PHY393N – Measurement of Semiconductor Laser Diodes

This project will study some of the fundamental properties of semiconductor laser diodes. These are the most important type of laser which have a wide range of applications including data storage, communications, medical and basic physics research.

Aims

- Gain experience in the control of a laser current driver using LabView
- Measure the light vs current characteristic of a laser and determine the threshold current
- Study the optical spectra of a laser both below and above threshold
- Compare the properties of an LED and laser
- Investigate how temperature affects the performance of a semiconductor laser.

Hazards associated with this experiment

- Laser radiation. The laser diode is low power and the output beam is uncollimated. As a result the laser light poses no risk to the eye although it would be unpleasant to view directly. Do not insert a lens into the beam in an attempt to collimate it. Ensure the laser light strikes a nearby surface. Do not hold the laser near eyes or point towards another lab user.

Theory

A semiconductor produces light when an electron in the conduction band drops to the valence band annihilating a hole (the electron and hole are said to recombine). Energy may be conserved via the emission of a photon of energy approximately equal to the bandgap of the semiconductor. In a Light Emitting Diode (LED) photons are produced by spontaneous emission, in a laser the photon production is via stimulated emission. For lasing action to occur there must be sufficient amplification of the light to overcome losses. This requires a large number of electrons to be present in the conduction band and a similar large number of holes in the valence band. This is generally achieved by injecting a relatively large electrical current. At low currents there are insufficient electrons and holes created and spontaneous emission dominates; the device will act like an LED with a low power output. At a given current (threshold) there are sufficient electrons and holes to give the required amplification and lasing starts; stimulated emission now dominates. The light power output now increases much more rapidly than below threshold. Below threshold the spectrum of the emitted light is broad (similar to that of an LED), typically reflecting the thermal distribution of electron and hole energies. However, above threshold the spectrum is much narrower and results from the optical cavity modes formed by the two laser mirrors. Semiconductor lasers exhibit a temperature dependent threshold current. With increasing temperature electrons and holes are excited away from their relative band edges and cannot contribute to the lasing action. As a result, a larger current has to be injected to achieve lasing; the threshold current increases with increasing temperature.

Experimental work

Your measurements will be performed on a low power red laser diode. This has a maximum output power of 10mW at a wavelength of 639 nm. Specifications for the laser diode are given in the Appendix. The laser has a built in photodiode which allows the emitted light intensity to be measured. You will also have access to a LED to enable you to test your system and make comparison with the laser. The LED does not have a built in photodiode and so an external photodiode is needed.

A laser is generally operated from a current source and you are provided with a source that can provide a current between approximately 0 and 50 mA. The current produced is determined by a voltage applied to the input, you will use a myDAQ running with LabView to produce this voltage and also to measure the emitted light which is detected by a photodiode. You will also have a spectrometer with which to measure the spectrum of the light emitted by the laser. Details of the laser current driver and spectrometer are given in the Appendix.

Precautions

Both the LED and laser diode can be destroyed by applying too high a current. The laser/LED interface box can be damaged if operated incorrectly. You must do the following

- **Do not apply electrical power to the interface box without either the LED or laser connected.**
- **When applying or removing electrical power to the interface box the Laser off/on switch should be set to Off.**
- **Do not apply a current of more than 30mA to the LED. This corresponds to a myDAQ output voltage of approximately 6V.**
- **The voltage from the laser photodiode should never be greater than 0.4V (4V if x10 gain is used). This corresponds to a myDAQ output voltage of approximately 8V but will change if the temperature of the laser changes.**
- **The resistor connected to the temperature controller can get hot. Do not touch this.**

If you have any doubts / questions, ask a demonstrator.

Week 1 – initial setup and determination of the light-current characteristics of an LED

Software

The first task is to write two LabView programs to control the laser/LED and read in the photodiode voltage. The first program should let you set the myDAQ output voltage (and hence laser or LED current) and read in the photodiode voltage. This voltage can vary over the range 0 to +10V. This should run in a continuous loop (while loop). A typical front panel is shown in the Appendix. The second program is more complex as it needs to scan the laser current (I) from zero to a set maximum and for each current value measure the intensity of the light produced by the laser (L). The program should produce a plot of L vs I. Because a simple loop will leave the highest current flowing through the device on termination you should write a LabView VI that on completion of the loop the myDAQ output voltage is reduced to zero. You can achieve this using a Sequence structure in LabView. An example of the front panel for this VI is shown in the Appendix. It is helpful to have the visual indications of voltage out and voltage in so you can monitor these as the program runs.

Your programs will use DAQ assistants to set the myDAQ output voltage and read in the photodiode voltage. It is recommended that you use an XY graph to display the results of second program. You will need some way of saving results for analysis and use in your report.

When running with pulsed mode the photodiode voltage is not fully constant and so it is necessary to take a number of readings and average these. This can be achieved by setting the DAQ assistant to N samples with 10~20 samples at a frequency of 10 Hz. This should result in fairly smooth data.

The DAQ assistant used to read in the photodiode voltage produces dynamic data which needs to be converted to a format consistent with that required by the XY graph – this requires use of Convert from Dynamic Data with the output set to Single Scalar

Calibration and measurements

As lasers are fairly sensitive and can be easily broken by applying too high a current, the initial experiments will be performed using a red LED. With all equipment switched off plug the LED and photodiode into the interface box. Connect the interface box to the myDAQ as described in the Appendix. Switch on the equipment and use a LabView program to set the voltage output to a relatively small value (~ 1V). You should see the LED emit light. This part of the experiment should use the CW setting.

The relationship between the voltage produced by the myDAQ (range 0 to 10V) and the current applied to the LED has to be determined. Connect a DMM to the black and yellow terminals and measure the voltage between these terminals for a known output voltage from the myDAQ (do not use a voltage greater than 6V). The DMM voltage is related to the device current by V=I*10. Think how you can best use this measurement(s) to calibrate the myDAQ output voltage in terms of LED or laser current.

Place the photodiode close to the LED using the small length of rubber tube. You may have to screen them from room lighting. Run the program to scan the current and measure the light output via the photodiode. Do not exceed the safe maximum LED current of 30 mA (approximately 6V). When you have recorded a good example of the L vs I characteristic for the LED save the data.

