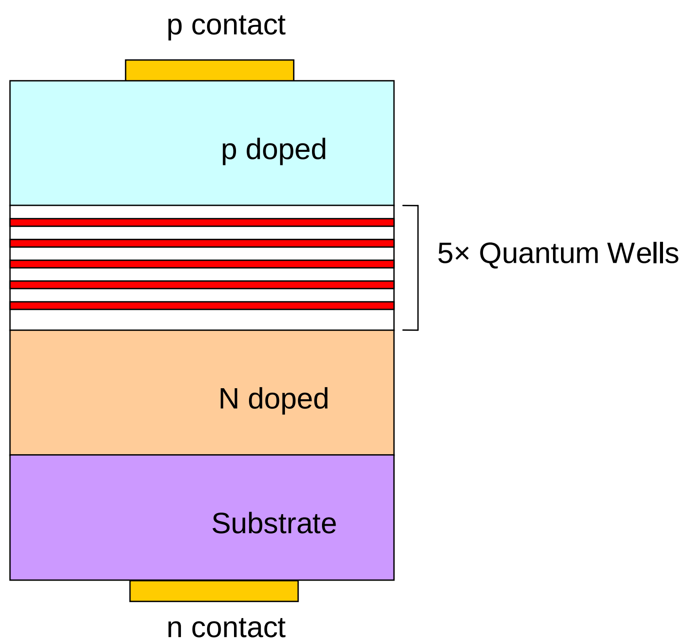
Measurement Lab 0: Resistance Measurements:

The Diode laser is basically a diode junction. Same as all the other semiconductor diode junctions, we should be able to see difference in resistance for different polarities.

Positive polarity: conduction, lower resistance.

Negative polarity: Shut-off, higher resistance.

Basic doping structure:



Measurements:

1. Use a Multimeter to test the resistance of your laser; Record the resistance for both polarities.

(As we go along with the following measurements, we would re-measure the resistance from time to time, which serves as an indicator to see if it is still working or broken.)

Measurement Lab 1: Spectral analysis:

Learning Objectives:

1. Amplified spontaneous emission.
2. Lasing spectra.
3. Line width of the lasing transition as a function of injection current.

In this lab, you would be measuring the spectral components of your laser.

Measurements:

1. Before you use the FTIR, cool down the MCT detector using liquid nitrogen.
2. Open the software OMNIC from desktop and select scan settings from Bench.
3. Choose the wavenumber range from 6000 cm^{-1} to 7000 cm^{-1}.
4. Choose the detector to be MCT and the source to be external.
5. Place your laser in the cryostat cold finger and align it approximately with the red light from the FTIR.
6. Connect the pulser to your laser through a 50 ohm resistance and a current probe.
7. Carefully and steadily increase the voltage on the pulser and keep track of the current.
8. Stop when you reach about 0.4 – 0.5 A at room-temperature and do fine alignment.
9. The settings for your scan would depend on whether you want to observe a lasing transition or an amplified spontaneous emission.
10. For lasing transitions, you need very high resolution but very few scan averages.
11. For amplified spontaneous emission, you can do with coarse resolution but need a large number of scan averages. Choose appropriately. The TAs would help you choose the right parameters.

Measure the laser spectra of 3 lasers with different cavity lengths.

A. Plot the laser spectra for each of the lasers, clearly labeling the axis.
B. For each of the lasers, measure the line width of the spectra as a function of injection current. (From threshold to about 3 x threshold.)
C. Distinguish between amplified spontaneous emission and lasing by plotting the spectra for each of the lasers below and above threshold. Note down the line width in both the cases and comment on the different that you observe.

Measurement Lab 2: Light-Current-Voltage (LIV) measurements

Learning Objectives:

1. LIV characteristics of a laser.
2. Concepts of threshold current, slope efficiency and wall plug efficiency.

Each time you fabricate an laser, first we need to do basically two kinds of characterizations: carrier transoport (IV) and lasing (IL). Usually people do both of these two and plot them in one figure.

What does the LIV plot tell us?

