

The Laser Diode

1 Introduction

This set of laboratory experiments is primarily design to have you become familiar with the properties of laser diodes and to become familiar with optical spectrum analyzers typically used in fiber and laser instrumentation to asses spectral characteristics of sources. In addition you will become familiar with the now common technique of using an optical grating to stabilize and to tune the frequency of a laser diode.

The discussion and figures in this section are for the Sharp 780 nm, LT025MDO diode laser. The Sharp laser is infrared and so for this laboratory you will be working with a 635 nm visible laser from Hitachi, though for historical reasons we retain the Sharp diode for the context of this discussion. The general concepts are relevant to both diodes.

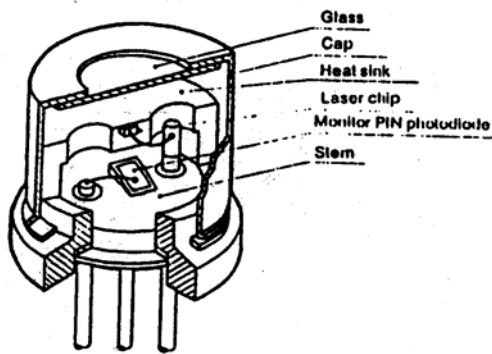


Figure 1. Internal structure of the Sharp LT025MDO diode la

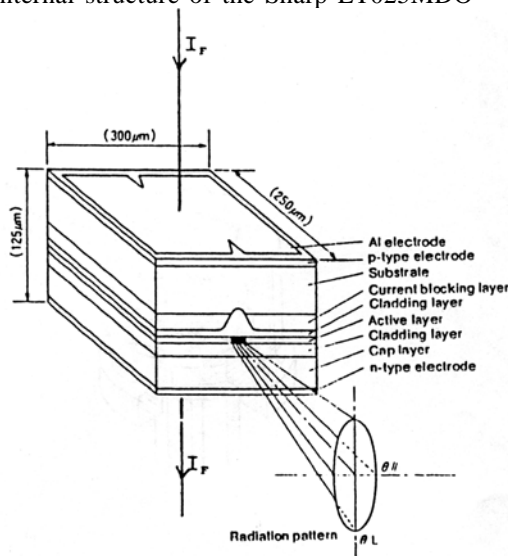


Figure 2. Chip structure of the Sharp LT025MDO diode laser.

Figure 1 shows the diode laser with a cut-away of the housing where the chip mounts. Figure 2 shows the laser chip structure, typical chip dimensions, the direction of the forward current, and the radiation pattern. The radiation is produced in the active layer, which is a small fraction of the height of the chip, hence the radiation is diffracted when it emerges from the active region analogously to the diffraction of radiation passing through a narrow slit. The diffraction produces the radiation pattern shown in Figure 2. Figure 3 shows the optical power output versus forward current and monitor current. The maximum operating forward current and power output are specified by the manufacturer for each diode laser. Figure 4 shows the wavelength versus case temperature. Figure 5 shows how the power output depends on the wavelength, where the spectral width of the laser line at 30 mW is about 20 MHz. The Hitachi diode that you will be using is much lower power, about 5 mW.

The mirrors for a diode laser chip are the cleaved facets of the semiconductor, which are smoother and flatter than any mechanically polished mirror. If there are no coatings on the end surfaces of the laser chip, then the reflectivity R of a surface is given by:

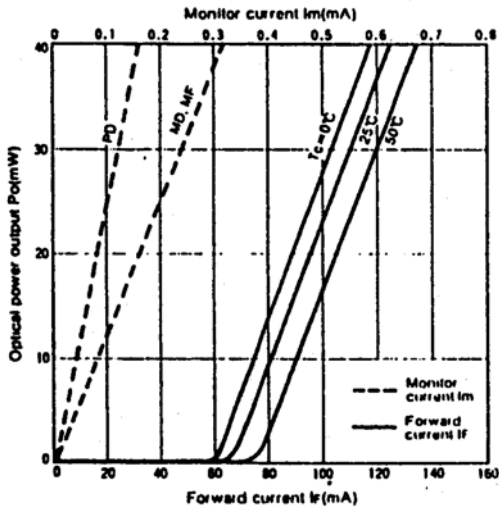


Figure 3. Optical power output versus forward current (for three laser temperatures) and monitor current.

