30

Measuring High Power Laser Diode Junction Temperature and Package Thermal Impedance

APPLICATION NOTE

ILX Lightwave
Photonic Test and Measurement

Measuring High Power Laser Diode Junction Temperature and Package Thermal Impedance

By: Lawrence A. Johnson and Andrew Teh

Laser diode operating characteristics and life time are greatly affected by the temperature of the semiconductor junction. This is particularly true for high power laser diodes in which several watts of waste heat must be removed from a small semiconductor laser chip. In this case die bond quality and package thermal impedance are critical to achieving good device performance. During production, chip burn-in temperature must be accurately controlled in order to ensure adequate screening of defective devices is achieved without excessive loss of good devices. A simple, accurate method for measuring junction temperature and heat sink-to-chip thermal impedance is needed to enable the development and production of high power laser diodes. This article presents a simple cw method based on the use of readily available test and measurement instrumentation.

Background

Measurement of junction temperature has been recognized as critical to the advancement of laser diode technology for decades. Commonly used measurement methods are based on some change in the physical properties of the semiconductor junction with temperature. For laser diodes the most commonly used methods are based on change in optical output power, threshold current, forward voltage, or wavelength[1]. Generally, these methods are based on a change in the measured physical property between pulsed and continuous wave (cw) operation of the laser diode. When operated with very short pulses ($< 1\ \mu s$) and low duty cycle (0.1%), there is essentially no heating in the semiconductor junction and the temperature of the junction is equal to that of the heat sink that the packaged laser is mounted to. Measurement techniques based on voltage and wavelength measurement under pulsed and cw operation have been described by Hughes[2] and Paoli[3] respectively.

While these methods have been shown to be accurate, they require the use of short current pulses which can be inconvenient to provide in practice, especially when high currents are required. The simpler method described here is based on cw measurement of laser output power and power-averaged wavelength using a wavelength sensing optical multimeter.

Laser junction temperature is related to heat sink temperature by the following relationship.

$$T_j = T_{hs} + R_{th} * P_j \qquad (1)$$

where,

T_j = junction temperature in °C
T_{hs} = heat sink temperature in °C
R_{th} = thermal impedance from the laser chip to the heat sink in °C/W
P_j = waste heat dissipated in the laser junction in W

Waste heat is the thermal power dissipated in the junction and is equal to the total power supplied to the junction less the power that is radiated optically in the laser's light output. The waste thermal power dissipated in the junction is determined by the following relationship.

$$P_j = I * V - P_o \qquad (2)$$

where,

I = laser forward current in A
V = laser forward voltage in V
P_o = optical output power in W

The optical output spectrum of a Fabry-Perot laser diode is generally complex and dependent on the gain profile of the semiconductor laser medium combined with the longitudinal modes of the laser cavity[4]. In low power laser diodes, the optical output spectrum is often characterized by only a few longitudinal modes which shift in a complex manner with changes in temperature. The optical output spectrum of high power laser diodes and laser diode bars is usually highly multi-mode, effectively "filling" the gain profile of the laser medium. Over operating conditions of interest for most applications the relationship between the wavelength of the spectral peak and junction temperature is essentially linear. The optical output spectrum of a typical 940 nm high power laser diode is shown in figure 1.