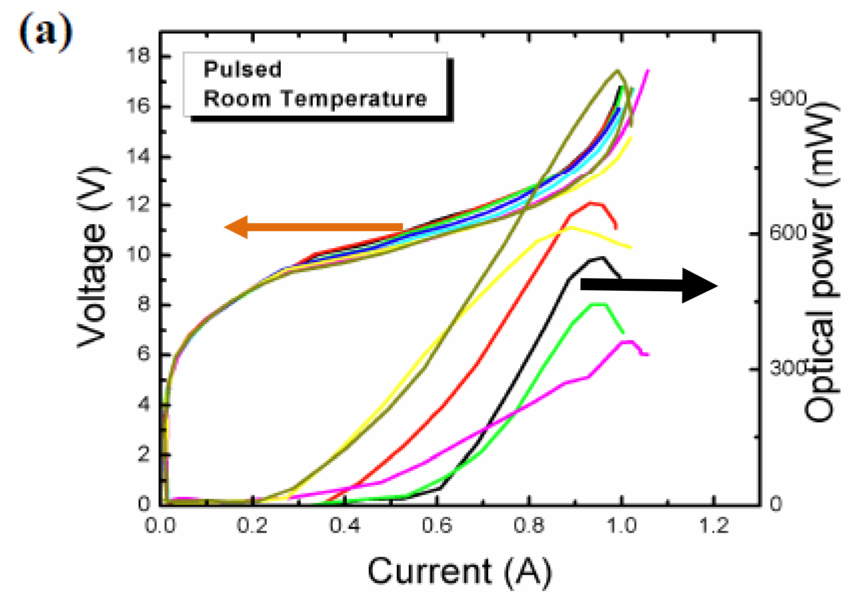
From the IV curves, we usually do it under different temperatures. The IV curve gives information about carrier transport in the structure. A working diode laser should behave like an semiconductor junction in the IV, which means it should have a low turn-on voltage and an exponential increase after that. When the laser gets shorted, it would behave like a simple resistor and will not lase anymore.

When lasing begins, the carriers (electrons and holes) recombine quickly due to stimulated emission. This improves carrier transport, as seen in a marked drop in differential resistance.

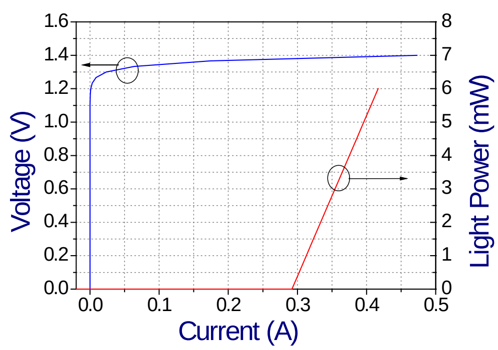
For IL curves, we can measure the threshold of a laser, the slope efficiency, and the saturation behavior. The laser doesn't turn on at low currents, simply because the gain is still lower than the loss; or to say threshold population inversion is not achieved. As current increases, thereby increasing the gain, the material will start lasing and you would be able to see light. This threshold current varies with temperature. Under high temperature, usually the threshold is higher. The slope efficiency is the rate of change of light output as a function of current above threshold. This essentially tells you the quantum efficiency of your laser. At high currents, the light output gets saturated, often limited by the carrier density in the laser. You can see the maximum light output of your laser in the IL curves.

Measurements:

1. Take the laser that you fabricated, put it onto LIV setup, and try to see if it is lasing.
   a. Do a rough alignment or put the detector very close to the laser;
   b. Increase current slowly, for above threshold you should be able to see light signal;
   c. Do a fine alignment: tune the positions of the lenses, detector and the laser, and maximize the light signal.
2. Record one LIV curve under room temperature. Observe the saturation.
3. Plot the LIV curve in one figure; use linear scale.
4. Find the threshold. Plot the IL curve under log-log scale, and identify the kink.
5. Calculate the slope efficiency and current density at threshold.



Sample LIV Plot:



Measurement Lab 3: Temperature Analysis:

Learning objectives:

1. Temperature dependence of threshold current – investigating T0, T1, slope efficiency and power efficiency.
2. Temperature dependence of spectra – investigating wavelength shift, tuning coefficient, line width, modal analysis.

In this lab, you would be performing measurements similar to what you had done in the previous two labs as a function of temperature.

Procedure:

1. The procedure for LIV and spectra measurements are the same as given in the previous two labs.
2. Connect the Lakeshore temperature controller to the cryostat.
3. To set any temperature, click on SET → set desired temperature → Enter.
4. Switch on the heater to medium by clicking Heater Range → Med → Enter. (As a thumb rule, set the temperature to about 3 C lower than what your desired set point is.)
5. Wait until the temperature stabilizes before performing your measurements.

Measurements:

1. Take Light-Current-Voltage measurements (LIV) from 25 C to 65 C in steps of 10 C.

A. Plot the threshold current density as a function of temperature and deduce the characteristic temperature T0.
B. Plot the slope efficiency as a function of temperature and deduce T1.
C. Plot power efficiency (wall plug efficiency) for each of the plots in A at different temperatures.