The relationship between LED optical power and photodiode voltage is Power(μW) = $(252\pm10)V_{photodiode}$(V) where the gain is set to x10. Using this relationship you can calibrate the L axis of your LI graph and determine the slope in W/A and also the quantum efficiency of the LED.

Use the spectrometer to record the emission spectra produced by the LED for a number of different currents (e.g. 5, 10, 15, 20, 25 and 30 mA). Ensure that you store each of these spectra and record the experimental conditions used.

Week 2 - Determination of the light-current characteristics of a laser

You should now be able to measure the L vs I characteristic of a device and also the spectrum of its emitted light. This week you will perform these measurements on a semiconductor laser. With the equipment switched off, replace the LED with the laser. The laser has an inbuilt photodiode so a separate photodiode is not needed. Unlike an LED, which has a maximum specified current, a laser has a maximum specified power output. As the relationship between applied current and output power is temperature dependent this means that it is not possible to specify a safe maximum current. For the laser the maximum output power is 10 mW, which corresponds to a photodiode voltage of ~0.4V (or 4V if using x10 gain). Do not exceed this voltage.

Ensure that the interface box is switched to pulsed. Use your LabView program to set a low output voltage (~ 1V) and measure the photodiode voltage. Gradually increase the output voltage in steps ~0.5V and monitor the photodiode voltage. Above a certain laser current the light emitted will increase rapidly in intensity. Continue to increase the output voltage using smaller steps (~0.2V) and determine the value corresponding to the maximum allowed light output. Use your second program to measure the L vs I behaviour making sure the maximum voltage does not cause the photodiode voltage to go above 0.4V. Do you observe the expected behaviour with a clear lasing threshold (you may need to research what is meant by threshold for a laser)? What is the threshold current?

For the laser the relationship between output power and photodiode voltage is Power(mW)=(25$\pm$5) $V_{photodiode}$(V). You can use this relationship to calibrate the L axis of your LI in terms of laser power which allows the slope above threshold to be calculated in A/W and allows the quantum efficiency to be determined.

As for the LED use the spectrometer to measure the emission spectra of the laser for applied voltages both below and above threshold. Try to record spectra for applied voltages around threshold.

Optional Measurements

With the laser above threshold shine it onto a suitable surface (e.g. a piece of white paper). Observe the non-symmetrical spatial beam profile. Try to record this profile with a camera. As an optional exercise try and determine the variation in intensity along the two perpendicular axes. What can you determine from this variation?

Set the myDAQ output voltage to 0V and switch the interface box to CW. Carefully increase the current is steps of ~0.5V to again determine threshold (this might occur at a different voltage from the previous pulsed measurements). Once you have determined the threshold voltage switch of the laser. Set the myDAQ output voltage just above threshold (~0.5-1V above) and switch on the laser. Observe what happens to the photodiode voltage as a function of time. You may want to write a new LabView VI to record this data. You should be able to explain the observed behaviour after the final week's measurements.

Week 3 – Temperature dependence of a semiconductor laser

Both the threshold current and emission spectra of a laser vary with temperature. In particular, the threshold current increases as the temperature increases.

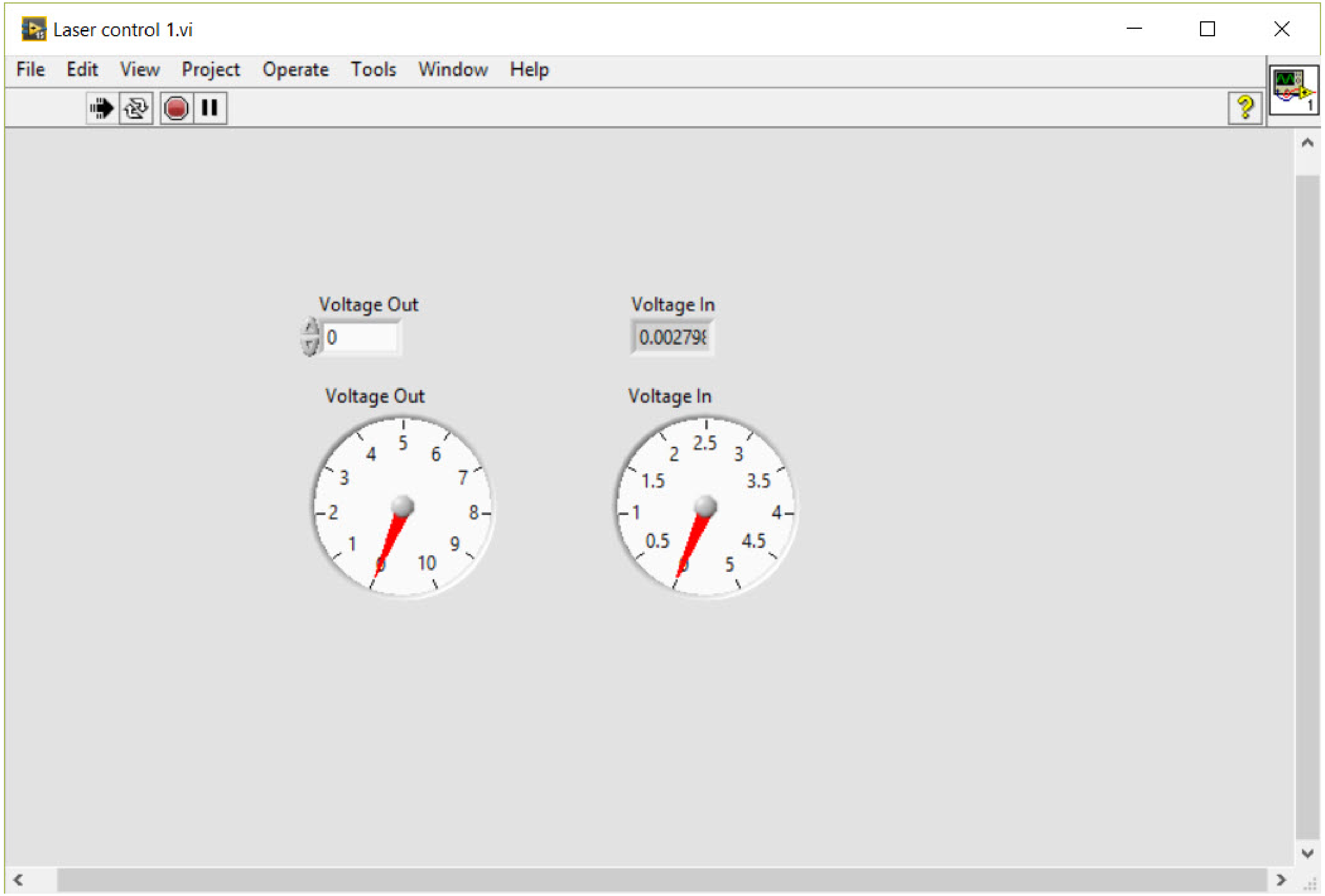
Carefully insert the laser into the hole in the aluminium block of the temperature controller. Switch on the temperature controller and use it to vary the temperature of the laser over the range 0 to 35°C (do not use temperatures outside this range).

