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|---------------|----------------|--------|-------|----------------|-----|
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|---------------|----------------|--------|-------|----------------|-----|

Feedback to the student

☐ See also comments in the text

|  |   | Very good | Good | Needs improvmt |
|--|---|-----------|------|----------------|
| C<br>O<br>N<br>T<br>E<br>N<br>T                          | <b>Completeness, quantity of content:</b><br>Has the report covered all aspects of the lab? Has the analysis been carried out thoroughly?                                   |           |      |                |
|  | <b>Correctness, quality of content</b><br>Is the data correct? Is the analysis of the data correct? Are the conclusions correct?  |           |      |                |
|  | <b>Depth of understanding, quality of discussion</b><br>Does the report show a good technical understanding? Have all the relevant conclusions been drawn?                  |           |      |                |
|  | Comments:   |           |      |                |
| P<br>R<br>E<br>S<br>E<br>N<br>T<br>A<br>T<br>I<br>O<br>N | <b>Attention to detail, typesetting and typographical errors</b><br>Is the report free of typographical errors? Are the figures/tables/references presented professionally? |           |      |                |
|  | Comments:   |           |      |                |

|                      |     |
|----------------------|-----|
| Raw report mark      | / 5 |
| Penalty for lateness |     |

*The weighting of comments is not intended to be equal, and the relative importance of criteria may vary between modules. A good report should attract 4 marks.*

*1 mark / week or part week.*

*Please use allowance forms to inform the teaching office about mitigating circumstances.*

Marker:

Date:

# 1 Introduction

This lab activity investigates laser characteristics, including light-current characteristics and output spectrum. The goal is to understand the behavior of lasers under different conditions and analyze their performance based on the measured data.

## 2 Part I: Measurement of Light-Current Characteristics

The apparatus used for this measurement includes a laser diode, a driver circuit, a photodiode for measuring output power, and a transimpedance amplifier to quantify output power by voltage output. The raw data collected from the experiment will be analyzed to determine some key parameters of the laser, and the circuits used in the experiment. The raw data will be available in appendix.