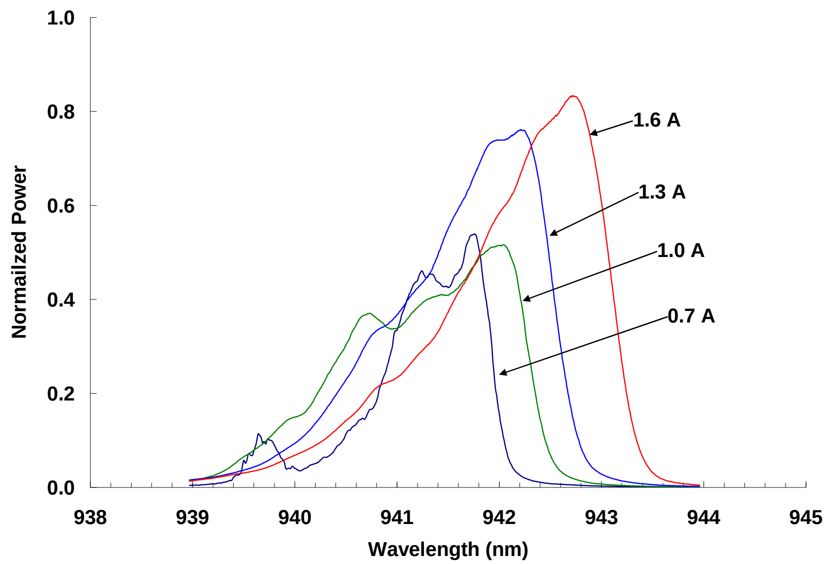

Figure 1. Optical Spectrum of a High Power 940nm Laser Diode at Heat Sink Temperature of 20°C

Previous techniques generally rely on using a spectrometer to measure the peak or average wavelength of the optical output spectrum. A more convenient wavelength measurement technique based on colored glass filters may also be used and does not require coupling the output of the laser into an optical fiber. The technique presented here measures power-averaged wavelength[5]. As shown in Figure 2, the relationship between power-averaged wavelength and temperature is very linear. The data in Figure 2 was obtained by measuring power-averaged wavelength vs heat sink temperature with a constant waste thermal power of 1500 mW. At a constant thermal waste power, junction temperature is related to heat sink temperature by a constant offset, $\Delta T = R_{th} * P_j$. Once the relationship between wavelength and junction temperature has been characterized for a particular laser structure, this relationship can be used as a calibration table to determine junction temperature through a simple cw power-averaged wavelength measurement.

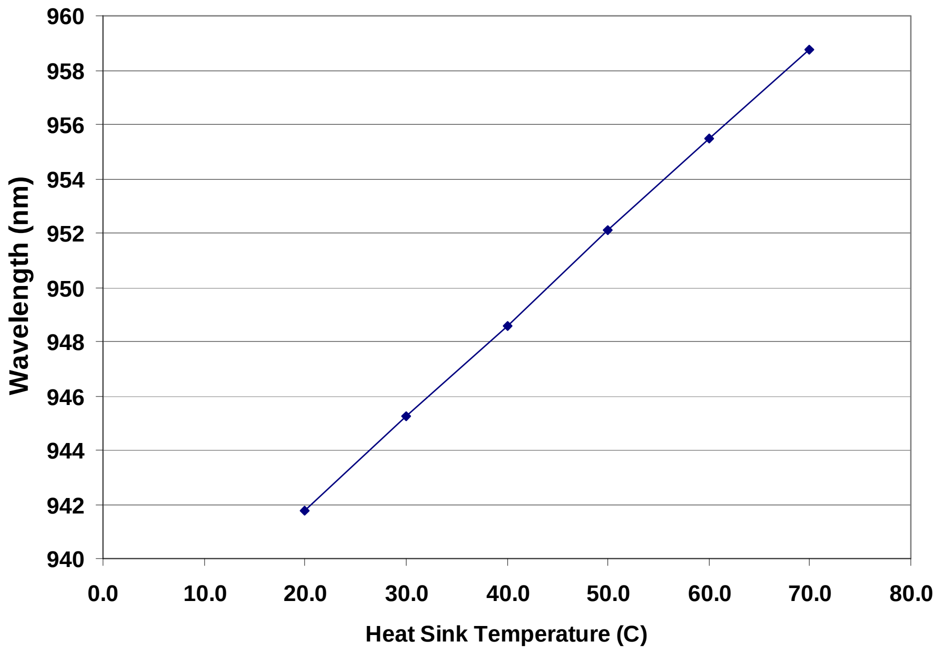

Figure 2. Power-Averaged Wavelength vs Heat Sink Temperature

Test Technique

To demonstrate this test technique a high power 940 nm AlGaInAs broad area pump laser manufactured by JDSU was used. The laser structure features an InGaAs strained-layer quantum well active region and a separate confinement heterostructure waveguide region. The C-mount packaged laser diode was mounted on a temperature controlled heat sink and its optical output is coupled into a power and wavelength optical multimeter as shown in Figure 2. In this experiment an ILX Lightwave LDM-4409 C-Block Mount was used with the laser held in place using the mount's quick release clip. Lower thermal impedance could have been obtained by using the mount's capability for screw mounting. Forward device current was supplied by a stable laser diode current source which was also capable of accurate four-wire voltage measurement. Four-wire voltage measurement is required to eliminate measurement of the voltage drop in the cable that connects the current source and laser. For high power laser diodes this voltage drop can be significant due to the high drive currents required.