Because the threshold current decreases as the temperature decreases for a given applied voltage the output power from the laser will increase with decreasing temperature. Hence the range of voltages used to record the L vs I characteristics has to be varied to avoid damaging the laser. At each temperature use your first program to slow increase the output voltage (steps of 0.25V) and observe the photodiode voltage. Find the value of the output voltage which gives a photodiode voltage of no more than 0.3V (or 3V with x10 gain) and use this as the upper limit for program 2 when you record the L vs I characteristic.

At each temperature measure the L vs I characteristic and emission spectra below and above threshold. You will need to measure data for ~ 10 different temperatures. Operation of the temperature controller is described in the Appendix. For each temperature determine the threshold current (I_{th}) and produce a plot of I_{th} against temperature. Do you observe any changes in the emission spectra?

David Mowbray

February 2019


Laser control 1.vi
File Edit View Project Operate Tools Window Help
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0
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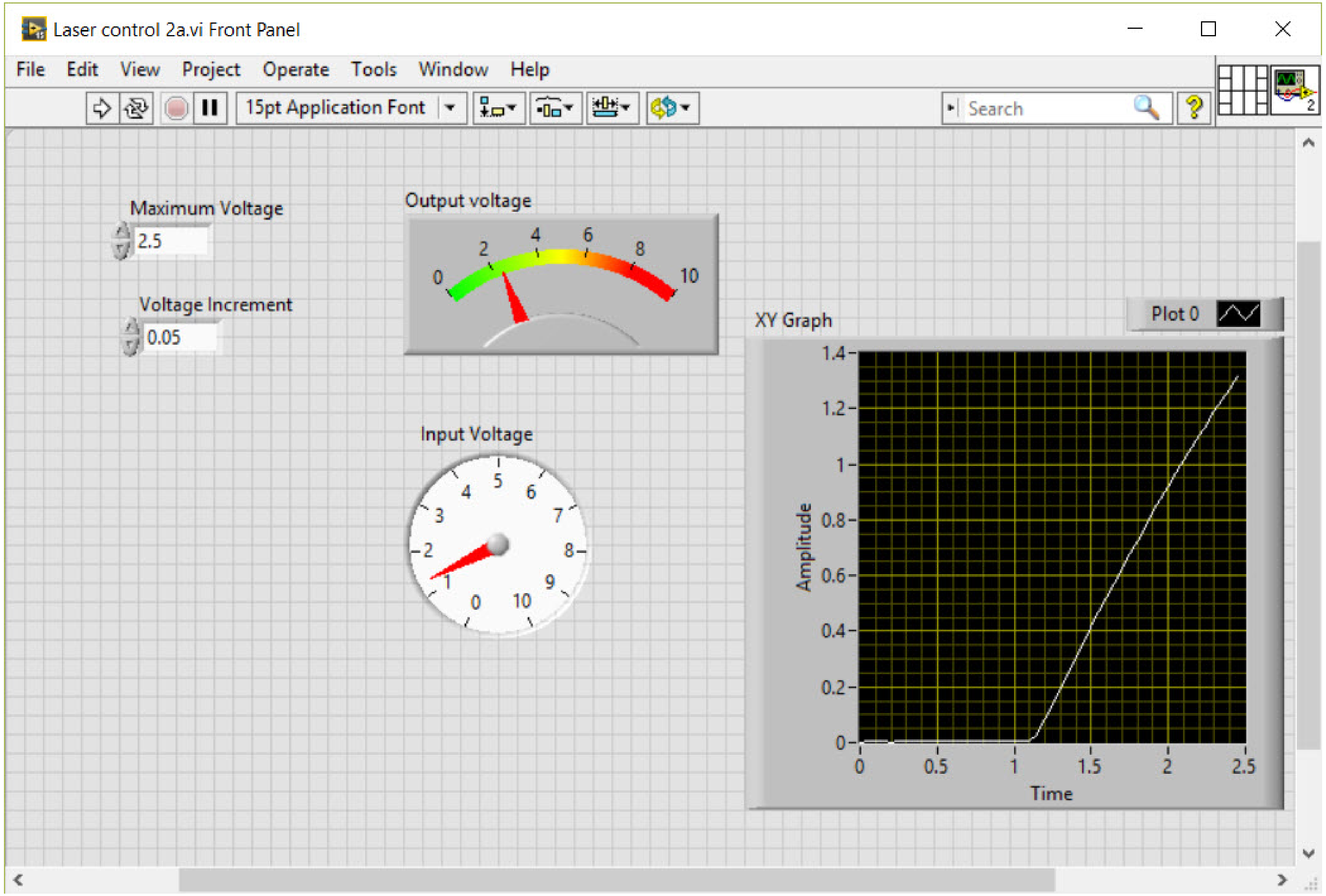
Voltage Out
0 1 2 3 4 5 6 7 8 9 10
Voltage In
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