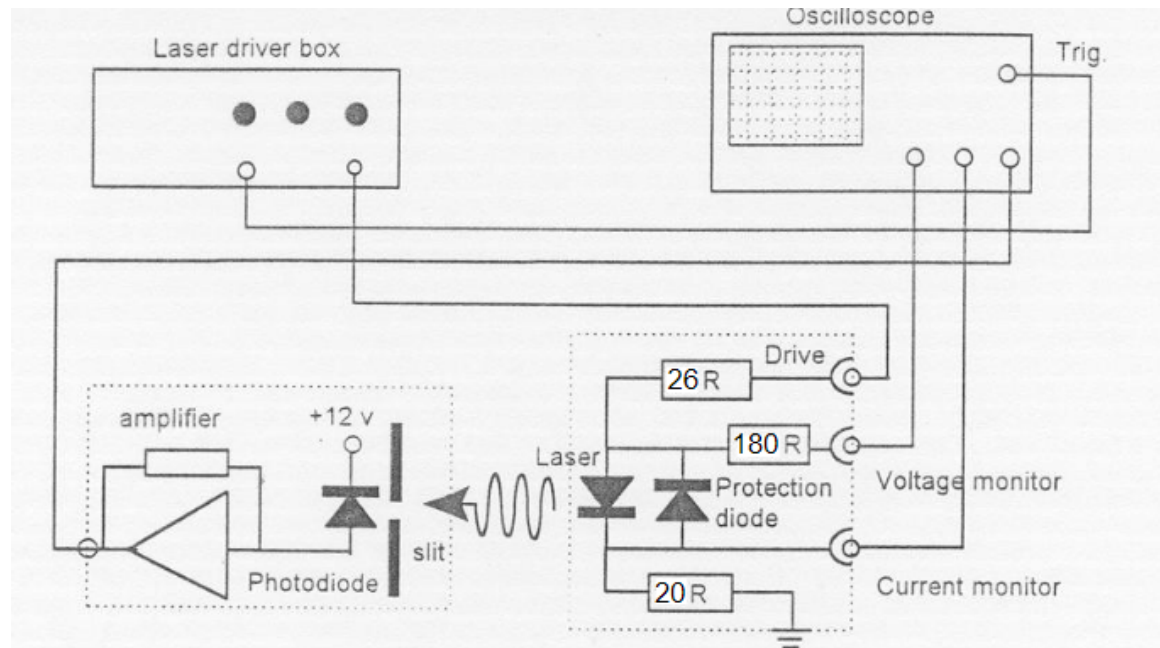


Figure 1: Circuit Diagram

### 2.1 Laser Theory

According to laser theory, photon emission becomes stimulated when the gain exceeds the losses in the laser cavity. This could be observed in the light-current (L-I) characteristics of a laser, where the output power increases significantly once the threshold current is reached. The expectation of the L-I curve is that it will show a linear increase in output power after the threshold current, with a steep slope indicating efficient lasing action.

As given in the lab handout, this threshold current is between 40 and 55 mA, while the actual threshold current observed from the raw data is around 75 mA. This could be reasonable, because the

operation of laser diode is very temperature sensitive. The threshold current can increase significantly with temperature.

## 2.2 Data Analysis

As shown in Figure 2, the plot of the raw data of L-I curve shows a clear threshold behavior. Below the threshold current, the light output is negligible. This is because the gain is not sufficient to overcome the losses in the cavity. the laser is not lasing, and only spontaneous emission occurs. Above the threshold current, the output power increases rapidly, indicating that the laser is lasing and the gain exceeds the losses. The large slope of the L-I curve above the threshold can provide insights into the efficiency of the laser, with a steeper slope indicating higher efficiency in converting electrons to photons.

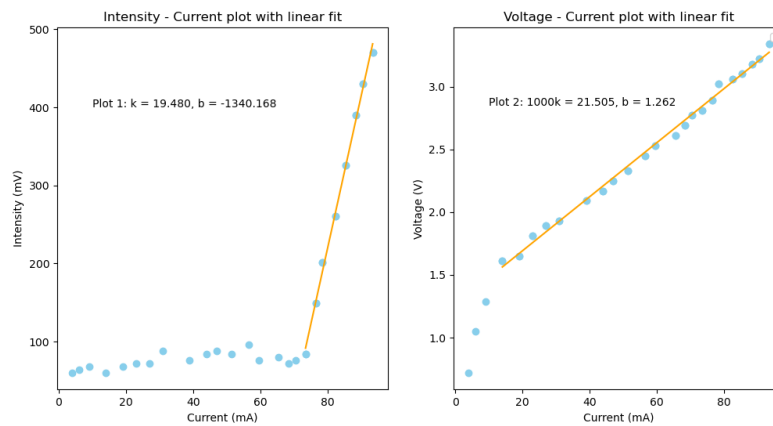


Figure 2: Plot and linear fit of raw data

While the other plot shows relation of voltage across the laser diode and the current through the laser diode. The V-I relation can be derived from the equivalent circuit of the laser diode, as shown in Figure 3.

There is a non-negligible stray series resistance in the laser diode, which contributes to the increase in voltage across the laser diode as the current increases.

The relation could be expressed as:

$$V = V_{th} + I \cdot R_s$$

Where V and I are the voltage across the laser diode and the current through the laser diode, respectively.  $V_{th}$  is the threshold voltage, and  $R_s$  is the stray series resistance.

