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Estimating Laser Diode Lifetimes and Activation Energy

APPLICATION NOTE

ILX Lightwave

Photonic Test and Measurement

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Introduction

The estimation of laser diode lifetime is important to both manufacturers and users of laser diodes. For example, a manufacturer of a laser diode based sensor product may wish to know if the laser used in the product will deliver a median time to failure of at least five years of continuous use at a case temperature of 40°C. The answer to this question can be answered through statistical analysis of actual lifetime data. Since laser diode lifetimes can be into the 100,000 hour range it is generally not practical to test the laser diodes at normal operating ranges due to the long test time. In order to shorten the testing process, accelerated aging tests are performed at higher than normal temperature and operating currents.

In order to use accelerated aging test data to estimate lifetimes at normal use temperatures, it is necessary to know the activation energy of the observed failure mode. This application note describes how multi temperature testing can be used to calculate laser diode lifetime statistics and activation energy, and how this information can be used to estimate laser diode lifetime at normal operating temperatures.

Background

Almost all commercially available laser diodes have been screened to remove devices that are likely to suffer from infant mortality. For many types of lasers, the remaining good devices exhibit a wearout failure mode which is characterized by a slow degradation of light output over time when the laser is operated at a constant temperature and forward current. If the laser is operated in a feedback loop that maintains a constant light output, wearout failure is characterized by a steady increase in the required forward current. In this case, time to failure is usually defined as the time at which the forward current has increased by 20% to 50% of its initial value.

One of the most common equations used to analyze laser diode lifetimes is the Arrhenius model[1]. The Arrhenius model uses temperature and activation energy to predict time to failure. The following equations show how the Arrhenius model can be expressed to show activation energy when time to failure and temperature are known.

$$t_f = A\,exp\left(\frac{e_a}{kT}\right) \quad (1)$$

Where,

t_f = Time to failure [hours]
A = Scaling factor
e_a = Activation energy [eV]
k = Boltzmann's constant [8.617×10^{-5} eV/K]
T = Temperature [Kelvin]

Taking the natural logarithm of equation 1 yields a linear equation in the form y = mx + b.

$$ln\,t_f = e_a\left(\frac{1}{kT}\right) + ln\,A \quad (2)$$

Where,

$$y = ln\,t_f$$
$$x = \left(\frac{1}{kT}\right)$$
$$m = e_a$$
$$b = ln\,A$$

Calculating activation energy and median time to failure (MTTF) require life tests to be performed at multiple temperatures. A typical life test consists of running batches of laser diodes in either an automatic current control (ACC) or automatic power control (APC) mode at elevated temperatures over 100's to 1000's of hours. When estimation of both MTTF and activation energy are required, the test system should provide high system stability and the ability to run multiple temperature tests simultaneously.

Once activation energy is known, it can be used to calculate lifetimes at different temperatures.

$$\frac{t_{f1} = A\,exp\left(\frac{e_a}{kT_1}\right)}{t_{f2} = A\,exp\left(\frac{e_a}{kT_2}\right)} \qquad (3)$$

Where t_{f1} and t_{f2} are the times to failure at temperatures T_1 and T_2 respectively. Solving for t_{f2} yields.

$$t_{f2} = t_{f1}\,exp\left(\frac{e_a}{k}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right) \qquad (4)$$

If both activation energy and the scaling factor A are known they can be used to calculate estimated lifetimes directly using Equation 1.

Additional information on laser diode life testing can be found in the White Paper "Laser Diode Burn-in and Reliability Testing" which is available on the ILX Lightwave web site.

Three Temperature Test Setup

A three temperature aging test was conducted in an ILX Lightwave LRS-9424B Laser Reliability and Burn-In Test system on 32 785nm 5mW AlGaAs laser diodes. The lasers were mounted in a 32 position TO-can fixture with an external 32 element Si photodiode array calibrated for 10mW full scale range. The LRS-9424B's laser diode current stability is ±0.2mA with a temperature stability of better than ±0.5°C and provides the flexibility to run multiple temperature tests simultaneously by using multiple fixtures. Due to the limited number of lasers available for this test a single fixture was used with sequential tests performed at three temperatures.