Laser control 2a.vi Front Panel
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
Maximum Voltage
2.5
Voltage Increment
0.05
Output voltage
0 2 4 6 8 10
Input Voltage
0 1 2 3 4 5 6 7 8 9 10
XY Graph
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Amplitude
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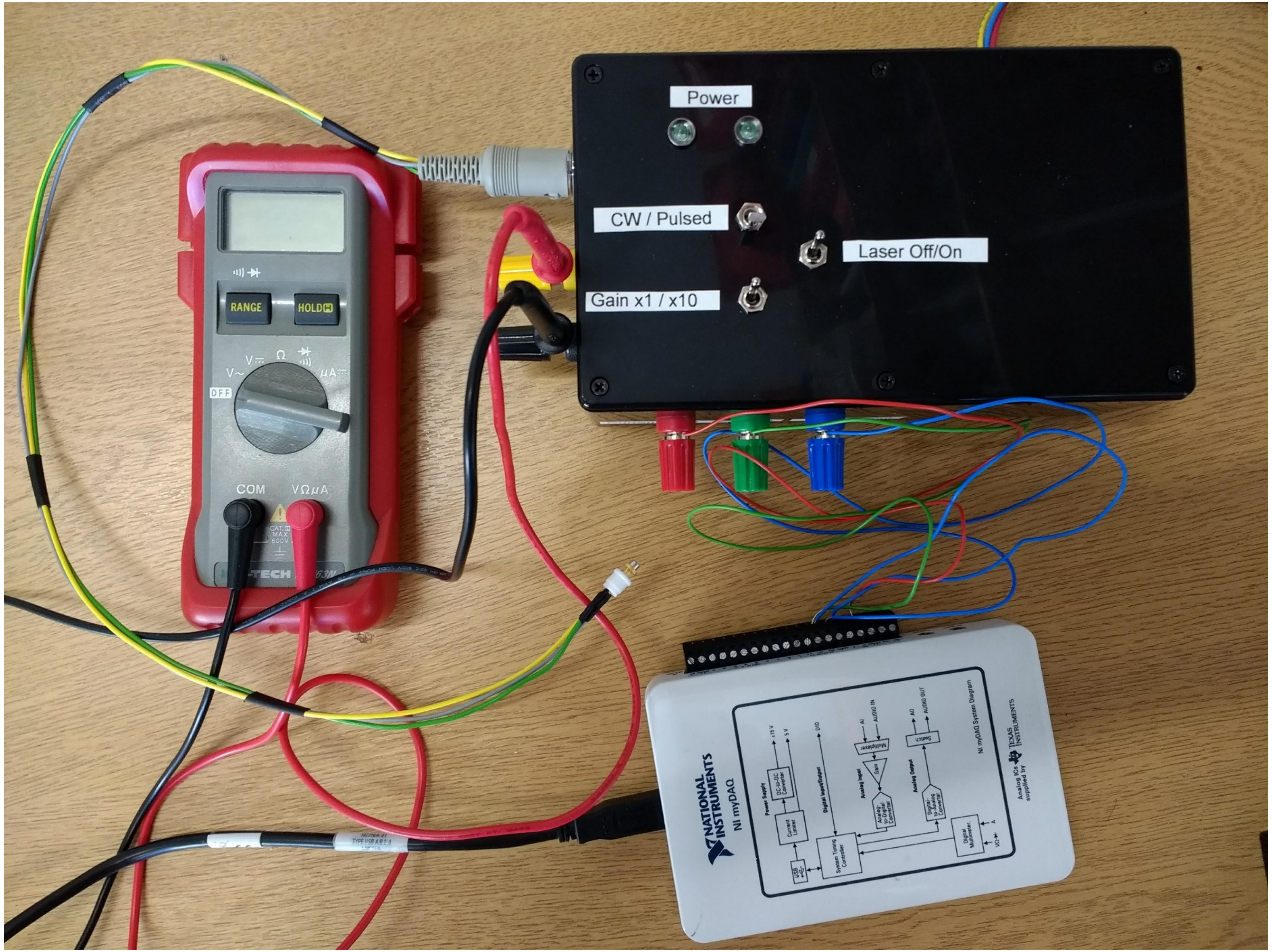
0 0.5 1 1.5 2 2.5
Time


Power
CW / Pulsed
Laser Off/On
Gain x1 / x10
RANGE
HOLD
COM
VΩμA
NATIONAL INSTRUMENTS
NI myDAQ

Laser/ LED interface box

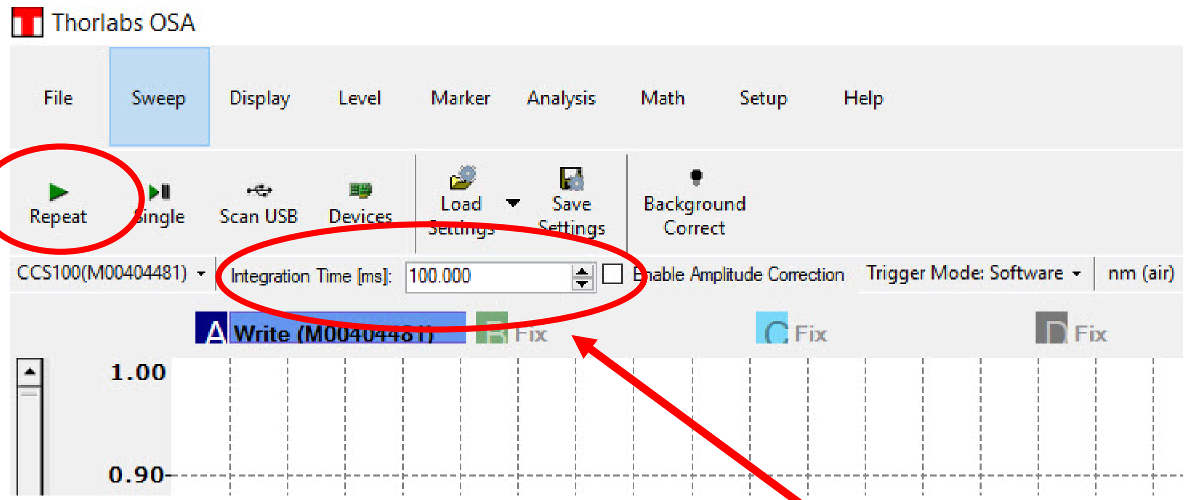
The interface box has a number of connections.

