#21

High Performance Temperature Control in Laser Diode Test Applications

APPLICATION NOTE

ILX Lightwave®

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High Performance Temperature Control in Laser Diode Test Applications

By Scott Remington

Optimization of PID Control Loops Allows Rapid Temperature Stabilization

Introduction

A typical application in laser diode test is the characterization of laser output over wide temperature ranges, typically from 0°C to 85°C. Quick changes to and rapid stabilization of laser diode case temperature implies increased production throughput due to quicker laser characterizations.

What is required to quickly change a device's temperature to either a hot or cold extreme and maintain it? In the case of temperature control with thermoelectric coolers, this typically requires a TEC capable of producing a large temperature gradient between its hot and cold sides in addition to pumping a large amount of heat. TECs of this type require current on the order of 5-10 amps in order to pump tens of Watts of heat. A telecom diode laser for example may only produce 1-2 Watts of heat at most so why is such a large heat pumping capacity required? Heat pumping capacity must be larger than what the device under test produces because in order to reach the required extreme temperatures, the heat that must be pumped into or out of the device comes from several sources.

In general, the total heat flow required to maintain a specified temperature can be described by the equation

(1) $$Q_{total} = Q_{ambient} + Q_{TEC} + Q_{load}$$

When cooling below ambient, heat must be removed from the laser so all terms of Q_{total} are negative. When heating above ambient, heat must be pumped into the laser which causes $Q_{ambient}$ and Q_{TEC} to be positive and Q_{load} to be negative since the heat is already being generated inside the laser. The heat transfer $Q_{ambient}$ comes from heat being lost to the environment when $T_{load} >$ ambient and heat being absorbed from the environment when cold. This transfer is through convective, conductive, and radiated means. The convective, conductive and radiated heat can be quantified as shown in Equations 2, 3 and 4.

(2) $$Q_{conv} = hA\Delta T$$

(3) $$Q_{cond} = \frac{kA\Delta T}{l}$$

(4) $$Q_{rad} = \sigma e_1 A_1 (T_1^4 - T_2^4)$$

A complete description of these terms can be found in *App Note #1 - Controlling Temperatures of Diode Lasers and Detectors Thermoelectrically* on the ILX website and their definitions are not required for the current discussion.

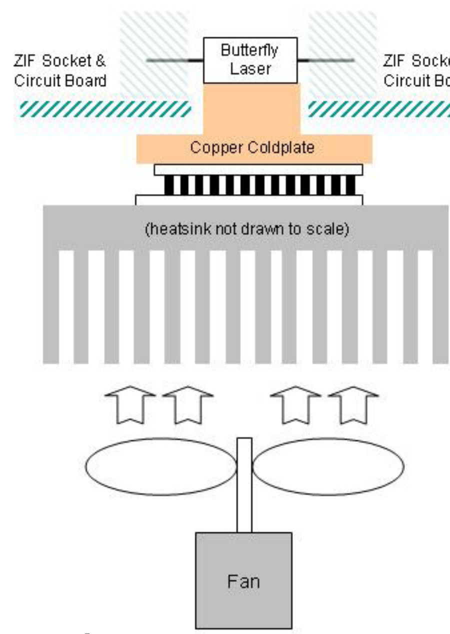
The point of interest regarding the above equations is that the heat lost or absorbed is proportional to the temperature difference between the device being controlled and the environment. In most cases, the predominant heat transfer mechanisms will be convective and conductive implying that as the temperature becomes hotter or colder, a larger amount of heat will need to be moved. This in turn requires a higher power TEC and a controller to drive it.

The purpose of this Application Note is to provide information for rapid temperature cycling of a thermal load over wide temperature extremes using an ILX Lightwave LDT-5980 120W temperature controller. The focus will be on controlling a 1.5W thermal load at temperatures of 0°C, 25°C and 85°C. Because optimizing the LDT-5980's PID control loop can be a time-consuming task, even with the instrument's Auto-Tune feature, examples of PID constants will be provided that allow the LDT-5980 to rapidly change and stabilize the thermal load's temperature.

Test Setup

A fixture was designed to allow the case of a standard 14-pin butterfly laser mount to be temperature controlled. A Marlow Industries® model DT12-8-01 thermoelectric cooler was sandwiched between a finned heatsink (aluminum) and an OFHC (Oxygen Free High Conductivity) coldplate. The coldplate top was designed as a pedestal to allow the butterfly package to be secured to it without any additional exposed surface area. The coldplate base was sized to allow complete contact with the Peltier's top surface so that thermal transfer to the TEC could be maximized. A 10 kΩ thermistor was installed in the coldplate pedestal for feedback to the temperature controller. A 94 CFM fan was installed approximately ½" away from the fins (due to space constraints within the mount) to provide airflow for convective cooling.