A three step accelerated aging test was conducted on all 32 laser diodes in order to determine estimated lifetimes at each of three temperatures. Each step was 1000 hours in length and conducted in constant power (APC) mode at a constant optical output power of 3.0 mW. Step one was conducted at 60°C, step two was conducted at 70°C, and step three was conducted at 80°C.

Pre and post LIV data were collected at 40°C in order to identify any unusual device characteristics.

Test Results

LIV Test Results

The pre and post burn-in LIV tests at 40°C produced typical, well behaved parametric curves for output optical power and voltage vs laser drive current. These LIV tests were performed before and after the three 1000 hour aging tests. The results of these tests are shown in Figures 1 and 2 below.

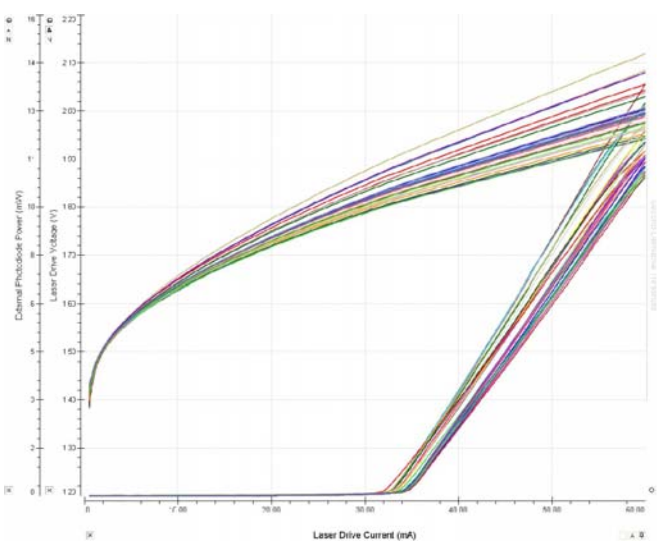

Figure 1 - Pre Aging LIV Test Results

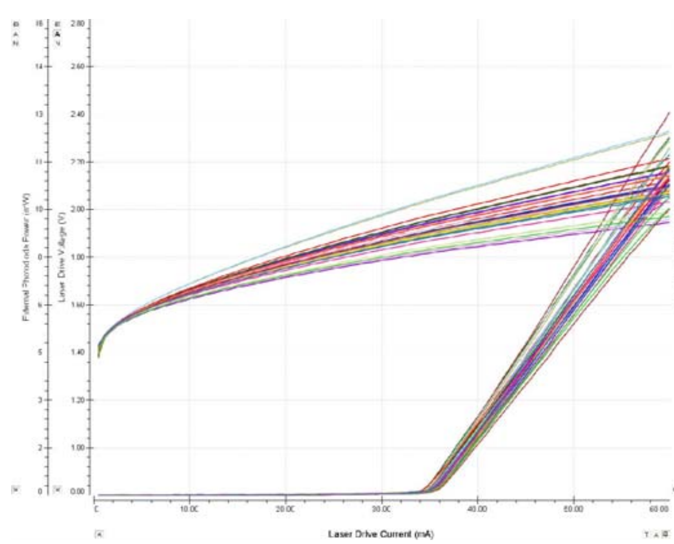

Figure 2 - Post Aging LIV Test Results

Aging Test Results

During the three 1000 hour aging tests each laser was held at a constant optical power of 3.0 mW by increasing the laser diode drive current (Iop) as the devices aged. Figure 3 shows the aging trend data for the 60°C 1000 hour step. No random failures were observed during any of the 1000 hour aging test steps. Device 15 did not turn on due to a short circuit in the device. Several devices did show a step in their aging trend which is believed to be mode hoping of the devices.