By the linear fit of the V-I curve, we can determine the threshold voltage and the stray series

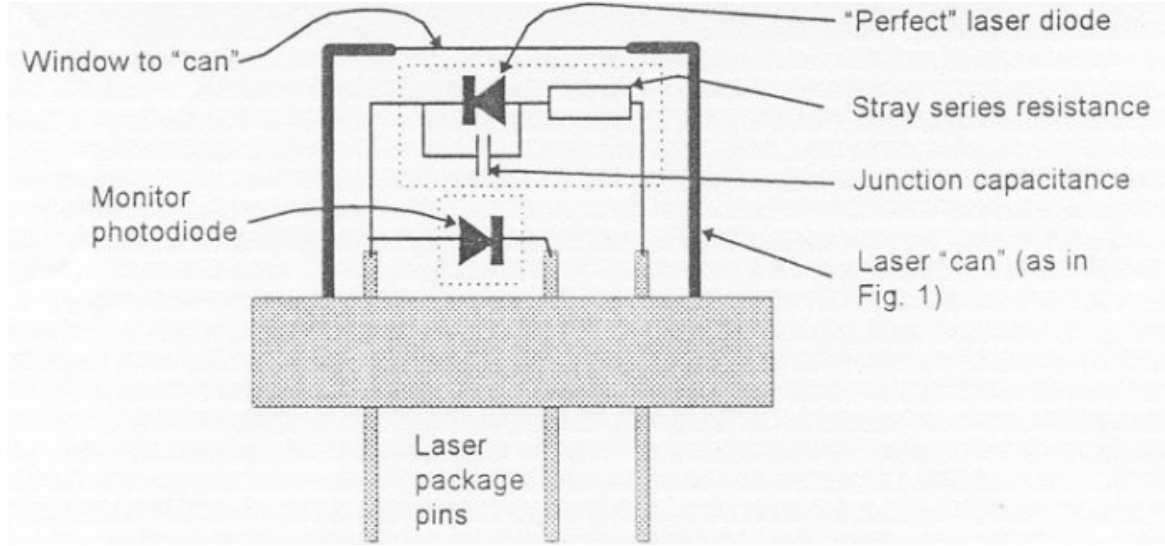


Figure 3: Equivalent Circuit of Laser Diode

resistance.  $V_{th} \approx 1.262V$ , and  $R_s \approx 21.505\Omega$ .

From the circuit diagram given, the stray series resistance is  $26\Omega$ , which is close to the value obtained from the linear fit, with an error of 17.3%. This error could be attributed to the measurement errors, and the non-ideal behavior of the laser diode.

With the threshold value of perfect diode, we could estimate the lasing wavelength of the laser diode  $\lambda_0$  by the following equation:

$$\lambda_0 = \frac{hc}{eV_{th}}$$

The value of wavelength is 983.12nm, which is within infrared range. This calculation agrees to the observation during the lab. There was no visible light emitted from the laser diode.

## 2.3 Error Analysis

## 3 Part II: Measurement of laser output spectrum

In this part, the output spectrum of the laser diode is measured using an optical spectrum analyzer. Data is collected for both stimulated and under-stimulated conditions, and the results are analyzed to understand the spectral characteristics of the laser output.

### 3.1 Effective Refraction Index of the Semiconductor Material

Within the cavity of the laser, the light forms a standing wave, with a wavelength  $\lambda_g = \frac{\lambda}{n}$ . Where  $\lambda$  is the wavelength of the light in vacuum, and  $n$  is the effective refraction index of the semiconductor

material. This wavelength should satisfy the resonance condition of the cavity, which is given by:

$$m \frac{\lambda_g}{2} = L$$

Where  $m$  is an integer representing the mode number, and  $L$  is the length of the cavity. By rearranging the equation, we can express the wavelength in vacuum as:

$$\lambda = \frac{2nL}{m} \rightarrow f = \frac{mc}{2nL}$$

The change in frequency is:

$$\delta f = \frac{c}{2nL}$$

From  $f = \frac{c}{\lambda}$ ,  $\delta f = \frac{c}{\lambda^2} \delta \lambda$ , we can derive the change in wavelength as:

$$\delta \lambda = \frac{\lambda^2}{2nL}$$

Thus, the effective refraction index can be calculated as:

$$n = \frac{\lambda^2}{2L\Delta\lambda}$$

### 3.2 Measurement of Laser Output Spectrum

The observed output spectrum of the laser diode shows multiple peaks, which correspond to different longitudinal modes of the laser cavity. Figure 6 and Figure 7 in the appendix show the output spectrum under stimulated and under-stimulated conditions, respectively. The collected data is shown in Figure 4.