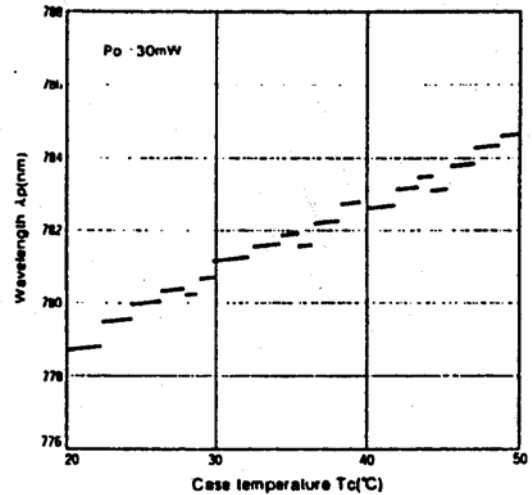


Figure 4. Emitted wavelength versus case temperature. Note the discontinuities.

$$R = \frac{\int_{\lambda} n_c - n_a}{\int_{\lambda} n_c + n_a} \hat{\sim}^2, \tag{1}$$

where n_c and n_a , are the indices of refraction of the chip and air, respectively.

The LT025MD0 diode laser has a reduced reflective coating on the output facet of the chip; therefore, the reflectivity of this facet is less than that calculated in Exercise 1. The grating reflectivity is about 40%, hence it dominates the front facet of the chip in forming the laser cavity. Therefore, the length of the cavity is the distance from the grating to the far chip facet. The purpose of this configuration is to change the laser wavelength by displacing the grating.

2 Experiment

2.1 PREPARATION

You will be using a Hitachi laser diode from ThorLabs No. HL6316G. Begin by looking over the specifications sheet for the diode. In particular you will want to notice the operating current. You would normally also note the maximum allowed operating current, but this specification sheet does not provide it. Instead note the "Typical Characteristics Curves where they show up to about 50 mA.

When you are ready to begin turning on equipment first find the Melles Griot Inc. diode laser driver. When you first turn on the key in enters a safe mode. The "display" indicator shows limit. Check to see that the "mode" indicator is on "cur" for "current". If not, press it once and the mode should change from "PWR" or "power" to "Cur. The "output" indicator should read, "preset.

Underneath the "Level" dial is a hoe labeled "limit". There is a small trimmer potentiometer that can be adjusted with a jeweler's screwdriver. You must set this trimmer for the maximum output current. The digital LED indicator will indicate the limit level in milliamps. Set it to be between 40 and 45 mA.

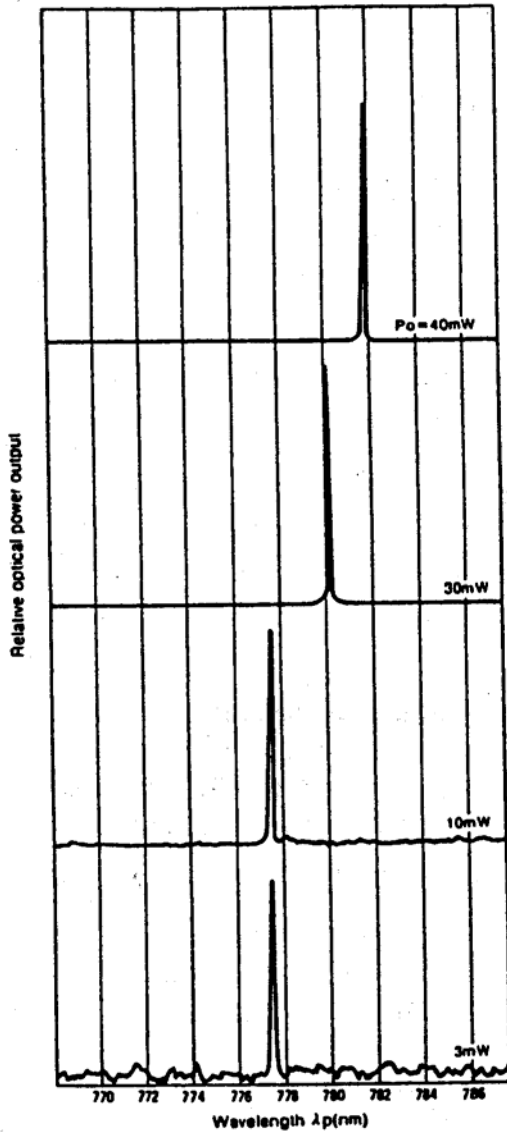


Figure 5. Power output dependence of wavelength.