Lifetime Analysis

In order to estimate lifetimes it is necessary to establish a criterion for end-of-life. For this analysis we have defined end-of-life as a 20% rise in laser drive current (Iop) over the initial value. Using this definition, the aging trend for each laser diode was extrapolated to end-of-life using a linear regression of laser drive current vs. aging time. The regression was performed from hour 100 to 1000 to remove the period of the rapid change in drive current that is frequently observed during the first 100 hours of operation. A typical linear regression is shown by the yellow line in Figure 4 on the following page.

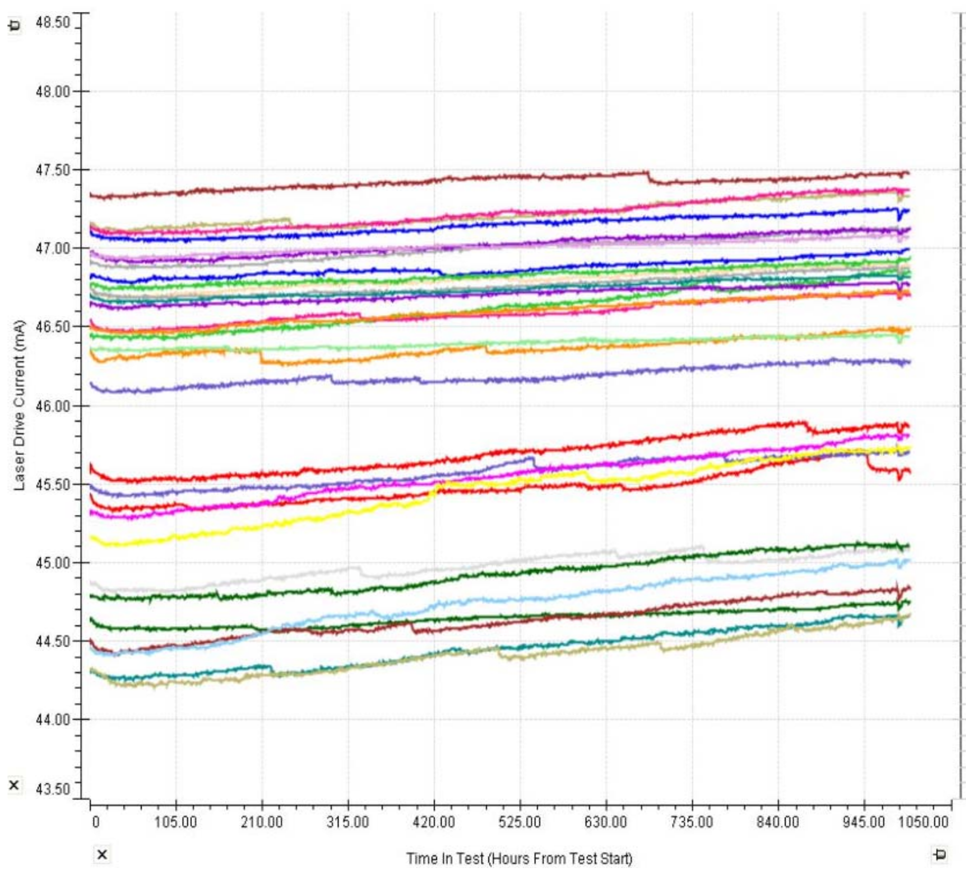

Figure 3 - 60°C 1000 Hour Aging Test

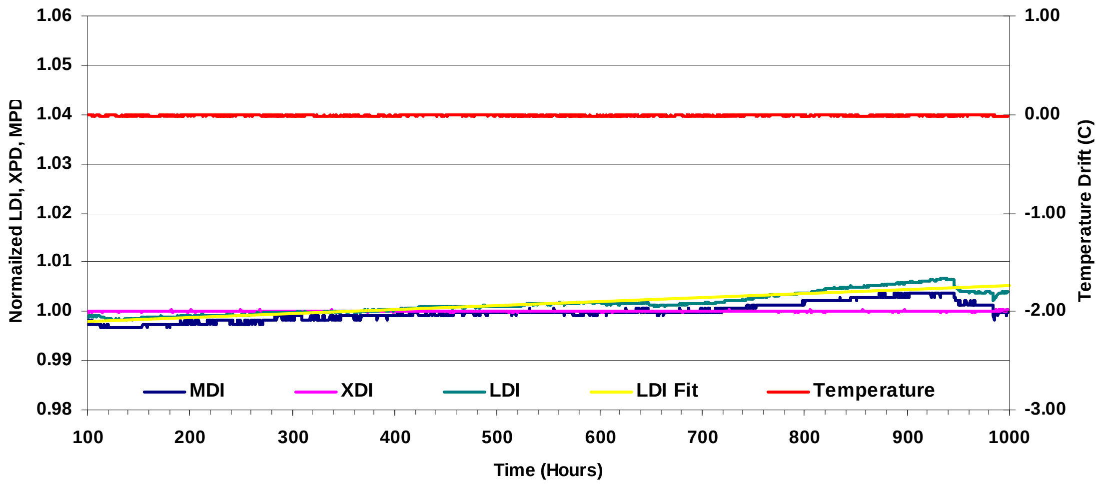

Figure 4 Detailed Aging Trend and Linear Regression at 60°C, Device 2

The table below provides a summary of the estimated 60°C, 70°C, and 80°C lifetimes based on this analysis.

Table 1 Estimated Lifetimes

Device	60°C	70°C	80°C
1	42,625	39,461	15,722
2	25,411	21,069	16,238
3	46,908	23,023	12,095
4	34,362	14,406	23,980
5	33,996	48,586	43,786
6	40,930	48,634	24,612
7	28,577	34,371	30,645
8	45,533	43,464	27,380
9	19,398	14,579	10,421
10	22,784	20,119	11,739
11	20,172	22,783	10,460