2. Measure the laser spectra from 25 C to 65 C in steps of 10 C.

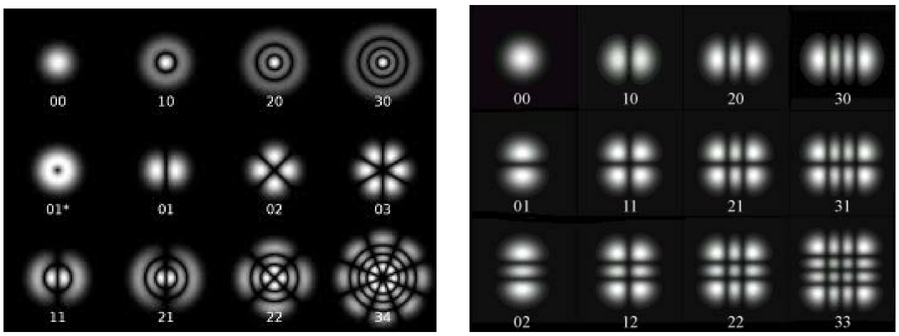
A. Plot the laser wavelength as a function of temperature and deduce the tuning coefficient.
B. At any particular injection current (1.5 x threshold current), plot the laser line width as a function of temperature.

Measurement Lab 4: Far-field and polarization dependent measurements:

<u>Learning Objectives:</u>

1. To map the far field pattern of the laser and to characterize the spatial modes of the laser.

The laser may have different far field patterns, due to possible different modes:



Depending on the geometry of the cavity - The left figure corresponds to circular cavities, and the right ones correspond to the square cavities.

Our task is to measure the cavity modes.

2. To see polarization dependent intensity variations in the output light.

Polarization of the output laser light depends on the detailed physics of interband transitions in quantum wells. In general, diode lasers can emit both TE and TM polarized, with different relative intensities. Your job is to measure the output intensity as a function of polarization angle at a constant injection current.

<u>Measurements:</u>

1. Far field pattern: Use a translation stage, move the detector and scan over the facet area of the laser. Your data points should be dense enough to resolve the modes; and you should cover enough area so that you can see the modes. Record the intensity and plot it as function of position.
2. Polarization measurements:
   a. Measure the spectrum of the laser at different polarization angles. (Start from 0 and go in steps of 5 degrees upto 90 degrees)

Measurement Lab 5: Loss measurements:

Learning Objectives:

1. To estimate waveguide loss by measuring threshold current as a function of cavity length.

After the laser is fabricated, we need to extract information about the losses in the cavity. Light can get attenuated when it is traveling in the waveguide. Some of the mechanisms responsible for this include absorption by free carriers and scattering by sidewall roughness. And of course it can get lost on the mirrors. So:

$$\alpha_{tot} = \alpha_w + \alpha_m$$

Where α_w stands for the waveguide loss and α_m stands for the mirror loss.

The mirror loss, equals to:

$$\alpha_m = \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

Where L is the cavity length, and R_1 and R_2 are the reflectivity of the two facets (mirror). And the waveguide loss can be assumed to be constant at a fixed temperature.

So how do we measure the loss?

As we know, when lasing happens, the gain is equal to the loss. For above threshold operation, the gain is clamped at the loss. For below threshold, we can assume that the pumping current is proportional to the gain. Thus we have:

$$J_{th} = A \cdot g_{th}$$

And:

$$\begin{aligned} g_{th} &= \alpha_w + \alpha_m \\ &= \alpha_w + \frac{1}{2L} \ln \frac{1}{R_1 R_2} \end{aligned}$$

So:

$$J_{th} = A \cdot \alpha_w + A \cdot \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

As we can see, if we have several lasers with exactly same every parameters but different cavity lengths, then we can have a relation of:

$$J_{th} = A \cdot \alpha_w + \left(A \cdot \frac{1}{2} \ln \frac{1}{R_1 R_2} \right) \frac{1}{L}$$

If we measure the different threshold currents, and plot it as function of 1/L, and linearly fit it, we would be able to extract two parameters, which is the slope and the intersect on y-axis:

$$k = A\frac{1}{2}\ln\frac{1}{R_1R_2}$$

$$d = A\alpha_w$$

Where k stands for the slope, and d stands for the intersect. So,

$$\alpha_w = \frac{d}{2k}\ln\frac{1}{R_1R_2}$$

The reflectivity R can be calculated, assuming a perfect facet, by:

$$R = \frac{n-1}{n+1}$$

Where n is the refraction index of the material that you are using. If both facets are the same, then:

$$\alpha_w = \frac{d}{k}\ln\frac{1}{R}$$

<u>Measurements:</u>

1. Do 1/L measurements, measure the threshold current of at least three lasers with different cavity length at room temperature.
2. Plot threshold as a function of 1/L, do linear fit and find out the waveguide losses.
3. Change to different temperature and re-do the measurement again. Does the waveguide loss depend on temperature?