Make sure that the photodiode is powered with a Lemo cable from the small bass-colored power supply on the optical bench.

Connect a BNC cable from the photodiode output to the oscilloscope. Place the photodetector in front of the laser beam, not the signal on the oscilloscope and optimize the oscilloscope settings. (The presence of light sends the oscilloscope trace downwards).

2.3 THE TEMPERATURE CONTROLLER.

The laser diode housing has two thermistors -one for the temperature controller and one to provide a direct measurement of the diode's temperature. The monitor thermister is model YSI44008. You will find two sheets in the lab indicating the thermister's resistance as a function of temperature. You can

When the mode switch is set to current, the diode laser driver will control the current to the diode so that it remains at a fixed level determined by the "level" knob. When the mode switch is set to power, the driver controls the laser diode to provide fixed output power. For the entire experiment leave the mode switch set to current.

Turn the "level" knob all the way counter-clockwise. Now set the display indicator to "laser". As the level knob is increased in the clockwise direction the current indicator will increase. At this time no current is actually going to the laser, it only indicates the current that will be supplied when the output is changed to "laser". The laser will be turned on after a few other items are attended to.

Turn on the "Lambda" power supply. It provides power to the laser diode temperature controller. Do not change the knobs. The left hand voltage setting should be 3.5-4 V, with the current knob all the way up (clockwise). The right hand power supply should be at 15 volts with the current again full on. While you are at it, turn on the oscilloscope and Ando spectrum analyzer.

2.2 LASER DIODE

Now preset the laser diode current to about 15 mA and push the output button so that it is switched from "preset" to "laser". Turn up the level knob so that the current goes up to about 30 mA. Notice the output from the laser (*DO NOT LOOK DIRECTLY INTO THE LASER BEAM!*) The laser should have a collimating lens in front of it, and nothing else. If there is other optics in the way, such as grating, move it so that you can see the laser output on the wall of the room.

Using the brass-colored photodetector module you will measure the power output as a function of current and temperature.

read out the resistance using a digital multimeter (dmm). You can interpolate from the resistance table to find the temperature for a given measured resistance. Notice that the temperature coefficient is negative, that is, the higher the temperature the lower the resistance.

The temperature of the laser diode is controlled by a small trimmer potentiometer on the corner of the circuit board sitting on a small post on the optical table. Leave the other trimpot set as it is.

The temperature of the laser diode is lowered, as the adjustment trimpot is turned clockwise. Try turning the adjustment trimpot a bit and then observe the dmm on the monitor thermister. Note the time it takes for the temperature controller to settle to the new value.

Set the laser diode temperature to about 25 degrees C. Make a measurement of the detected output power (proportional to the voltage on the oscilloscope) as a function of laser diode current. Start considerably below threshold. Then increase current in steps of 3-5 mA to the maximum current. Then go back and fill in more data points near the threshold value of current. Make sure you keep track of the oscilloscope voltage setting as you take measurements.

Now retake the power versus current curve at two more temperatures. One at nearly the coldest temperature that the controller can manage (it is possible to set the control trimpot to a lower temperature than the controller can attain. Then take a curve at about 40 degrees C.

Finally, set the current to about 20-25% above the threshold value for 25 degrees C and take a power versus temperature curve. Do not exceed about 45 degrees C. (The specification sheet says 50, but you must account for the fact that the thermister does not really measure the diode temperature but the temperature of the diode mount.

2.4 THE OPTICAL SPECTRUM ANALYZER.

In this next portion of the lab you will be taking the wavelength spectrum of the diode. The optical spectrum analyzer is at first intimidating but in the end rather user friendly. Familiarize yourself with the controls with the help of the manual.

To obtain a spectrum you must inject the laser diode light into a fiber. One end of the fiber is already mounted in an optical claw. Take the short (15mm) focal length lens and place it after the collimating lens of the laser diode. Use a post-it note to determine the position of the focal point. Then place the fiber at this position. The easiest way to align the fiber more precisely is to look directly at the output of the other end of the fiber. (Yes it is safe at these power levels.) When the fiber is correctly positioned the light through the fiber is quite bright, and you can easily use the fiber to illuminate a nearby object.