12	29,636	29,771	12,190
13	17,121	15,455	11,461
14	35,782	29,504	17,609
15			
16	13,909	16,116	17,692
17	84,110	39,722	42,938
18	14,984	9,000	8,355
19	72,689	30,984	40,093
20	47,016	28,972	42,535
21	52,650	53,132	25,635
22	20,723	17,367	7,189
23	20,436	14,916	10,660
24	20,352	17,691	13,094
25	41,391	37,515	16,617
26	58,192	41,618	18,031
27	39,142	35,174	22,161
28	33,987	18,496	18,454
29	50,771	32,145	35,157
30	93,863	21,896	21,652
31	51,648	33,553	21,349
32	48,369	52,824	44,074

Using the Excel based Reliability Workbook that can be downloaded from the ILX Lightwave website lifetimes were estimated based the time at which 50% cumulative failures had occurred (MTTF). The summary of these results can be seen in the following table and Figure 5 shows the graphical representation a lognormal chart on the following page.

Table 2 Estimated Lifetimes

	60°C Lifetime (Hrs)	70°C Lifetime (Hrs)	80°C Lifetime (Hrs)
50% Cumulative Wearout Failures	34,634	26,556	19,100

Lifetimes reported in the table above correspond to a 20% increase in driver current. Longer lifetimes can be achieved by designing drive circuitry that can accommodate a larger increase in current than the 20% increase that was used to define end-of-life in this analysis.