- The three wires (red, blue and green/yellow are the +12V, -12V and 0V power connections)
- The yellow and black terminal allow the current through the LED/laser to be determined. A digital multi meter should be connected to these.
- The red terminal is connected to an analogue output from the myDAQ – the voltage applied to this terminal determines the current applied to the LED or laser.
- The blue terminal gives a voltage proportional to the photodiode current and hence light detected. It should be connected to one of the myDAQ analogue inputs (the + side).
- The green terminal is ground. It should be connected to AGND of the myDAQ and also the – side of the analogue input.

The three switches are

- CW/pulsed – determines if current is applied continuously (DC) or pulsed. Generally use CW for the LED and pulsed for the laser.
- Laser off/on – must be set to off when applying power to the interface box and when switching off the power. Switch to on when taking measurements.
- Gain x1 / x10 – photodiode voltage gain. Use x10 for the LED and either x1 or x10 for the laser.

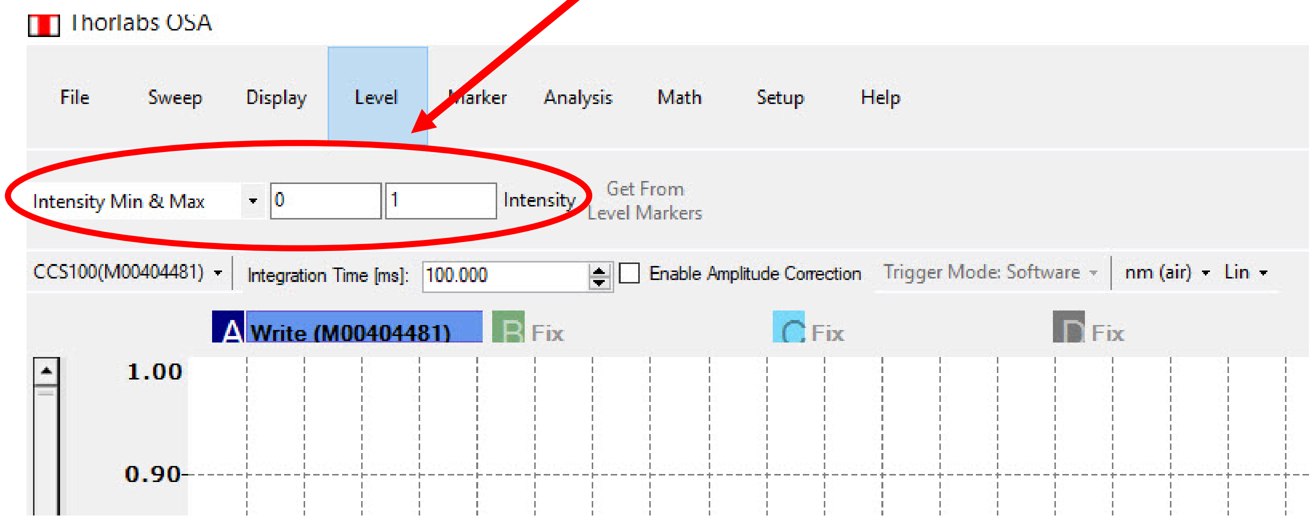
Appendix E – Spectrometer Software



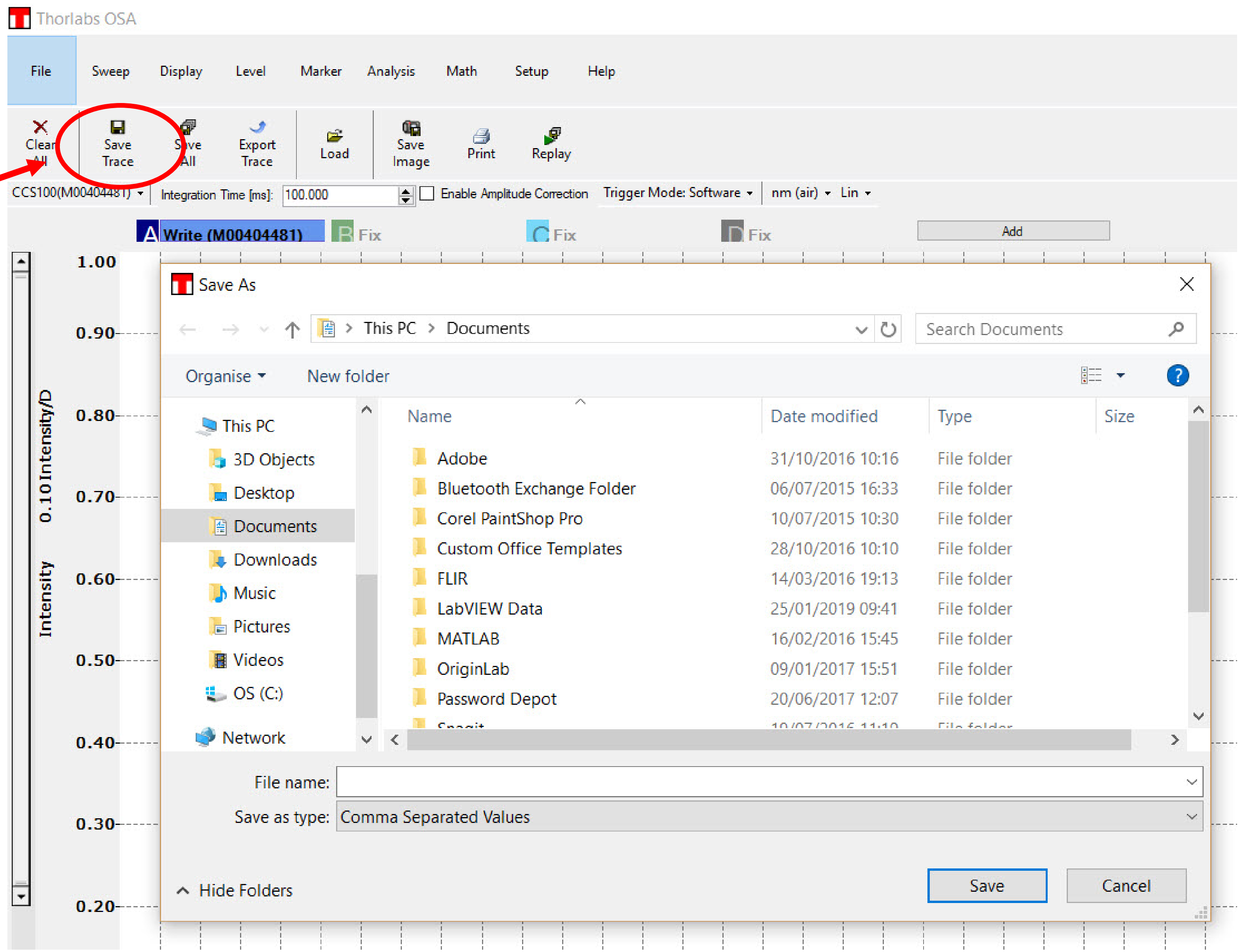
Start acquiring spectra

Integration time in ms

Set maximum and minimum intensity values to 0 and 1

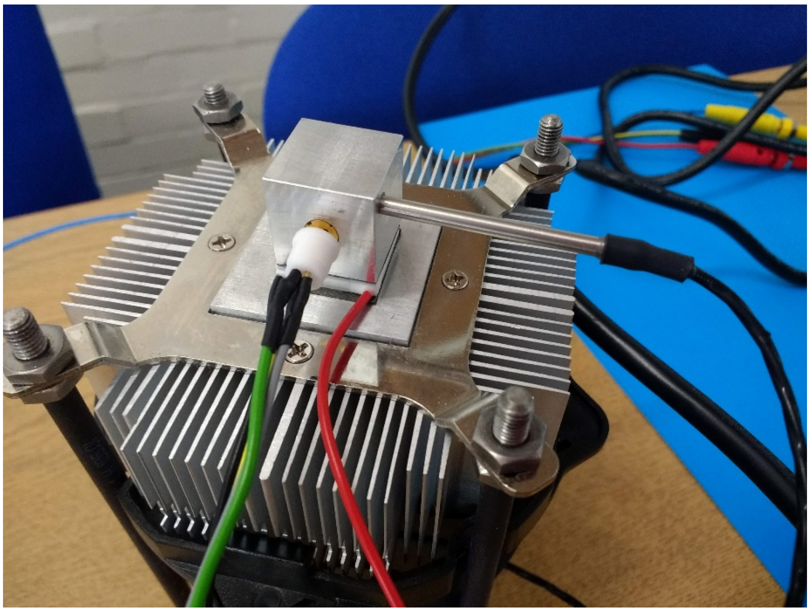


Click to save spectrum in a data file

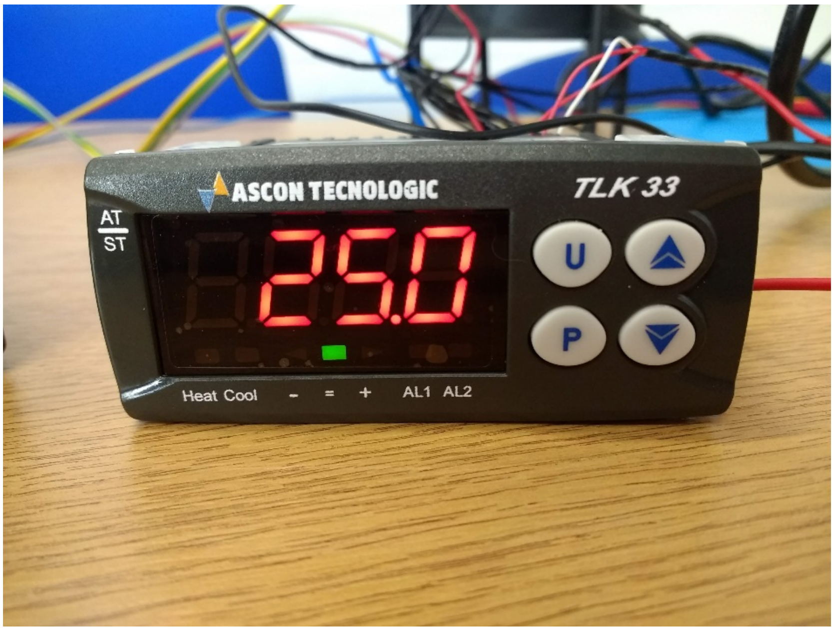


Temperature Controller

Ensure that both the laser and temperature probe are inserted into the aluminium block



Switch on the power and the display on the controller should illuminate.



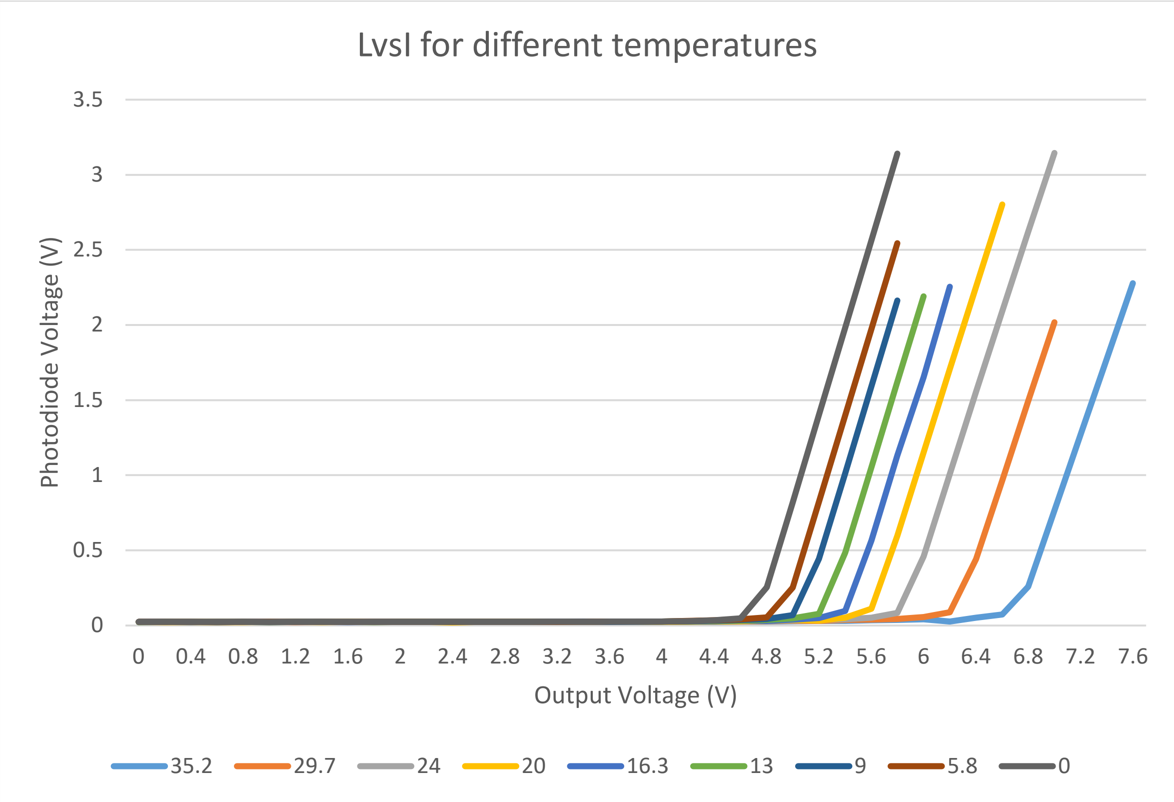
You may need to press Button P to show the current temperature.