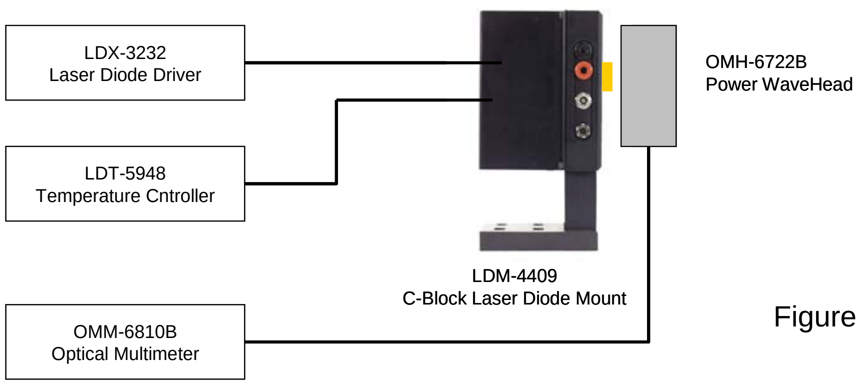

Figure 2. Test Setup

An LDT-5948 precision temperature controller was used to control the fixture temperature with a stability of better than ±0.1 °C. The output of the laser diode was coupled into the sensing head of an integrating sphere-based optical multimeter. In this experiment an ILX Lightwave OMH-6722B Silicon Power/WaveHead was used. The use of an integrating sphere ensures that all of the diverging output beam of the laser is captured and allows accurate absolute optical power measurement. The ILX Lightwave OMM-6810B Optical Multimeter provides a convenient simultaneous measurement of both optical power and power-averaged wavelength without the need for a separate optical spectrometer.

In order to determine the relationship between wavelength and chip temperature the following procedure was repeated at a range of heat sink temperatures. Laser current, voltage, output power, and power-averaged wavelength were recorded for five or six laser drive current set points above the threshold current. At each point the laser was allowed to reach thermal equilibrium before recording each set of data. Equilibrium was easily verified by ensuring the wavelength measurement was stable. The minimum current set point used should be at least 25% above the threshold current of the laser at the current temperature. Measurement results for a heat sink temperature of 50°C are shown in the table below.

MEASURED PARAMETERS				**CALCULATED PARAMETERS**	
Current I (A)	**Voltage V (V)**	**Output Optical Power P_o (mW)**	**Wavelength (nm)**	**Supplied Electrical Power I * V (mW)**	**Waste Thermal Power P_j (mW)**
0.6	1.437	107.6	950.3	862.2	754.6
0.7	1.456	178.7	950.7	1019.2	840.5
0.8	1.474	250.8	950.9	1179.2	928.4
0.9	1.494	325.9	951.6	1344.6	1018.7
1.0	1.514	401.3	951.7	1514.0	1112.7
1.1	1.535	476.0	951.8	1688.5	1212.5
1.2	1.558	552.4	951.9	1869.6	1317.3
1.3	1.583	628.9	952.1	2057.9	1429.0
1.4	1.611	706.5	952.2	2255.4	1548.9
1.5	1.644	780.1	952.4	2466.0	1685.9
1.6	1.672	855.5	952.5	2675.2	1819.7
1.7	1.692	931.2	952.7	2876.4	1945.2

Table 1. Laser Operating Parameters and Calculated Results
for 50°C Heat Sink Temperature