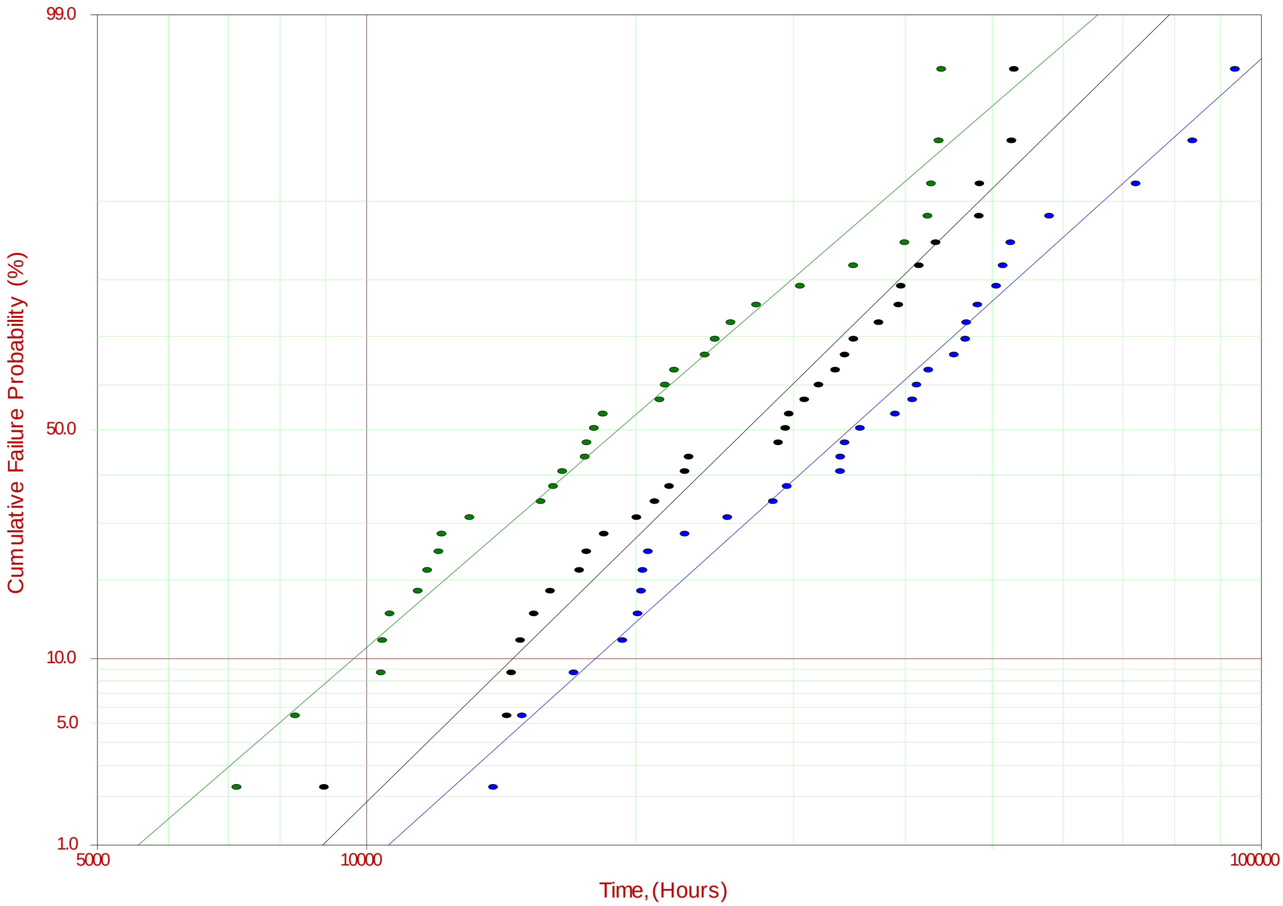

Figure 5 Lognormal Plots of Times to Failure

Activation Energy Calculation

Using Equation 2 activation energy and the scaling factor A were calculated from a linear regression of ln t_f and (1/kT) using the values from Table 2. The data points were plotted in Excel and using the linear fit function a line equation was calculated. The slope of the line equation is the activation energy and the intercept is ln A. Two point linear fits were also calculated using pairs of data points to estimate the uncertainty in the activation energy and scaling factor A values.