| Current (mA) | center wavelength (um) | 3dB width (um) | ripple width (nm) |
|--------------|------------------------|----------------|-------------------|
| 17.63        | 1.5565                 | 0.0049         | 1.205             |
| 13.02        | 1.5547                 | 0.0254         | 1.205             |

Figure 4: Spectrum Data

### 3.3 Discussion and Analysis

By comparing the two sets of data, it is clear that the only discrepancy is the 3dB width of the spectrum. The 3dB width of the spectrum under stimulated condition is narrower than that under under-stimulated condition. This is expected because the stimulated photon emission leads to a more concentrated spectrum, while spontaneous emission results in a broader spectrum due to the random

nature of photon emission.

The center wavelengths of the two spectra are very close, which indicates that the lasing wavelength range is consistent regardless of the stimulation condition.

At last, the ripple width corresponds to  $\Delta\lambda$  in the equation for effective refraction index. As the two measurements use the same laser diode, the ripple widths are expected to be the same.

The effective refraction index could be calculated as:

$$n = \frac{\lambda_{center}^2}{2L\Delta\lambda} =$$

### 3.4 Error Analysis

## 4 Conclusion

## 5 Appendix

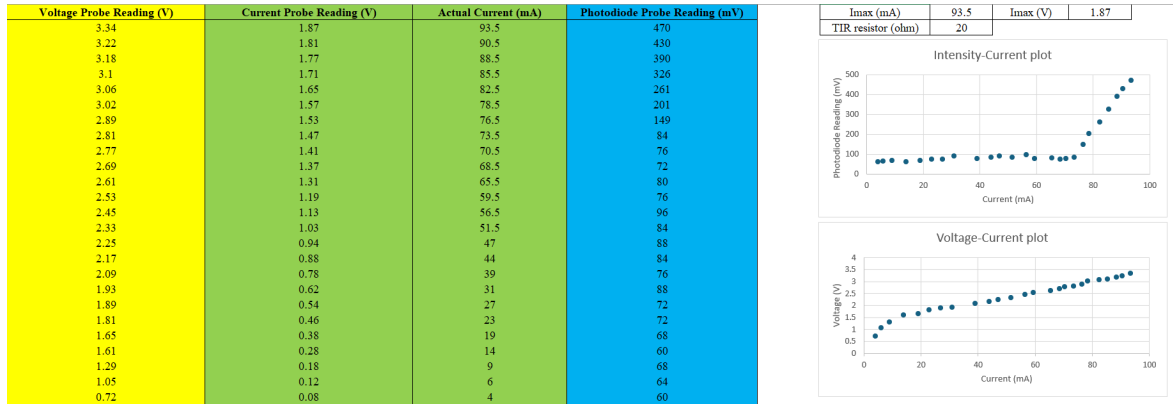
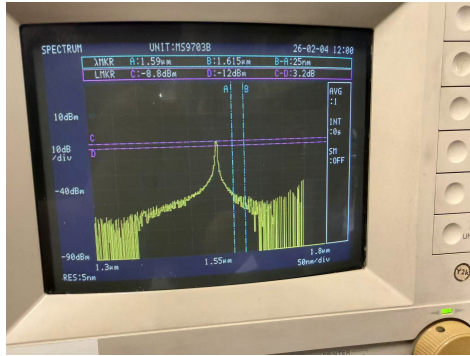
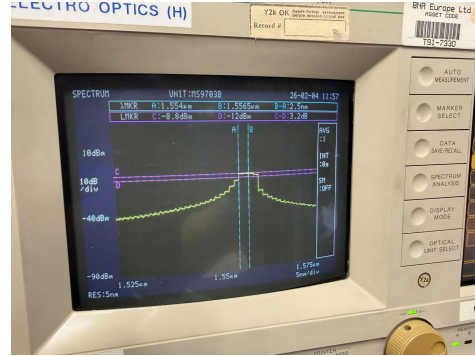