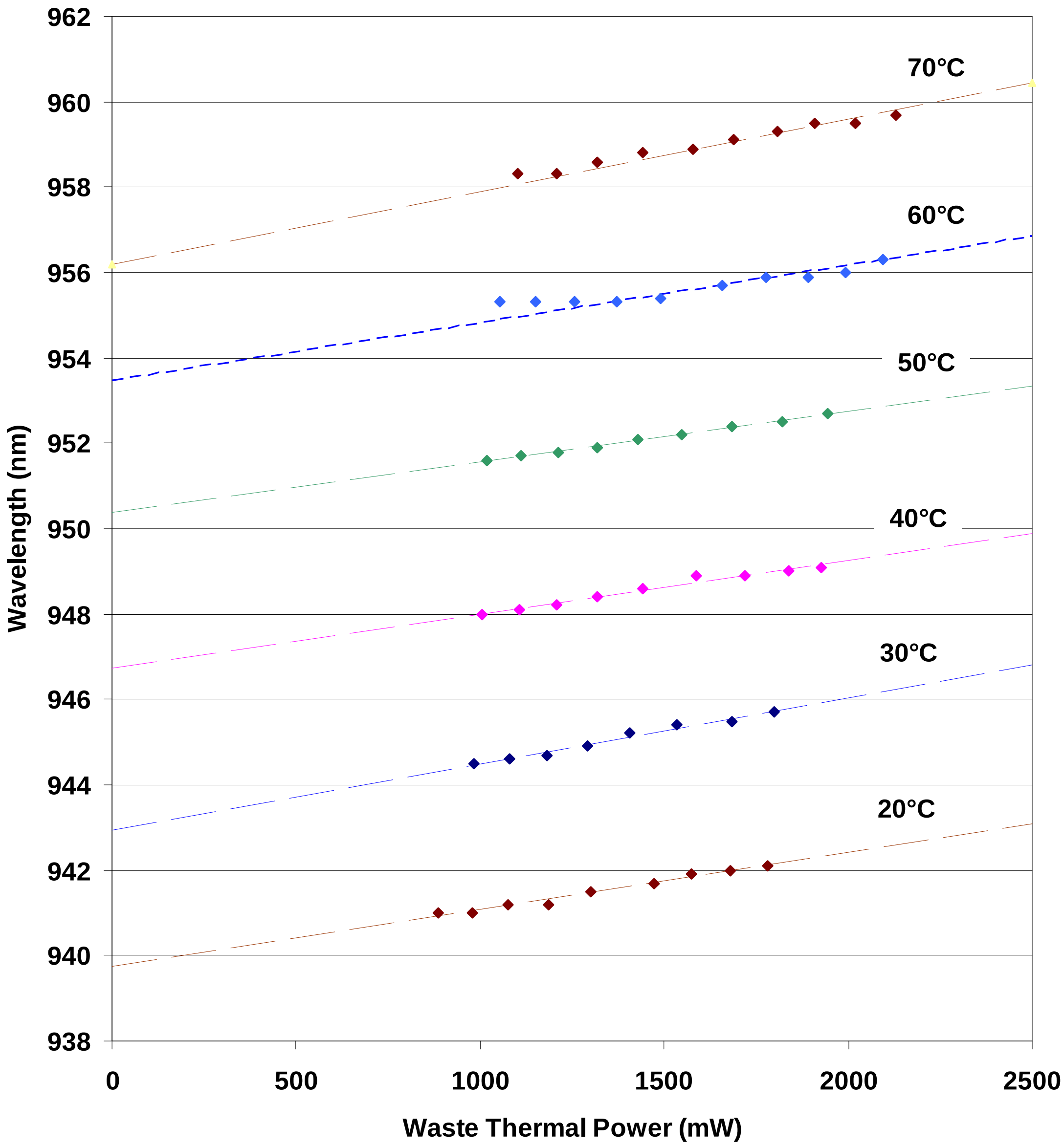

Figure 3. Power-Averaged Wavelength vs Waste Thermal Power

A linear fit was then calculated for each data set. The zero power intercept for each data set predicts the power-averaged wavelength of the output spectrum at a laser junction temperature, Tj, since at the zero power intercept, $T_j = T_{hs}$. These zero-power intercepts were then plotted versus temperature to obtain the calibration relationship desired. This relationship for the lasers tested in this experiment is plotted in Figure 4.