The thermal load consisted of a 14-pin butterfly laser package with an internal TEC and thermistor. To simulate a 1.5W heat load, the internal TEC was enabled with a constant current of 1.1A. This had the effect of driving the internal temperature 40 to 60 degrees below the case temperature. *Note: Thermal joint compound is NOT used between the test load and the coldplate. This was done to simulate a more productionized environment where shortened test time is most important.* Refer to Figure 1 for details on the test fixture.



Test Procedure

Figure 1. Test Fixture

The test procedure used was designed to mimic the characterization of a laser diode as L-I-V tests were run at 0°C, 25°C and 85°C. A LabVIEW™ program was written to

To maximize this performance, the current limits for heating and cooling were set to the maximum current recommended by the TEC manufacturer. For the Marlow DT12-8, this limit is 7.4 Amps. The PID and current limit values used to reach each setpoint are shown in Table 2.

In order to minimize oscillations the PID values shown were optimized from those obtained from the instrument's autotune feature.

Setpoint Temperature	25°C	0°C	85°C	25°C
Proportional Term	12.5	7.75	50.0	12.5
Integral Term	1.65	1.5	5.5	1.65
Deriviative Term	4.5	4.5	8.1	4.5
Cooling Current Limit	7.4A	7.4A	7.4A	7.4A
Heating Current Limit	-7.4A	-7.4A	-7.4A	-7.4A

Table 2. LDT-5980 Control Parameters

ILX Application Note #14, references the fact that maximum current may not be the optimal choice when a TEC is being used to cool an object. This subject was investigated and for the parameters of this test, was found to provide negligible benefit. The only change noticed was an increase in the time needed to cool down to the setpoint temperature. If extended periods of time are needed with the temperature at 0°C or colder, a current limit below device maximum is recommended to prevent the heatsink from saturating (thermal runaway).

The graph representing the internal temperature in Figure 2 shows the temperature lag experienced due to thermal resistance between the case and the internal components of the laser. The thermal lag illustrates the point that if stabilization of the internal temperature is important, a dwell time must be built into the test.

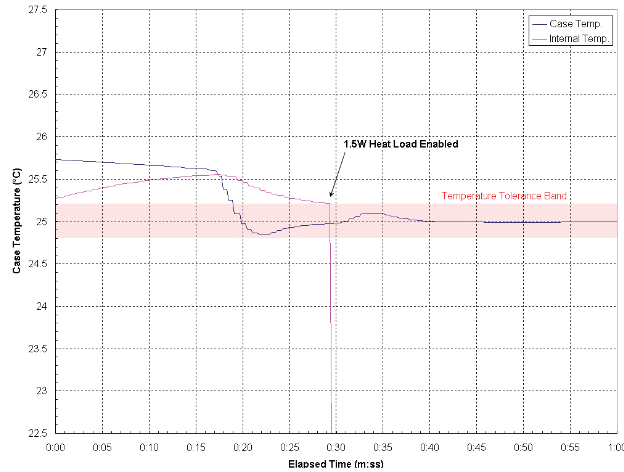


Figure 3. Effect of Thermal Load on 25°C Setpoint

As can be seen in Figure 3, the case temperature changes ~0.1°C when the 1.5W thermal load is applied. The variations, however, do not go outside the ±0.2°C temperature tolerance band for this test. The quantization of temperature seen in graphs with expanded scales is due to the approximate 2 Hz measurement update rate of the instrument.

Figure 4 shows similar behavior occurring at 0°C. There is an approximate 0.1°C increase in the case temperature due to the enabling of the heat load but it is brought back to the setpoint in less than five seconds.

Figure 5 shows how enabling the 1.5W thermal load affects the case temperature at the 85°C setpoint. In this case, the external temperature actually exceeds the 0.2°C tolerance band for several seconds.

record the data and configure the temperature controller for each step shown below:

1. Enable temperature controller output with setpoint of 25°C.
2. Allow laser case temperature to stablize to 25°C ± 0.2°C.
3. Enable 1.1A to internal TEC to generate a 1.5W heat load.
4. Wait 30 seconds to simulate the L-I-V data gathering.
5. Disable 1.5W heat load.
6. Change temperature controller setpoint to 0°C.
7. Allow laser case temperature to stabilize to 0°C ± 0.2°C.
8. Apply 1.5W heat load.
9. Wait 30 seconds.
10. Disable 1.5W heat load.
11. Change temperature controller setpoint to 85°C.
12. Allow laser case temperature to stabilize to 85°C ± 0.2°C.
13. Apply 1.5W heat load.
14. Wait 30 seconds.
15. Disable 1.5W heat load.
16. Change temperature controller setpoint to 25°C.
17. Allow laser case temperature to stabilize to 25°C ± 5°C to simulate the cooling-down needed to allow an operator to safely remove the laser from the fixture.