To set a temperature press Button P and then use the two Arrow buttons to enter the required temperature. Then press Button P to confirm. The controller will apply either heating or cooling to change the temperature of the aluminium block towards the set temperature (either the Heat or Cool lights will flash). The ‘ –‘ or ‘+’ lights will illuminate depending on if the current temperature is blow or above the set temperature. When the current temperature is close to the set temperature the green light above ‘=’ will light.

The current temperature may take a long time to move through the last 1 °C as it approaches the set temperature. You can make measurements when the temperature is still varying as long as it doesn't change significantly (< 0.2°C) during the measurements.

The laser diode should not be operated above 50 °C but temperatures above 40 °C may damage the bonding material used to mount the aluminium block. Hence the maximum temperature used should not be above 35 °C. Although the laser can be operated down to -10 °C to prevent ice build-up you should not cool the laser below 0 °C.

Important note – the resistor connected to the temperature controller can get hot so do not touch this.



HL6358MG/59MG

Low Operating Current Visible Laser Diode

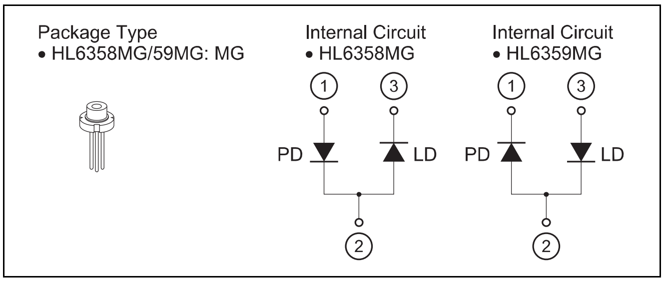
ODE2024-01 (M)
Rev.1
Dec. 09, 2008

Description

The HL6358MG/59MG are 0.63 µm band AlGaInP laser diodes with a multi-quantum well (MQW) structure. They are suitable as light sources for laser levelers, laser scanners and optical equipment for measurement.

Features

- Visible light output: 639 nm Typ
- Single longitudinal mode
- Optical output power: 10 mW CW
- Low operating current: 40 mA Typ
- Low operating voltage: 2.5 V Max
- Operating temperature: +50°C
- TE mode oscillation



Absolute Maximum Ratings

(T_C = 25°C)

Item	Symbol	Ratings	Unit
Optical output power	P_O	12	mW
LD reverse voltage	$V_{R(LD)}$	2	V
PD reverse voltage	$V_{R(PD)}$	30	V
Operating temperature	Topr	–10 to +50	°C
Storage temperature	Tstg	–40 to +85	°C

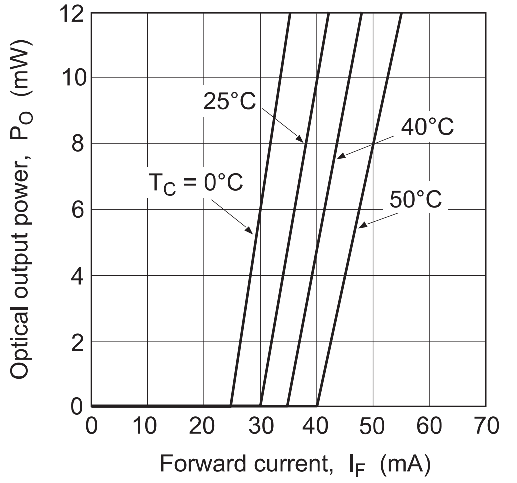
Optical and Electrical Characteristics

(T_C = 25°C)

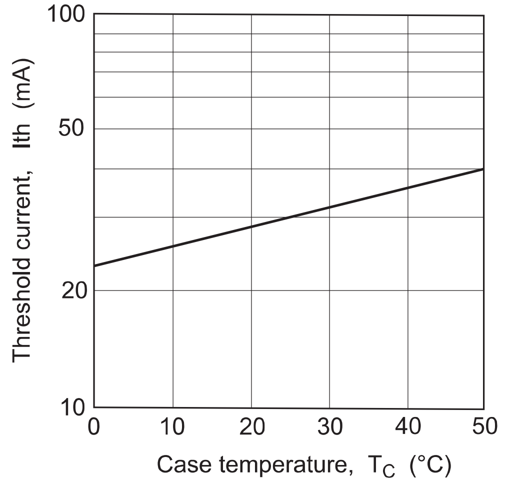
Item	Symbol	Min	Typ	Max	Unit	Test Conditions
Threshold current	Ith	—	30	35	mA	—
Operating current	I_{OP}	—	40	50	mA	P_O = 10 mW
Operating voltage	V_{OP}	—	2.3	2.5	V	P_O = 10 mW
Beam divergence parallel to the junction	θ//	6	8	11	°	P_O = 10 mW
Beam divergence perpendicular to the junction	θ⊥	16	21	24	°	P_O = 10 mW
Lasing wavelength	λp	630	639	643	nm	P_O = 10 mW
Monitor current	I_S	0.5	1.0	2.0	mA	P_O = 10 mW, $V_{R(PD)}$ = 5 V

