#31

Mounting Considerations for High Power Laser Diodes

APPLICATION NOTE

ILX Lightwave®

Mounting Considerations for High Power Laser Diodes

By: Patrick Gale and Andrew Shull

Introduction

As the optical power of laser diodes increases into the tens and even hundreds of watts, the thermal design of the laser diode mount becomes more important. When selecting or designing a laser diode mount the total heat generated by the laser diode and thermoelectric modules must be considered. This total heat will be used to determine which type and size of heat sink is required for the application.

Also, as laser diode power increases, the thermal interface between the laser diode package and laser diode mount becomes more important. A poor thermal interface can lead to higher operating temperatures and potential damage to the laser diode.

This application note will cover thermal resistance design and different types of heat sinks. For additional design criteria for laser diode mounts please see ILX Lightwave Application Note #3 Protecting Your Laser Diode.
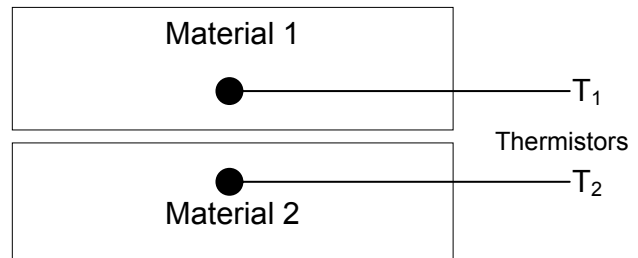
Thermal Resistance

Thermal conductance is the measure of the rate at which heat energy flows through a surface, and is quantified in W/ºC. Thermal Resistance is measured in ºC/W and is calculated when two or more materials are transferring heat, such as a laser diode mounted to a cold plate. The transfer of heat between two surfaces is usually inhibited by two factors: the thermal conductance of the two materials and the thermal resistance of the interface between them. When two surfaces are joined together, small imperfections in the surfaces create tiny gaps between the two materials. When these gaps are spanned by a material with low thermal conductivity, such as air, the transfer of heat between the two surfaces is impeded. When attempting to minimize the thermal resistance of that joint, it is important to consider how well the materials themselves conduct heat, how the size of the gaps can be reduced by perfecting the surfaces or using more

force to join them, and the thermal conductivity of the material occupying the remaining gaps.

Equation 1 is used to calculate thermal resistance between two materials using two imbedded temperature sensors.

T = Temperature (ºC)
Q = Heat (W)
Θ = Thermal Resistance (ºC/W)

Equation (1): $\Theta = (T_1 - T_2) / Q$

This equation can be used to illustrate why special consideration must be given to thermal resistance with high power laser diodes. Choosing arbitrary, constant values for thermal resistance (Θ) and cold plate temperature (T_2), the laser diode temperature (T_1) can be calculated using different heat loads (Q), which simulate the difference in power of the laser diodes.

Low Power Laser Diode	High Power Laser Diode
Θ = 2 ºC/W T_2 = 25 ºC Q = 0.03W	Θ = 2 ºC/W T_2 = 25 ºC Q = 10.00W

By using equation one T_1 can be calculated.

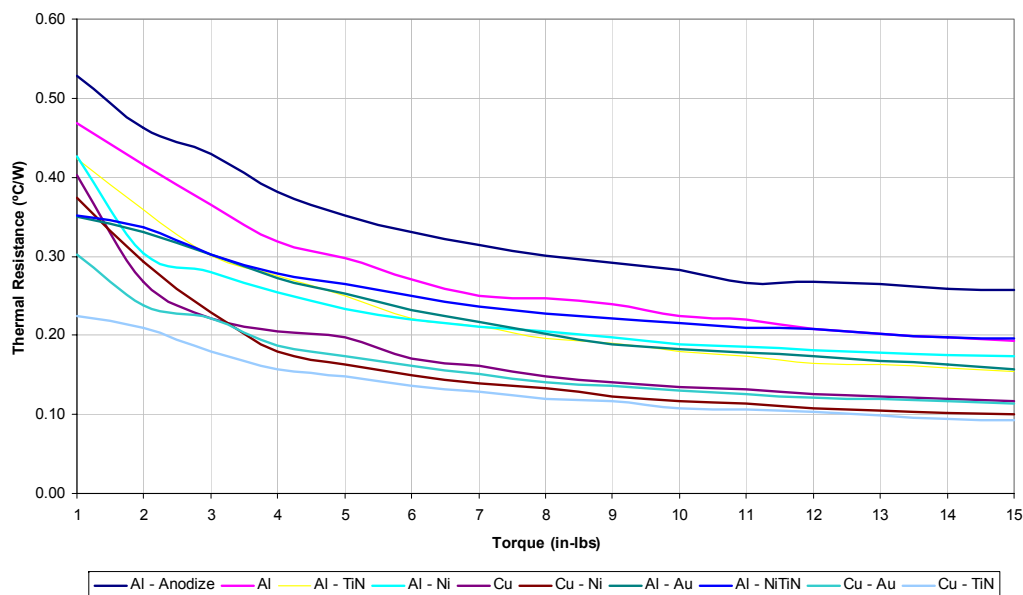| Low Power Laser Diode	High Power Laser Diode
T_1 = 25.06 ºC	T_1 = 45 ºC