When the fiber is aligned, screw the output end into the spectrum analyzer. Note that the fiber is keyed, and correctly fits into the receptacle in only one orientation. The threaded collar is annoyingly difficult to screw into the spectrum analyzer but it can be done.

Set the spectrum analyzer center wavelength to 635 nm and the span to 20 nm. Set the wavelength to the maximum of 0.1 nm. Set the laser current above threshold. Set the vertical scale to be logarithmic. You should easily observe a peak in the spectrum with no substantial noise for +/- 5 nm or so around the peak. At this point center the peak and change the span to 10 nm.

Now observe the spectrum for a few values of current both above and below the threshold. Record any interesting features and phenomena in the spectrum as a function of power. Note in

particular the sinusoid-like pattern in the "pedestal" near the peak. Measure the spacing (in nm) between successive peaks. What do you conclude about the length of this laser diode?

Now measure the position of the peak as a function of temperature for a current about 20-30% above threshold. Also at 25 degrees C measure the wavelength of the central peak as a function of current. Record your findings.

2.5 EXTERNAL CAVITY LASER DIODE

For this portion of the experiment you will employ an optical grating of 1200 lines per mm. The grating is placed on a mount having a piezo transducer, which can be used to tilt the grating by minute amounts. Place the grating as close as possible to the collimating lens mount. Tilt the grating so that the first order diffracted beam is reflected back into the diode. The zeroth order is available for measurement.

It is a bit tricky to ensure that the 1st order is indeed retro-reflected back into the laser. Follow this procedure:

Place the photodetector on the zeroth order beam. A.C. couple the oscilloscope input and turn up the gain almost all the way. Center the trace on the screen. As you move the vertical and horizontal adjustment screws on the grating mount observe the scope trace. Tap lightly on the mount. When the beam is properly retro-reflected the output power will appear to be very sensitive to your tapping. Maximize the tapping noise observed on the scope with the two grating adjustment knobs. At this point the grating is adequately adjusted.

Now align the fiber again to obtain a spectrum of the laser diode. Adjust the temperature to 25 degrees and the current to about 15% above threshold.

Hook up the piezo to the power supply sitting beneath the scope. Turn the voltage knob fully counter-clockwise and turn on the power supply. Notice on the right-hand side of the supply is an "output" switch. Turn it on, too. Note that the actual output to the piezo is twice the meter reading. This is because this is a "dual" supply and the two voltages track and are added together. Thus when the meter reads 30 V the actual output voltage to the piezo is 60 V. The maximum allowed piezo voltage is 100V.

Now turn up the piezo voltage to 60 V (30 on the meter). Note the peak on the spectrum analyzer. Does it shift? If so, by how much? You may want to decrease the wavelength span. Be careful, sometimes the laser mode-hops between two modes. If you see the spectrum change, pin down whether or not a mode hop is responsible for the change.

We will now proceed to calibrate the piezo wavelength control using the same technique as the Laser Spectroscopy lab (except there the system is a fancy commercial one).

2.6 UNBALANCED MICHELSON INTERFEROMETER

Remove the fiber from the beam path. Construct an unbalanced-path Michelson interferometer. Use Figure 6 as a guide –though your optical arrangement may look rather different in detail. Your instructor originally told you to use a path length difference to make $c/2(L_2-L_1)$ about 0.5 GHz. However, with this piezo that value is too small. Start with a path length difference as large as you can --place an extra mirror in the longer arm if you wish to fold it to make it still larger. Record the distances from the beamsplitter to the respective end mirrors for later use.

