power is measured either with an external photodetector or by using an internal monitor photodiode if one is available within the laser package. Constant power aging is used most frequently in life test studies because it closely resembles the typical mode of operation of laser diodes in use.

Periodic Sample Testing - In cases where lasers are to be aged at temperatures above approximately 100°C lasing action is not present and it is necessary to periodically reduce the temperature of the laser to a lower measurement temperature. In this type of test lasers are operated in constant current mode during the high temperature aging. In very long term tests, the sample interval may be varied over the duration of the test in order to reduce the amount of data collected. Measurement samples may be taken every hour at the beginning of the test and every few days after the test has been running for a period of months.

In periodic sample testing, measurements may either be made *in situ* within the test system or at a separate test stand. *In situ* testing gives the most repeatable measurement results and reduces the hazard of laser damage due to handling. The use of a separate test stand reduces overall cost, especially when several thousand lasers are involved in long term life test studies.

In practice, difficulties in laser diode life testing arise from temperature instability, equipment measurement and control instability, equipment reliability, and power failures. The first challenge associated with temperature control arises from the self-heating of the laser during operation. Even a tightly clamped TO-can laser on a bare aluminum heat sink may have a thermal impedance of 5 to 10 C/W. If the laser is operated at 100 mA and 1.8 V, there can be a temperature difference of 1.5°C between the case of the laser and the heat sink. This problem becomes even more significant for high power laser diodes. Additionally, heat sink temperature fluctuations as small as 0.1°C manifest themselves as noise in the measurement of optical power due to the temperature sensitivity of laser output power at a given current. Finally, if an external photodetector is used to measure optical output power, its temperature must also be controlled to ensure stable measurements.

Laser diode life test studies require the accurate measurement of changes in laser operating parameters as small as a few percent over thousands of hours. Consequently, the stability of the measurement equipment must be on the order of 0.1% per 1000 hours. In most locations occasional electrical power failures are inevitable during the course of a multi-thousand hour life test study. In many cases it is impractical to provide battery backup systems due to the high power required for heating in life test systems. As a result, the life test system must handle power failures without damage to the lasers, and must be able to resume a test precisely after power is restored.

Figure 6 shows the results of a 1000 hour life test study of sixteen DFB lasers conducted in APC mode at 75°C. As is common for most lasers, aging occurs rapidly in the first few hundred hours of high temperature aging and then settles into a steady wear out characteristic that is linear over time. Life time for each laser is estimated by fitting a straight line to the linear region of the data and extrapolating to a predefined change in

current. In the case of the study shown in Figure 6, end of life was defined as a 20% change in operating current. Resulting estimated life-times at 75°C varied from 360 hours to 16,460 hours. The data was found to follow a Weibull probability distribution (reference 2) that yielded a mean time to failure of 2,200 hours.

