ELEC0020: Photonics and Communication Systems

Photonics Laboratory

Learning Objectives

In this laboratory session, you will investigate the optical and electronic characteristics of some essential photonic devices: an **LED,** a **laser diode source**, and a **photodiode**. You will then build and measure the performance of a simple **optical fibre communications system** created by connecting the laser and the photodiode with a length of **optical fibre**, and use your system to measure the attenuation of the optical fibre. You will practise using **data sheets** to obtain information about the components you are using, and you will learn some basic information about **laser safety**.

Preparation

Reading:

In preparation for the lab refer to the following from the lecture notes on Moodle:

- Lecture 1: Photonics system (p. 7)
- Lecture 3: LED characteristics (p. 22)
- Lecture 4: What is a laser? (p. 3), Semiconductor laser light-current characteristic (p. 21), Dependence of I_{th} on temperature (p. 22)
- Lecture 5: *p-n* junction under illumination (p. 7), Effect of illumination on the I-V curve (p. 8), Responsivity (p. 12), Photodiode equivalent circuit (p. 21)
- Lecture 6: Optical fibres (p. 21), Fibre types (p. 25)
- Lecture 7: Modulation (p. 9), Attenuation (p. 12), Simple photoreceiver circuit (p. 28), Transimpedance amplifier (p. 30)
- Lecture 8: Signal impairments – extinction ratio (p. 17)

Pre-lab exercise:

Study the datasheets provided on Moodle for the LED, laser diode and photodiode that you will use in the experiment and answer the following questions to get familiar with finding information from the datasheets:

1. What semiconductor material is used for the light-emitting regions of the LED and laser diode? What are the approximate emission wavelengths of the LED and the laser? **AlGaInP on Si substrate** **LED: 640 nm** **Laser: 655 nm**
2. What is the typical threshold current of the laser at 25°C? **18 mA**
3. What is the forward voltage for the LED when the forward current is 25 mA? **2.1V**

4. What semiconductor material is used to fabricate the photodiode? Over what range of wavelengths does the photodiode usefully operate?
   silicon. Wavelength of peak sensitivity: 920nm; Bandwidth: 400 to 1000 (lambda_0.1)
5. What is the *absolute maximum* reverse voltage of the photodiode? What is its capacitance at a reverse voltage of 5 V?
   absolute max reverse V = 10 V
   capacitance: 400 pF

Checklist:

Make sure you are familiar with the following terms before the lab session:

- Laser diode
- Photodiode
- Drive current
- LI characteristic
- Threshold current
- Photocurrent
- Emission wavelength
- Optical output power
- Continuous wave laser operation
- Slope efficiency
- Responsivity

Laser safety

In this laboratory session you will use a low-power semiconductor laser. The *coherent* nature of laser light means that even low-power lasers are potentially hazardous, particularly those emitting visible light, as they could burn the retina (light-sensitive part) of the eye, causing permanent eye damage.

Because of this, lasers must be classified according to recognised standards: in the UK the applicable standard is British Standard EN 60825-1:2014 “Safety of laser products. Equipment classification and requirements”. This standard defines 8 laser classes, from Class 1 lasers (which are considered safe under all “reasonably foreseeable conditions of operation” [1]) to Class 4 lasers (which are generally considered so hazardous that they are usually kept locked away in laboratories and used only by highly trained operators).

To minimise any risk of harm, the laser you will use has been placed in a plastic housing with an optical fibre output (‘pigtail’). This has been designed so that the output from the optical fibre conforms to Class 1 (or at most Class 2), which can be considered to be safe for use in the teaching laboratory. Nevertheless, you should carefully read and act on the following **IMPORTANT LASER SAFETY** information:

WARNING: LASER RADIATION

CLASS 2 LASER: Maximum power 1 mW CW

DO NOT STARE INTO BEAM

DO NOT remove the plastic cover from the laser; DO NOT remove the fibre from the laser cover. If your laser or fibre is damaged, ask for a replacement.

Lab tasks

Complete the following five tasks.

Task 1: Measure the characteristics of the LED

Set up the circuit shown in Figure 1 on the breadboard. Place the LED (transmitter) at one end of the breadboard and the PD (receiver) at the other end. Choose the appropriate value of R_T to give approximately 25 mA through the LED with a power supply voltage of 5V (the forward voltage of the LED is approximately 2.2 V at a forward current of 25 mA). Use R_L = 10 kΩ in the receiver. Connect the transmitter to the receiver using a 1 m length of optical fibre. (Push the fibre connectors into the holes on the LED and PD housings as far as they will go; they may be loose – think about how this might affect your experiment).