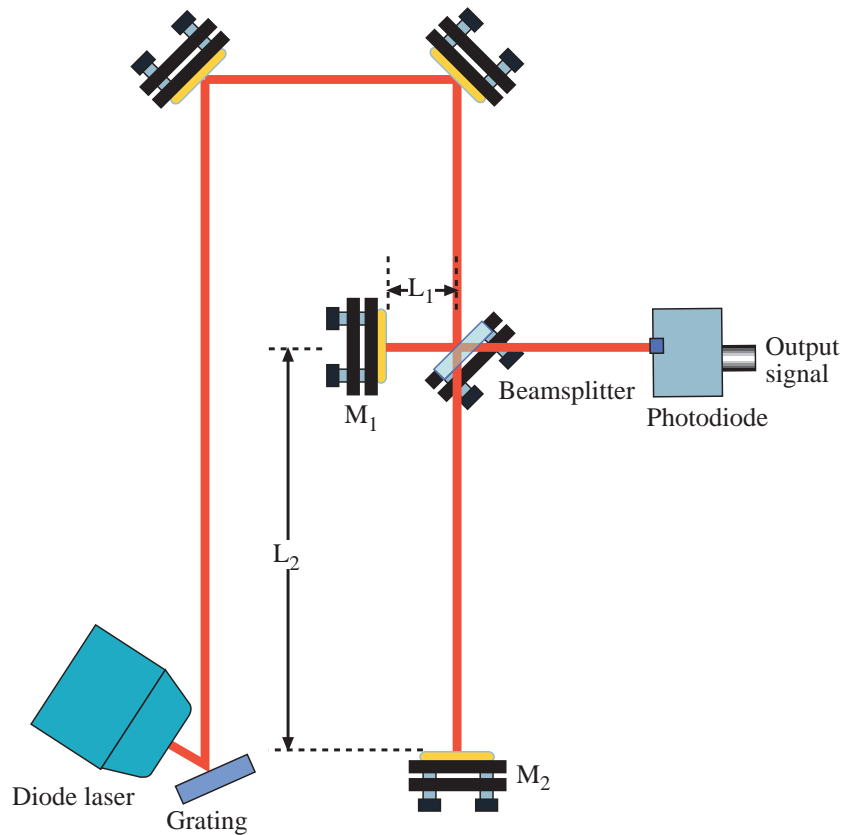


Figure 6. Unbalanced Michelson interferometer for calibrating the piezo controlled grating tilt.

Hook up the piezo to the Wavetek signal generator rather than the power supply. Send the output of the signal generator to the oscilloscope channel 2 as well. Connect the "synch out" output of the generator to the external trigger input of the scope. Set the sweep to triangular. Set the scope to external trigger. Put the output at about of the generator to about halfway. Observe the triangle wave on the oscilloscope.

Adjust the output amplitude and the dc offset of the signal generator so that the triangle output does not go negative, and so that the upper portion of the waveform does not distort. Set the signal generator frequency to somewhere between 500-1000 Hz. You should easily hear piezo "sing". No sound is indicative of a wiring problem.

Now set the signal generator frequency to between 40 and 100 Hz. Place the photodetector at the output of the Michelson interferometer and set the oscilloscope to view the photodetector and triangle waveforms simultaneously. You should see a sinusoid output from the detector that is synchronized with the triangle wave. If the laser is oscillating in more than one mode then the photodetector may show a beat envelop on the sinusoid. Try changing the laser current a bit if you run into this. If you can't get rid of it, then tolerate it. Your goal is simply to measure the change in piezo voltage that causes one full fringe at the photodetector. One full fringe corresponds to $c/2(L_2-L_1)$ change in frequency.

Observe the geometry used to tilt the grating with the small green piezo attached to the optical mount. Using your above measurement, the grating specs of 1200 lines per mm, and the fact that it is used in littrow configuration, estimate the displacement of the piezo in microns/volt.

Congratulations! You're done!

3 Pre-lab Questions

1. The index of refraction of GaAs and air are about 3.6 and 1.0. What is the reflectivity of the chip facet? Compare your answer with the reflectivity of the mirrors used in the HeNe laser, which is about 0.99.
2. Assuming the length of the diode laser cavity is $250\ \mu\text{m}$ and the index of refraction of the cavity is 3.6, show that the frequency spacing $\Delta\nu$ of the axial modes is 167 GHz. (You may want to refer to the discussion of longitudinal modes in the mode matching experiment.)
3. What does the axial mode spacing correspond to in wavelength spacing? (Give your answer in nm)
4. You will be working with a grating with 1200 grooves per millimeter. Calculate the Littrow, or blaze, condition for 635 nm. That is, calculate the angle of incidence of the laser beam such that the first order is retro-reflected.
5. The grating above is tilted by 1×10^{-3} rad. What is the change in wavelength, in nm, of the laser diode?
6. You are using an unbalanced Michelson with a path length difference of 1.12 m. You observe that 8.3 V on the piezo that tilts the grating causes one complete fringe to appear on the oscilloscope (that is, for example, the photodetector output changes by one peak to the next). What is the frequency tuning constant in MHz/Volt of the piezo?