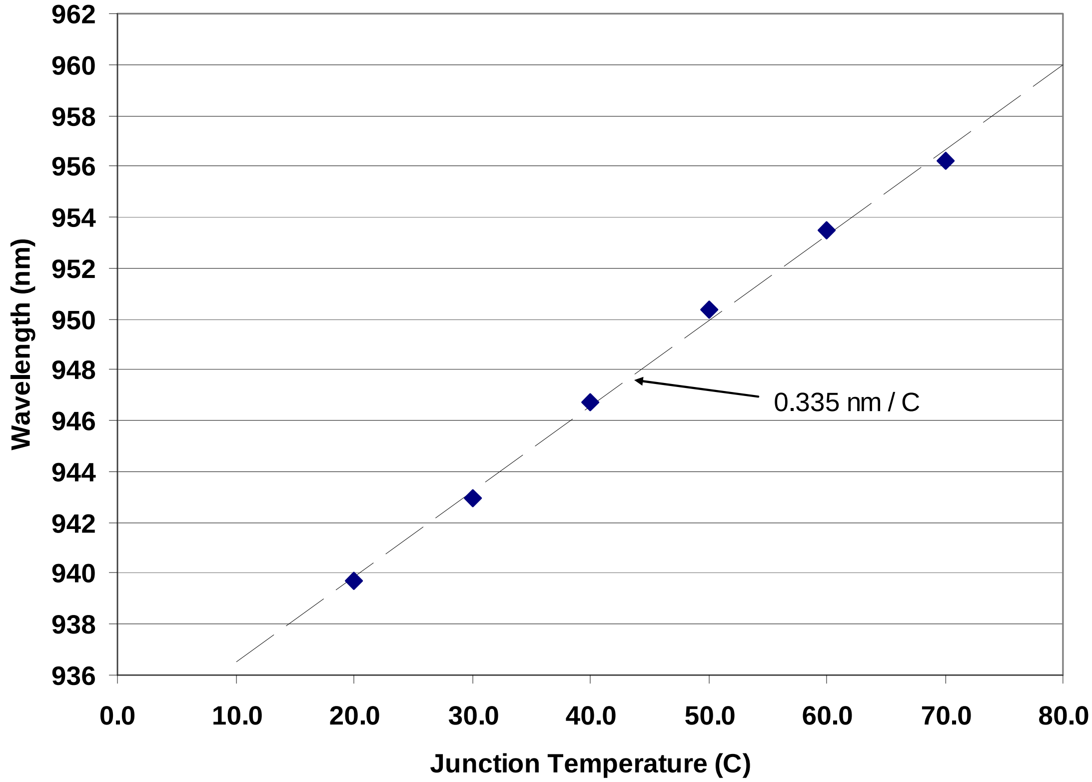

Figure 4. Power-Averaged Wavelength vs Laser Diode Junction Temperature

Results

The plotted data yields the following relationship between power-averaged wavelength of the laser's optical output and junction temperature of the laser,

$$\lambda = (0.335 \text{ nm/°C}) * T_j + (933.1 \text{ nm}) \quad (3a)$$

$$T_j = (\lambda - 933.15 \text{ nm}) / (0.3354 \text{ nm/°C}) \quad (3b)$$

where,

λ = wavelength in nm
T_j = junction temperature in °C

For example, using the data from Table 1 for a heat sink temperature of 50°C and laser drive current of 1.2 amps, the measured wavelength was 951.9 nm. The junction temperature can then be calculated using equation 3b,

$$T_j = (\lambda - 933.15 \text{ nm}) / (0.3354 \text{ nm/°C}) = 55.9\text{°C}$$

Thermal impedance between the junction and the heat sink can also be quickly calculated using equations 1 and 2 and the junction temperature, heat sink temperature, and waste thermal power.

Using the data in Table 1 again for a drive current of 1.2 amps, the power dissipated in the junction is calculated using equation 2,

$$P_j = (1.200) * (1.558) - (0.552) = 1.317 \text{ watts}$$

The thermal impedance is then calculated using equation 1,

$$T_j = T_{hs} + R_{th} * P_j \qquad (4)$$

$$R_{th} = (T_j - T_{hs}) / P_j = (56.1 - 50.0) / 1.317 = 4.6 \text{ °C/W.}$$

Averaging the thermal impedance values from all of the data collected yields the slightly smaller value of 4.2 °C/W.