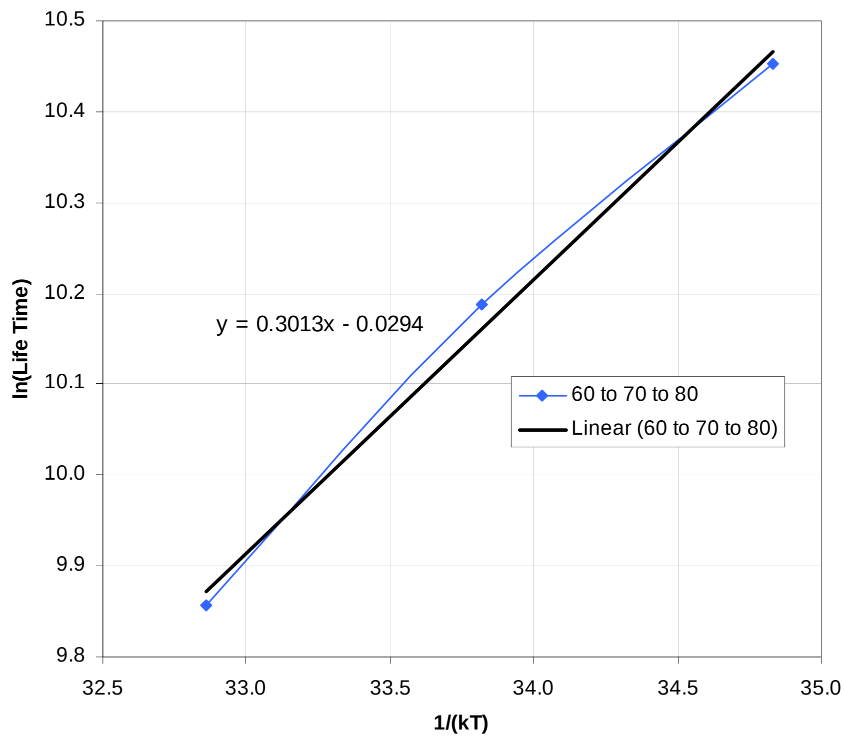

Figure 6 Three Point Linear Fit of Lifetime Data

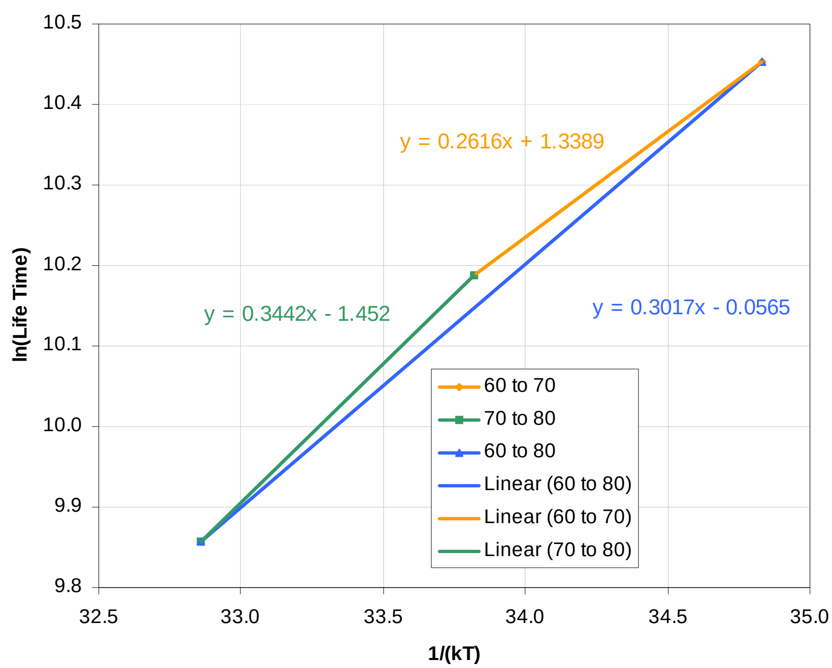

Figure 7 Two Point Linear Fit of Lifetime Data

Table 3 Activation Energy Values		
	Activation Energy (e_a [eV])	Scaling Factor (A)
3 Point	0.3013	0.97
2 Point (60°C to 80°C)	0.3017	0.95
2 Point (70°C to 80°C)	0.3442	0.23
2 Point (60°C to 70°C)	0.2616	3.81

Based on the results presented in Table 3 the activation energy and scaling factor A are estimated to be 0.30±0.04 eV and 0.97+2.84/-0.74 respectively.