Temperature Cycle Results

The test data in Figure 2 shows the coldplate (case) temperature and the laser's internal temperature as a function of time. The effect of enabling and disabling the 1.5W heat load is not completely obvious in this data because of the resolution of the vertical scale. The sharp changes in the internal temperature are due to the internal TEC being enabled and disabled.

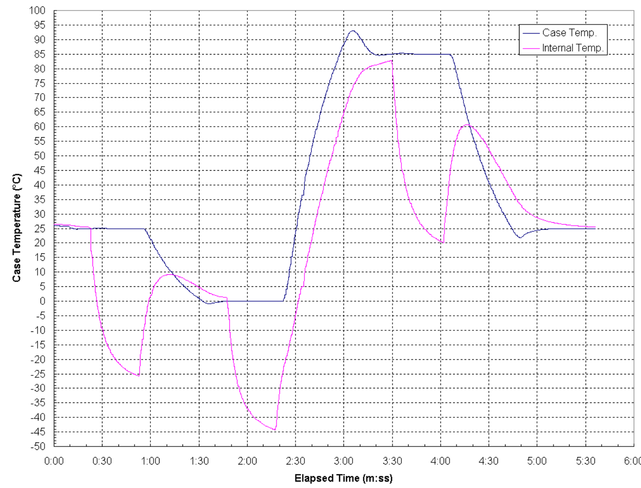


Figure 2. Case Temperature vs. Time

The data illustrates how quickly the setpoint temperatures can be reached to allow data collection. A summary of the time to change temperature is given in Table 1. The total test length can be considered to occur in less than five minutes. It is important to note that production setups with undersized temperature controllers can take tens of minutes to reach the same temperatures.

Temperature Change	Approximate Time Required (min:sec)
25°C → 0°C	0:45
0°C → 85°C	1:00
85°C → 25°C	1:00

Table 1. Time Required to Reach Temperature Setpoints

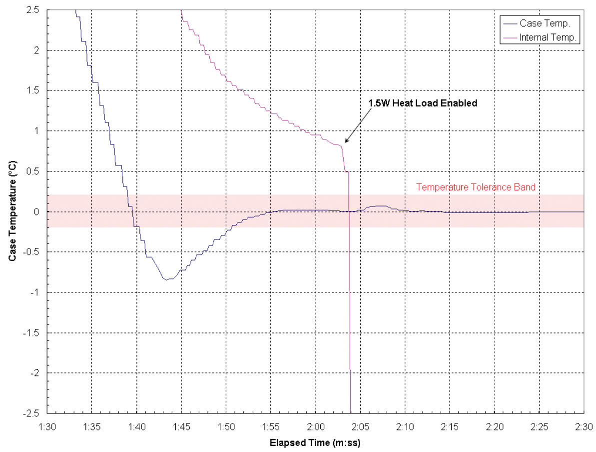


Figure 4. Effect of Thermal Load on 0°C Setpoint

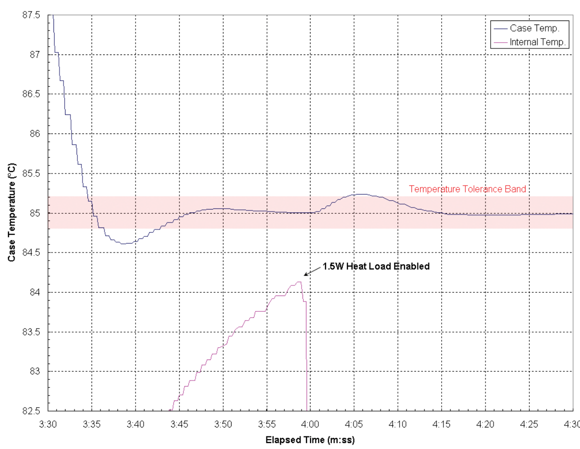


Figure 5. Effect of Thermal Load on 85°C Setpoint

This example shows that to maintain temperature stability, the L-I-V test must either be sped up to finish before the temperature exceeds the tolerance window or significantly slowed down to allow thermalization between each current ramp step.

As a final test, the laser diode was subjected to the same temperature profile as before but with time allowed for the internal temperature to stabilize to the setpoint temperature. This was done to see how much additional time would be required beyond case temperature