Alternate Method of Data Analysis

While the method of data analysis described in the previous section is intuitively appealing, a faster and more statistically rigorous method has been suggested by JDSU[6]. Assuming a linear relationship between wavelength and junction temperature, it can be expressed as,

$$\lambda = m * T_j + b \qquad (5)$$

Substituting T_j using equation 1 yields the following results.

$$\lambda = m * [T_{hs} + R_{th} * P_j] + b$$

$$\lambda = m * T_{hs} + m * R_{th} * P_j + b$$

or, $$\lambda = m_1 * T_{hs} + m_2 * P_j + b \qquad (6)$$

Equation 6 is a linear equation in two variables that expresses wavelength in terms of heat sink temperature and power dissipated in the junction, where $P_j = I * V - P_o$. The constants m_1, m_2, and b may be readily solved using Microsoft Excel and the LINEST worksheet function. Once determined, these constants can be used to express simple relationships for junction temperature and thermal impedance.

$$T_j = (\lambda - m_1) / b \qquad (7a)$$

$$R_{th} = m_2 / m_1 \qquad (7b)$$

Using the same data that is plotted in Figure 3, the following results are obtained,

$$T_j = (\lambda - 933.01 \text{ nm}) / (0.3427 \text{ nm/°C})$$

$$R_{th} = 3.7 \text{ °C/W}$$

These results compare favorably with those obtained in the preceding section. Over the temperature range of 20°C to 70°C calculated junction temperature agrees within ±0.6°C. The thermal impedance calculations differ from each other by 12%.

Conclusion

A simple method of measuring the junction temperature and thermal impedance of high power laser diodes has been described. The method presented here is based on cw measurements made with readily available instrumentation. Use of an integrating sphere based optical multimeter head allows simultaneous measurement of optical power and power-averaged wavelength, thereby avoiding the requirement for a separate optical spectrometer or the need to couple light into an optical fiber.

References

1. Stephen Bennett, "Testing Bond Quality by Measuring Thermal Resistance of Laser Diodes", Application Note #13, ILX Lightwave Corporation.

2. Thomas L. Paoli, "A New Technique for Measuring the Thermal Impedance of Junction Lasers," IEEE J. Quantum Electronics, QE-11, No. 7, p. 498, July 1975.

3. J. J. Hughes, et al, "Measurement of the Thermal Resistance of Packaged Laser Diodes," RCA Review, V. 46, p. 200, June 1985.

4. See for example M. Fukuda, "Reliability and Degradation of Semiconductor Lasers and LEDs", Artech House, Inc., Norwood 1991.

5. "Laser Wavelength Measurement Using a Colored Glass Filter," TN6810B-7, ILX Lightwave Corporation.

6. Private communication.

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 Loc-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

Application Notes

- App Note 1: Controlling Temperatures of Diode Lasers and Detectors Thermoelectrically
- App Note 2: Selecting and Using Thermistors for Temperature Control
- App Note 3: Protecting Your Laser Diode
- App Note 4: Thermistor Calibration and the Steinhart-Hart Equation
- App Note 5: An Overview of Laser Diode Characteristics
- App Note 6: Choosing the Right Laser Diode Mount for Your Application
- App Note 8: Mode Hopping in Semiconductor Lasers
- App Note 10: Optimize Testing for Threshold Calculation Repeatability
- App Note 11: Pulsing a Laser Diode
- App Note 12: The Differences between Threshold Current Calculation Methods
- App Note 13: Testing Bond Quality by Measuring Thermal Resistance of Laser Diodes
- App Note 14: Optimizing TEC Drive Current
- App Note 17: AD590 and LM335 Sensor Calibration
- App Note 18: Basic Test Methods for Passive Fiber Optic Components
- App Note 20: PID Control Loops in Thermoelectric Temperature Controllers
- App Note 21: High Performance Temperature Control in Laser Diode Test Applications
- App Note 22: Modulating Laser Diodes
- App Note 23: Laser Diode Reliability and Burn-In Testing
- App Note 25: Novel Power Meter Design Minimizes Fiber Power Measurement Inaccuracies
- App Note 26: ReliaTest L/I Threshold Calculations
- App Note 27: Intensity Noise Performance of Semiconductor Lasers
- App Note 28: Characterization of High Power Laser Diode Bars
- 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

For application assistance or additional information on our products or services you can contact us at:

ILX Lightwave Corporation
PO Box 6310, Bozeman, MT 59771-6310
Phone: 406-556-2481 • 800-459-9459 • Fax: 406-586-9405
Email: sales@ilxlightwave.com

To obtain contact information for our international distributors and product repair centers or for fast access to product information, technical support, LabVIEW® drivers, and our comprehensive library of technical and application information, visit our website at:

www.ilxlightwave.com

ILX Lightwave
Laser Diode Instrumentation & Test Systems

 Rev02.081409