Calculating Lifetimes at Operating Temperature

Using Equation 1 and the estimated activation energy and scaling factor A lifetimes can be calculated at any operating temperature. Figure 8 shows estimated lifetimes at different operating temperatures assuming activation energy of 0.30 eV and scaling factor A value of 0.97. It can be seen from the figure that longer lifetimes can be achieved at lower operating temperatures and that lifetime decreases by approximately a factor of two for every 20°C rise in operating temperature.

Conclusion

Calculating estimated lifetimes is an important step in the development and application of laser diodes. Lifetimes at normal use temperatures can be estimated from the lifetime statistics and activation energy obtained through multi-temperature testing. The laser diodes reported here are predicted to have a median time to failure of approximately 70,000 hours, or 8 years at a use temperature of 40°C.

In order to minimize the testing time required, the test system used should allow for multiple temperature tests to be run simultaneously in one system. The ILX Lightwave LRS-9424B Laser Diode Reliability and Burn-In System provides the capability for stable, long-term, multi-temperature testing of laser diodes and LEDs.

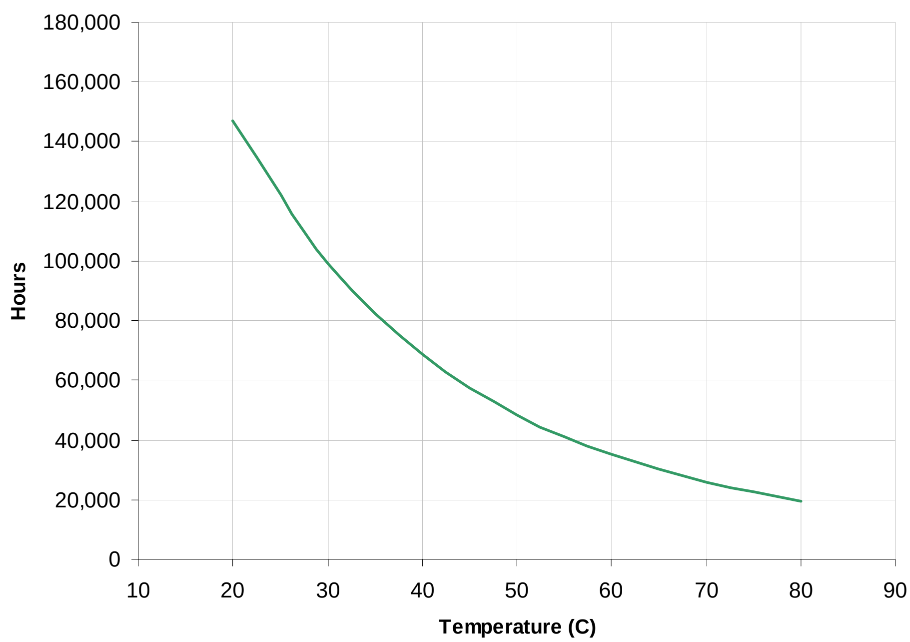

Figure 8 Temperature Plots of Lifetime vs. Operating Temperatures

Reference

1. Osamu Ueda, Reliability and Degradation of III-V Optical Devices, Artech House, Boston, 1996.

The following publications are available for download at www.ilxlightwave.com.