Typical Characteristic Curves

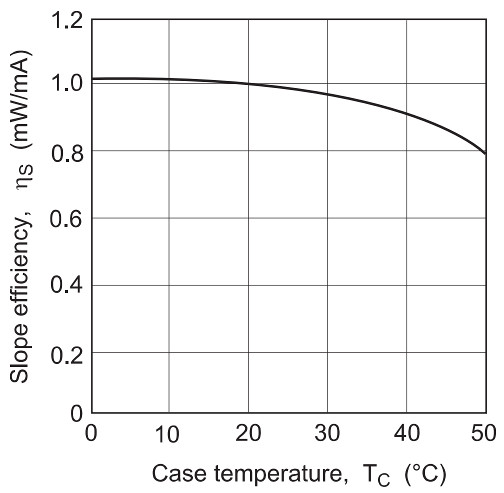
Optical Output Power vs. Forward Current



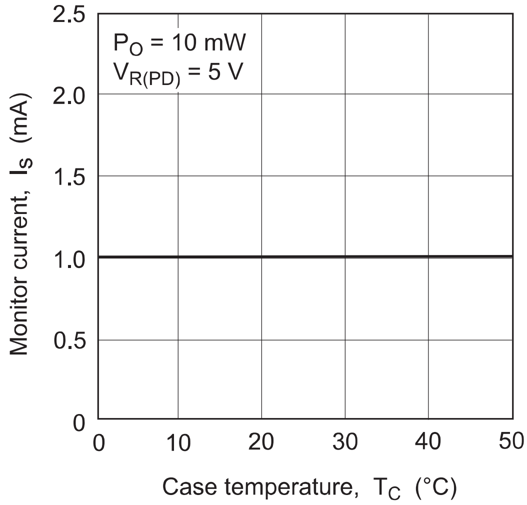
Threshold Current vs. Case Temperature



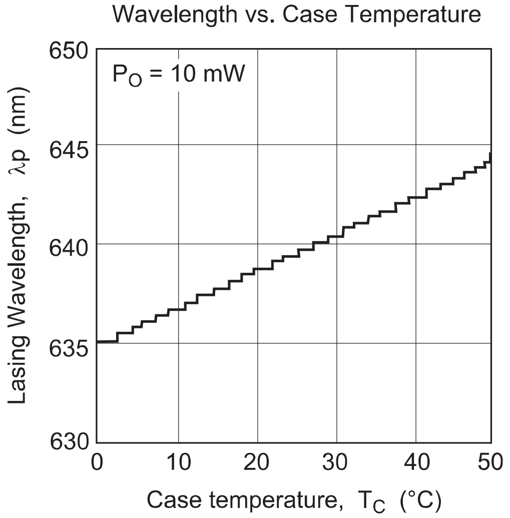
Slope Efficiency vs. Case Temperature



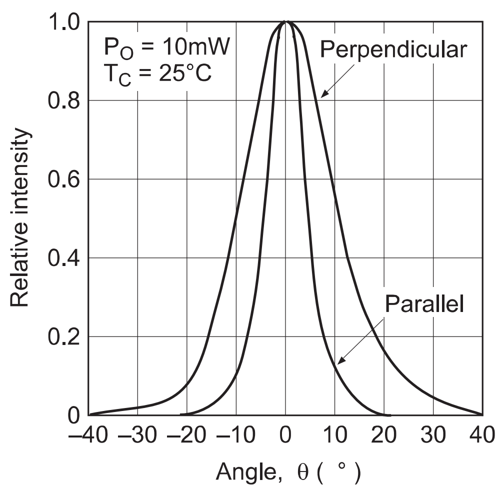
Monitor Current vs. Case Temperature



Wavelength vs. Case Temperature

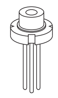


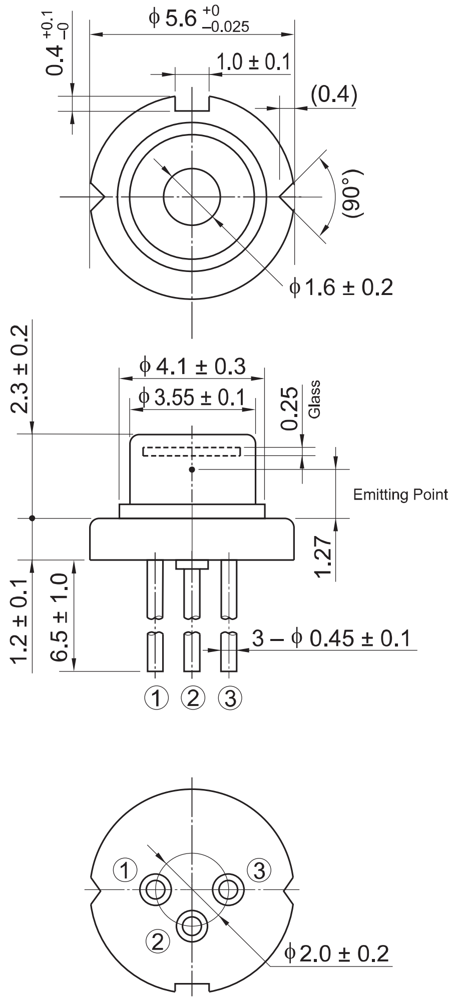
Far Feild Pattern



Package Dimensions

Unit: mm





OPJ Code	LD/MG
JEDEC	—
JEITA	—
Mass (reference value)	0.3 g

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Cautions

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Opnext Japan, Inc.
Takagi Bldg., 3F, 1-3-9, Iwamoto-cho, Chiyoda-ku, Tokyo 101-0032, Japan
Tel: (03) 3865-5591

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Colophon 5.0