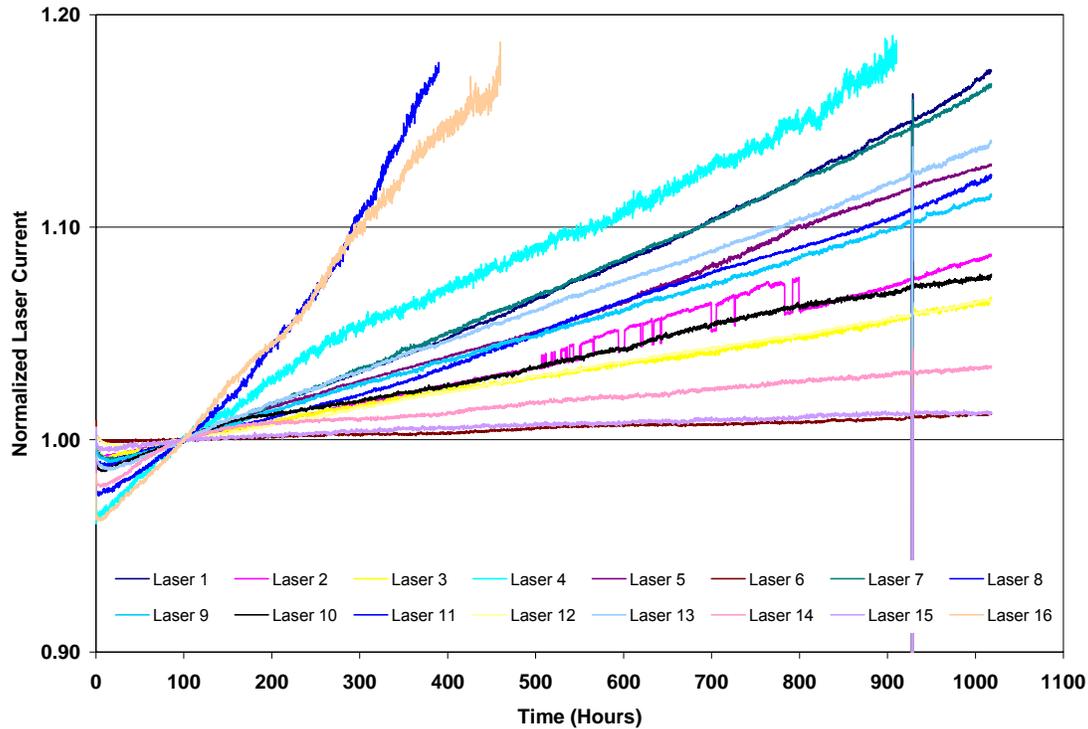


Figure 6 - Aging Data for DFB Lasers Operated at 75°C

The data in Figure 6 exhibits two of the practical problems encountered in laser diode life test studies. A power failure occurred at approximately 930 hours resulting in the system shutdown over a weekend. Fortunately, in this case the test system was able to recover and continue the test with excellent data continuity. On the other hand, erratic readings can be observed on Laser 2 between 500 and 800 hours during the test. The cause of these erratic readings was never satisfactorily explained.

Production Burn-In Screening

High temperature burn-in screening is used in laser diode manufacturing to screen out devices that are likely to have unacceptably short lives and to ensure that the remaining population of lasers will have a statistically acceptable level of reliability. Due to the impact of burn-in on manufacturing cost and cycle time, burn-in times of less than 100 hours are common.

Devices are generally screened on the basis of a change in one or more key operating parameters which are measured before and after high temperature burn-in. Commonly

measured operating parameters and screening criteria are shown in Table 1. The screening criteria are developed through a series of engineering tests used to determine the most effective burn in conditions. Burn-in temperature and operating current should be as high as possible to minimize burn-in time, yet not so high that a degradation mode is triggered that is not present under normal operating conditions for screened parts. Selection of burn-in conditions and screening criteria varies significantly with the type of laser and can be quite complex (reference 1).

Operating Parameter	Symbol	Typical Screening Criteria
Threshold Current	I _{th}	Change > 5 to 30%
Optical Output Power at Specified Operating Current	Pop@Iop	Change > 5 to 30%
Current Required to Achieve Specified Optical Output Power	Iop@Pop	Change > 5 to 30%
Slope Efficiency	η	Change > 5 to 30%

Table 1- Commonly Measured Operating Parameters and Screening Criteria

The two most common test strategies for production burn-in screening are the following:

Burn-In with *In Situ* Test - In the case of low production volumes or when the same system is used for both engineering evaluations and burn-in, it is often cost effective to perform parametric testing in the same system that is used for burn-in. In this case parametric data may be taken continuously or at the beginning and end of a burn-in cycle.

Burn-In with Separate Test - In almost all other cases it is more cost effective to use simple constant current, constant temperature burn-in chambers which are separate from the parametric test system. A semi-automated parametric test system can easily provide the throughput required to process over 1,000 lasers in an eight hour shift. This approach also has the advantage that the parametric test system can also be designed to incorporate spectral measurement which is difficult to implement in an *in situ* test system.

In practice, the challenge of manufacturing burn in testing is to achieve high throughput and accurate measurements at very low cost. Even at a medium production volume of 1000 parts per day the total cost of burn in test can be as much as \$0.50 per part for a TO-can packaged laser diode intended for a telecommunications application. In a market where selling prices for the same laser are less than \$10, this is a significant cost factor.

Summary

Life test and burn in are important test processes in the development and manufacturing of laser diodes. Although these test processes are simple in principle, actual tests are complicated by the diversity of laser types, requirements for low cost, and the need for high stability measurements over prolonged periods of time. Over the past three decades equipment and techniques have evolved to support this interesting area of technology.

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About the Author

Dr. Lawrence A. Johnson is the founder, President and CEO of ILX Lightwave Corporation, a leading manufacturer of laser diode instrumentation and test systems.

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