White Papers

- A Standard for Measuring Transient Suppression of Laser Diode Drivers
- Degree of Polarization vs. Poincaré Sphere Coverage
- Improving Splice Loss Measurement Repeatability
- Laser Diode Burn-In and Reliability Testing
- Power Supplies: Performance Factors Characterize High Power Laser Diode Drivers
- Reliability Counts for Laser Diodes
- Reducing the Cost of Test in Laser Diode Manufacturing

Technical Notes

- Attenuation Accuracy in the 7900 Fiber Optic Test System
- Automatic Wavelength Compensation of Photodiode Power
- Measurements Using the OMM-6810B Optical Multimeter
- Bandwidth of OMM-6810B Optical Multimeter Analog Output
- Broadband Noise Measurements for Laser Diode Current Sources
- Clamping Limit of a LDX-3525 Precision Current Source
- Control Capability of the LDC-3916371 Fine Temperature Resolution Module
- Current Draw of the LDC-3926 16-Channel High Power Laser Diode Controller
- Determining the Polarization Dependent Response of the FPM-8210 Power Meter
- Four-Wire TEC Voltage Measurement with the LDT-5900 Series Temperature Controllers
- Guide to Selecting a Bias-T Laser Diode Mount
- High Power Linearity of the OMM-6810B and OMH-6780/6790/6795B Detector Heads
- Large-Signal Frequency Response of the 3916338 Current Source Module
- Laser Wavelength Measuring Using a Colored Glass Filter
- Long-Term Output Drift of a LDX-3620 Ultra Low-Noise Laser Diode Current Source
- Long-Term Output Stability of a LDX-3525 Precision Current Source
- Long-Term Stability of an MPS-8033/55 ASE Source
- LRS-9424 Heat Sink Temperature Stability When Chamber Door Opens
- Measurement of 4-Wire Voltage Sense on an LDC-3916 Laser Diode Controller
- Measuring the Power and Wavelength of Pulsed Sources Using the OMM-6810B Optical Multimeter
- Measuring the Sensitivity of the OMH-6709B Optical Measurement Head
- Measuring the Wavelength of Noisy Sources Using the OMM-6810B Optical Multimeter
- Output Current Accuracy of a LDX-3525 Precision Current Source
- Pin Assignment for CC-305 and CC-505 Cables
- Power and Wavelength Stability of the 79800 DFB Source Module
- Power and Wavelength Stability of the MPS-8000 Series Fiber Optic Sources
- Repeatability of Wavelength and Power Measurements Using the OMM-6810B Optical Multimeter
- Stability of the OMM-6810B Optical Multimeter and OMH-6727B InGaAs Power/Wavehead
- Switching Transient of the 79800D Optical Source Shutter
- Temperature Controlled Mini-DIL Mount
- Temperature Stability Using the LDT-5948
- Thermal Performance of an LDM-4616 Laser Diode Mount
- Triboelectric Effects in High Precision Temperature Measurements
- Tuning the LDP-3840 for Optimum Pulse Response
- Typical Long-Term Temperature Stability of a LDT-5412 Low-Cost TEC
- Typical Long-Term Temperature Stability of a LDT-5525 TEC
- Typical Output Drift of a LDX-3412 Low-Cost Precision Current Source
- Typical Output Noise of a LDX-3412 Precision Current Source
- Typical Output Stability of the LDC-3724B
- Typical Output Stability of a LDX-3100 Board-Level Current Source
- Typical Pulse Overshoot of the LDP-3840/03 Precision Pulse Current Source
- Typical Temperature Stability of a LDT-5412 Low-Cost Temperature Controller
- Using Three-Wire RTDs with the LDT-5900 Series Temperature Controllers
- Voltage Drop Across High Current Laser Interconnect Cable
- Voltage Drop Across High Current TEC Interconnect Cable
- Voltage Limit Protection of an LDC-3916 Laser Diode Controller
- Wavelength Accuracy of the 79800 DFB Source Module

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- App Note 29: Accelerated Aging Test of 1310 nm Laser Diodes
- App Note 30: Measuring High Power Laser Diode Junction Temperature and Package Thermal Impedance
- App Note 31: Mounting Considerations for High Power Laser Diodes
- App Note 32: Using a Power / Wavehead for Emitter Level Screening of High Power Laser Diode Bars

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