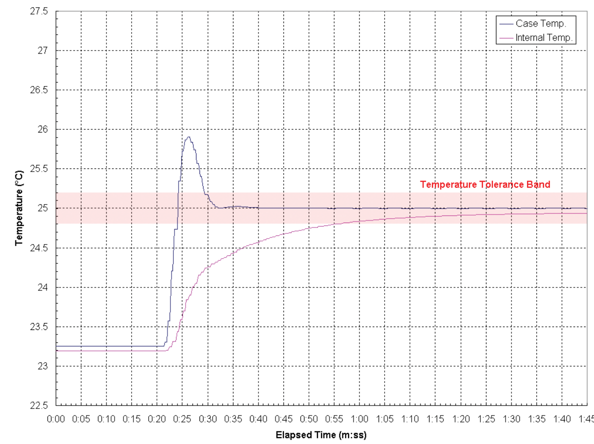


Figure 6. Laser Internal Temperature Stabilization at 25°C Setpoint

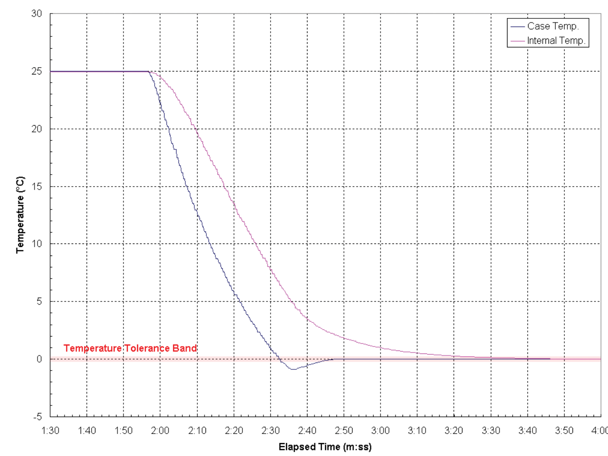


Figure 7. Laser Internal Temperature Stabilization at 0°C Setpoint

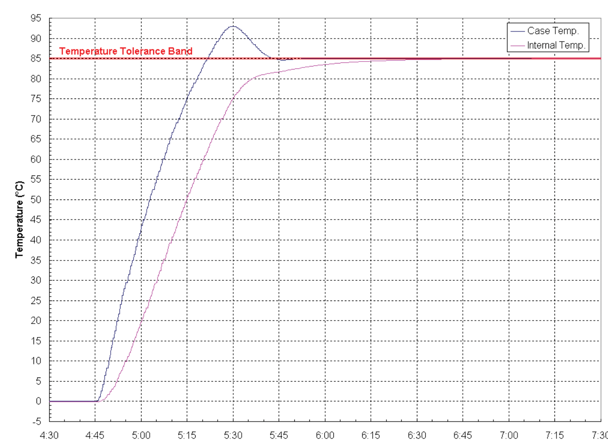


Figure 8. Laser Internal Temperature Stabilization at 85°C Setpoint

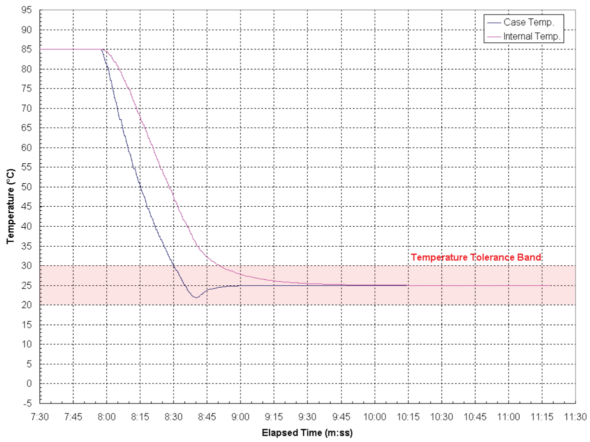


Figure 9. Laser Internal Temperature Stabilization at 25°C Setpoint

stabilization before a temperature-critical test could begin. Figures 6 - 9 detail this procedure at each temperature setpoint. In all cases, an additional 30 to 60 seconds are required to allow the internal temperature to stabilize.

Summary

In conclusion, the presented data demonstrates that rapid temperature shifts of case temperature are possible with a high power temperature controller such as an ILX Lightwave LDT-5980 Temperature Controller. Through a judicious choice of PID coefficients shown in Table 2, changing temperature between the setpoints of 0°C, 25°C and 85°C can quickly occur. In most instances, the actual time required to go from one case temperature to stabilization within ±0.2°C at another temperature can happen in 60-90 seconds. This scenario demonstrates that the L-I-V characterization of a laser diode can occur at three temperatures in less than five minutes total.

It must be remembered, however, that the time required for the internal temperature to stabilize will be significantly longer. This is because of thermal resistance between the case and the internal components of the laser package. If the internal temperature is to be stabilized as well, several additional minutes may be required to achieve this. The total test time will also depend on the temperature tolerance required.

Other ILX Lightwave Application Notes may be of interest when configuring a test station for rapid temperature cycling. These notes include:

App Note #1 - *Controlling Temperatures of Diode Lasers and Detectors Thermodynamically*

App Note #14 - *Optimizing TEC Drive Current*

App Note #20 - *PID Control Loops in Thermoelectric Temperature Controllers*

The following publications are available for download on 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

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 Mutlimeter
- 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

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