Test Setup

Several different metal plates were made with a typical CS Bar package dimensions (1" x 1"). The metal plates had embedded calibrated thermistors with an accuracy ± 0.2 °C. The metal plates were mounted to the gold plated aluminum cold plate of an ILX Lightwave LDM-4415 CS Bar Laser Diode Mount using four #8-32 screws. The torque applied to the screws fastening the plate to the mount was incremented from 1 in-lb to 15 in-lbs during the course of the experiment. The heat sink of a 5 Ω resistor was fastened to the plate with thermal compound between the metal plate and the resistor heat sink to allow maximum dissipation of power to heat the plate. Thermal compound was not used between the metal plates and LDM-4415 as the main interest lies in the thermal resistance of the different metal coatings. The mount was maintained at 25 °C using an ILX Lightwave LDT-5980 120 W Temperature Controller with temperature resolution of 0.001 °C and an accuracy of ±0.005 °C. An additional LDT-5980 was used to sense the temperature of the embedded thermistor in the metal plates. The plates tested were aluminum and copper with the following coatings:

- No Coating (bare)
- Titanium Nitride (TiN)
- Gold (Au)
- Nickel (Ni)
- Nickel and Titanium Nitride (NiTiN) (Aluminum only)
- Anodizing (Aluminum only)

For each plate, 4.968 W was dissipated through the resistor with the plate fastened to the mount with 1 in-lbs of torque in each of the four screws. In this application heat from the resistor dissipated into the air is assume minimal and will not be subtracted out for calculating thermal resistance. The temperature was allowed to stabilize and the thermal resistance, quantified in °C/W, was calculated from the disparity between the plate temperature and the LDM-4415 temperature. This was repeated as the torque was incremented in 1 in-lb steps to a maximum of 15 in-lbs.

Chart 1: Torque vs Thermal Resistance

Test Results

At the maximum torque of 15 in-lbs, every copper plate, regardless of coating, had a lower thermal resistance than any aluminum plate. The copper plates had a mean average thermal resistance of 0.11 °C/W, correlating to an average temperature difference of 0.53 °C between the plates with 4.968 W of heat being generated. The best thermal resistance found was a copper plate with a titanium nitride coating yielding a thermal resistance of 0.09 °C/W at a torque of 15 in-lbs. Although titanium nitride is an extremely hard coating, flaking occurred during testing as torque was applied to the screws. This was an unexpected result and occurred on both the aluminum and copper plates. Perhaps using a different vendor and thicker coating would prevent such damage. Titanium nitride was the only coating that was damaged during testing.

The aluminum had a mean average thermal resistance of 0.19 °C/W resulting in average temperature difference of 0.94 °C with the same heat load and at the same torque. The worst thermal conductor was the anodized aluminum plate, with a thermal resistance of 0.257 °C/W with 4.968 W of heat and 15 in-lbs of torque. That corresponds to a 1.275 °C disparity between the two plates. The results of the testing can be found in Chart 1.

Torque can be related to force by solving equation 2 for force.[1]