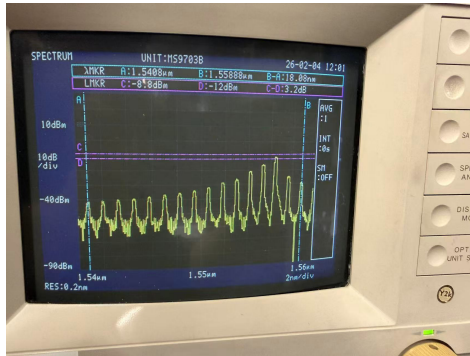
Figure 5: Raw Data



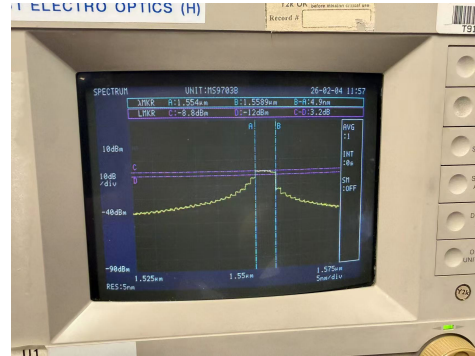
(a)



(b)

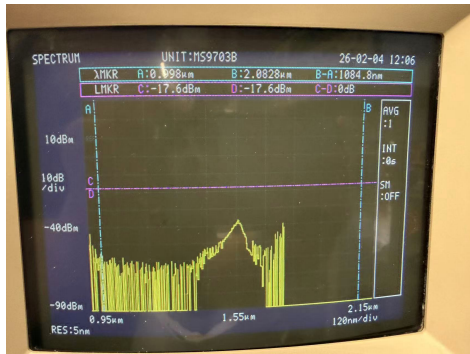


(c)

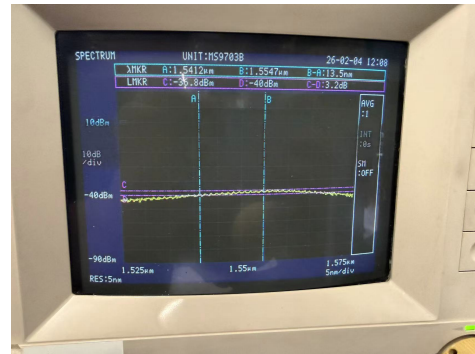


(d)

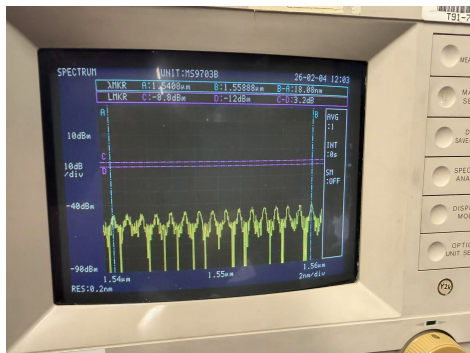
Figure 6: Stimulated Output Spectrum of the Laser Diode



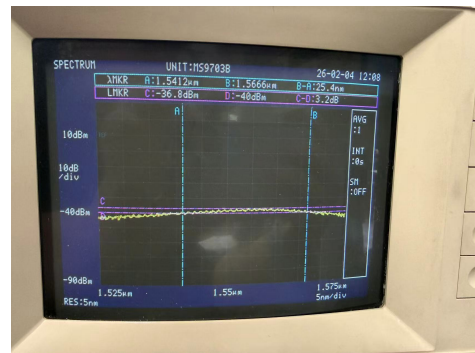
(a)



(b)



(c)



(d)

Figure 7: Under Stimulated Output Spectrum of the Laser Diode