T = Torque
K = Coefficient of Friction
F = Force
d = Nominal Outside Diameter

Equation (2): $T = K * F * d$
$$F = T / (K * d)$$

K is dependent upon material, size, surface friction, and threading of the bolt. A standard K value for most small to mid size bolts is 0.2.
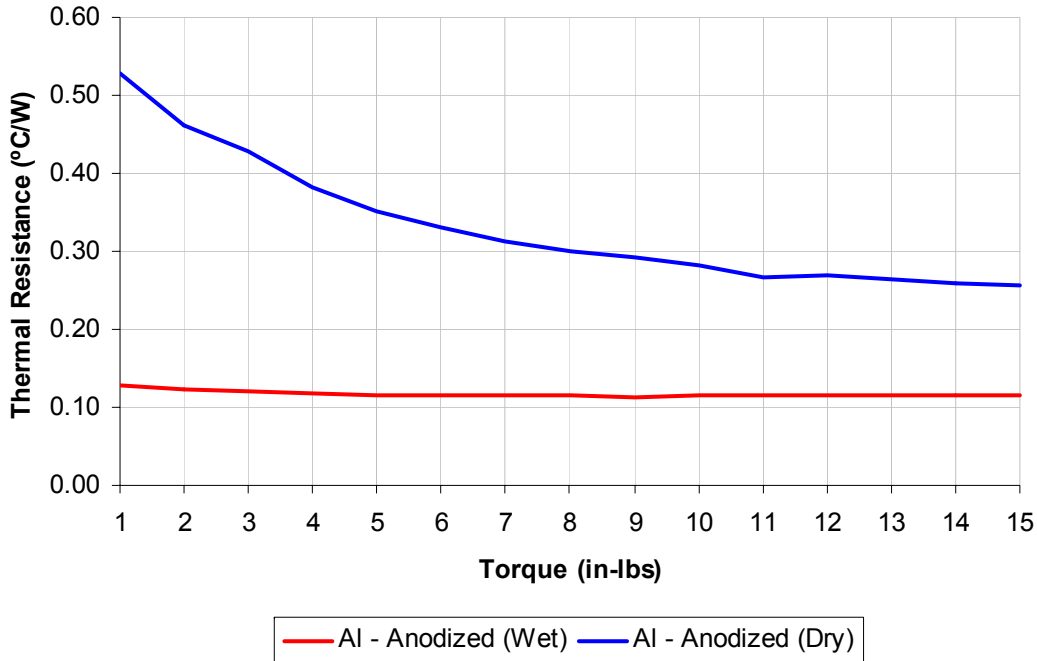
the #8-32 bolts used the nominal outside diameter is 0.164 in.

Torque (in-lbs)	Axial Force (lbs) - Single Screw	Axial Force (lbs) - All 4 Screws
1	30.49	121.95
2	60.98	243.90
3	91.46	365.85
4	121.95	487.80
5	152.44	609.76
6	182.93	731.71
7	213.41	853.66
8	243.90	975.61
9	274.39	1097.56
10	304.88	1219.51
11	335.37	1341.46
12	365.85	1463.41
13	396.34	1585.37
14	426.83	1707.32
15	457.32	1829.27

Improving Thermal Resistance

Having chosen a good thermally conductive material and having minimized the size of the heat transfer-inhibiting gaps between the two surfaces by using a maximum torque in the screws, the final consideration in improving thermal resistance is the thermal conductivity of the material occupying the remaining gaps. This is usually done by replacing the air in those gaps with ceramic or oil-based thermal compound. However in temporary applications, such as LIV testing, this method is messy and impractical. A suggested alternative was to use water as a thermal interface between the two surfaces. The anodized aluminum was chosen for this test because of its poor performance and potential to show the largest improvement. When one drop of water was placed between the mount and the anodized aluminum plate, the thermal resistance decreased by 75.94% at 1 in-lb and by 54.98% at 15 in-lbs. Using a drop of water is therefore very beneficial as a thermal interface for short-term applications, provided that measures are taken to protect the mount and laser diode. It should be noted that with the drop of water, the anodized aluminum has a more efficient thermal interface

Chart 2: Improving Anodized Al

at low torques than any dry plate tested. At the maximum torque (15 in-lbs), the wet anodized aluminum has a thermal resistance only 0.024 °C/W higher than the most efficient dry plate (wet anodized aluminum had a thermal resistance of 0.116 °C/W, dry copper with a titanium nitride coating had a thermal resistance of 0.092 °C/W).

Selecting a Heat Sink

There are many choices in heat sink design. In this application note, finned heat sinks and water-cooled heat sinks will be discussed. Before selecting a heat sink, the total thermal load will need to be known. The total thermal load is the sum of the loads of the laser diode and, if used, the thermoelectric cooler.

P_{LD} = Power from Laser Diode
P_{TEC} = Power from TEC
P_T = Total Thermal Load to be Removed by Heat Sink

Equation (3): $P_T = P_{LD} + P_{TEC}$

To calculate the thermal heat from the laser, the laser current, voltage, and efficiency of light output versus input power will be required. The typical efficiency of high power laser diodes is 50%, but it is best to use a lower efficiency as the efficiency will decrease over the life of the laser diode.

I = Laser Diode Current
V = Laser Diode Voltage
η = Efficiency of Laser Diode

Equation (4): $P_{LD} = I * V * (1-\eta)$

Calculating the total heat from the thermoelectric cooler (TEC) is more difficult due to the electrically dynamic nature of the device. The more current and voltage that is applied to the TEC the more heat it can remove from the laser diode. But with more current and voltage, more power is transmitted to the heat sink, creating

more heat for the heat sink to dissipate. In addition TEC's lose efficiency as the difference in temperature between the hot side (heat sink) and cold side (laser diode) increases. Most TEC manufacturers have free programs available to assist in selecting and calculating the total heat from the TEC. This number, combined with the waste heat from the laser diode, is the total power to be removed by the heat sink.

Equation 5 is a simple way to calculate the heat removal of a heat sink.

Q = Heat Removal Capacity of Heat Sink (W)
k = Thermal Resistance of Heat Sink (ºC/W)
Δt = Ambient Temperature (T_A) Minus
      Temperature of Heat Sink (T_{HS})

Equation (5): $Q = \Delta t / k$

Finned Heat Sinks
In order to remove heat, finned heat sinks rely on natural or forced convection. The performance of the heat sink will be limited by the size, fin height, and fin density. Forced convection can improve the performance of fin heat sinks. This can be easily accomplished by attaching a fan to the fins of the heat sink and forcing the air across the fins. Generally it is best to mount the fan in the middle of the heat sink and force the air out both ends of the fins.

There are many manufacturers of finned heat sinks, and there are elaborate fin designs to facilitate higher power laser diodes. One benefit of finned heat sinks can be the low cost to implement if the application permits a standard extrusion heat sink.

Water-Cooled Heat Sinks
For maximum heat removal in a small package, the best solution is a water-cooled heat sink. There are many styles of water-cooled heat sinks. A simple design consists of drilling holes in a metal block for water to pass through or mounting water-carrying copper tubing to a metal block to cool it. An example of a more elaborate design is a milled serpentine water channel in a metal block with a sealed cover plate.

The following example shows the increased heat removal capacity of a water-cooled heat sink versus a finned heat sink. In order to compare the heat sinks, a standard sized heat sink with an area of 7 inch by 6 inch was chosen and thermal resistance was taken from commercially available data sheets. Assuming the same ambient air and water temperature a maximum change of temperature of 10 ºC (Δt) was chosen in this example. An increase in Δt will allow greater heat removal by the heat sink. The selected water-cooled heat sink used copper tubing bent into a serpentine pattern. Thermal resistance was also calculated for using a forced convection of 6.1 m/s with the finned heat sink.

Water-Cooled	Natural Convection	Forced Convection
k = 0.10 ºC/W	k = 0.50 ºC/W	k = 0.11 ºC/W
Δt = 10 ºC	Δt = 10 ºC	Δt = 10 ºC

Using equation 5 Q can be calculated.

Water-Cooled	Natural Convection	Forced Convection
Q = 100.0 W	Q = 50.0 W	Q = 90.9 W

An advantage of the water-cooled heat sink is the ability to use a water chiller or heat exchanger to lower the ambient water temperature. In the following example Q is calculated when a chiller is used.

Water-Cooled	Water-Cooled with Chiller
T_{HS} = 33 ºC	T_{HS} = 33 ºC
T_A = 23 ºC	T_A = 13 ºC
Δt = 10 ºC	Δt = 20 ºC
k = 0.10 ºC/W	k = 0.10 ºC/W

Using equation 5 Q can be calculated.

Water-Cooled	Water-Cooled with Chiller
Q = 100 W	Q = 200 W

Conclusion

Most high power laser diode packages do not include embedded thermistors to monitor temperature. A high thermal resistance between a laser diode and the cold plate can lead to an operating temperature outside of the safe operation temperature of the laser diode. To ensure safe and accurate operation of the laser diode, an estimated temperature should be calculated for the set up. This calculation can be done using equation 1 presented earlier. To lower the temperature difference obtained from this calculation, consideration should be given to the thermal resistance of the laser diode mount.

When selecting or designing a laser diode mount, it is important to pay attention to the materials used. As illustrated in Chart 1, a coated mounting plate can greatly reduce the thermal resistance of the junction. Even with coating consideration should still be given to thermal resistance—there is more to the efficiency of the junction than just material. In addition to proper coating material, adequate force between the laser diode and the cold plate should be applied to increase the efficiency of that junction. A thermally conductive medium between the two surfaces can help even more. Thermal compound should be used in permanent applications, and a drop of water can dramatically decrease thermal resistance in temporary applications such as LIV testing. In temporary applications, the thermal resistance repeatability should also be considered. The repeatability of thermal resistance refers to the accuracy of the thermal resistance interface when repeatedly mounting a laser diode. If purchasing a laser diode mount from a vendor both thermal resistance and repeatability of thermal resistance should be specified and the vendor should have data to verify these specifications.

This application note is intended to give a general overview of key specifications when selecting or designing a laser diode mount.

Reference

1. Shigley, J., Mischke, C., & Budynas, R. (2004). *Mechanical Engineering Design* (7th edition). New York, NY: McGraw-Hill.

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

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
31950 Frontage Road, Bozeman, MT 59715
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®
A Newport Corporation Brand