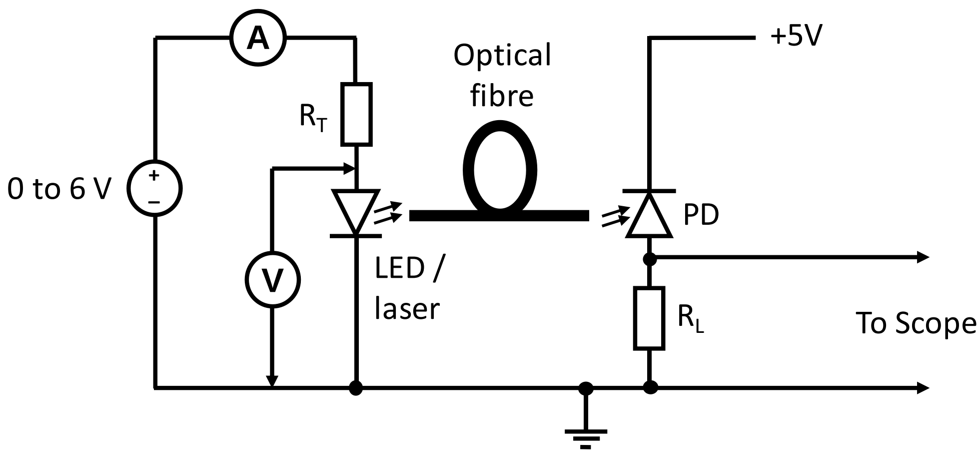

Figure 1: Circuit for measuring LED / laser characteristics

Set power supply limits to avoid damaging the devices:

- Set the LED power supply current limit to 30 mA and the voltage limit to 6 V.
- Set the PD power supply current limit to 5 mA and the voltage limit to 6 V.

Check the polarity of the components. The LED must be forward biased (anode positive). The PD must be reverse biased (cathode positive).

IMPORTANT: Before switching on, ask a demonstrator to check your circuit is correct and that the power supply limits are properly set.

For a range of LED forward currents up to 25 mA, simultaneously measure the voltages across the LED and across the PD load resistor R_L. Take care not to move the fibre, LED or PD while you make these measurements.

Plot your voltage vs current (VI) measurements and compare them with those in the datasheet. What is the LED voltage when its forward current is 25 mA? Is it what you expect?

Plot the voltage across the PD load resistor R_L against the current through the LED ('light' versus current or LI plot) and compare with the plot of Luminous Intensity in the datasheet.

Take note of the Laser Safety information on page 3 before moving on to the remainder of the experiment.

Task 2: Measure the characteristics of the laser diode

Use the same circuit as you used for Task 1, but replace the LED with the laser. (The pin-out of the laser is the same as that of the LED, so you can simply swap the LED for the laser.) Use the same resistor for R_T.

Before going any further, ask a demonstrator to check that the laser is working and is giving out a reasonable level of light.

Now, repeat the measurements you made in Task 1 and compare the laser VI and LI characteristics with those you obtained for the LED. From the LI characteristic, you should be able to identify the threshold current (I_{th}) of the laser diode. Estimate its value and compare your value with the information on the datasheet. If the value of I_{th} you measured is different from that given on the datasheet, think about reasons why that might be.

Task 3: Modulation of the laser diode / frequency response of system

Still using the same basic circuit as in Figure 1, replace the DC power supply driving the laser with a signal generator.

To modulate the output of the laser, you will need to bias the laser with a DC offset (bias current, I_{bias}) so that it is working in the linear region of the LI characteristic above the threshold current. Then, an a.c. signal with small peak-to-peak value can be added to modulate the light output from the laser (see Figure 2).

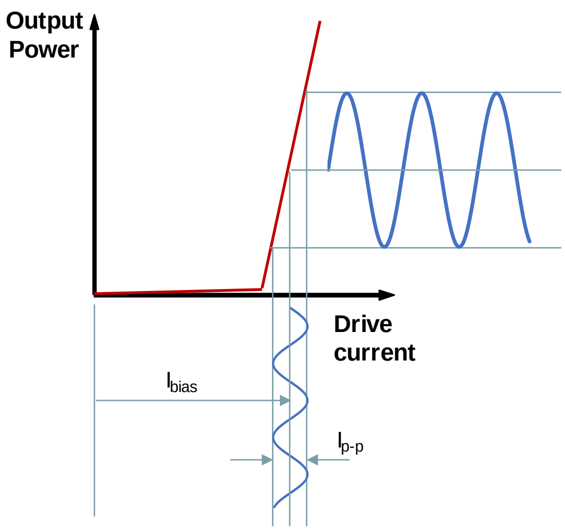

Figure 2: Modulating the laser

To set this up, first set the signal generator to give a 1 kHz sine wave with low amplitude (e.g. 10 mV p-p). Switch on the output of the signal generator, and increase the offset voltage until the current meter reads approximately 25 mA. You may find that the voltage required is more than the 5 V or so you set on the power supply to give the same current. (Why?)

Now increase the amplitude of the sine wave to 600 mV p-p. You should see a sine wave on the oscilloscope input connected to R_L. You may need to make small adjustments to the offset and peak-to-peak voltages to obtain an undistorted sine wave (but do not exceed 7 V for the offset voltage and 1 V for the p-p amplitude).

To get a stable trace on the oscilloscope, you may find it useful to use a splitter on the output of the signal generator, so that you can display its output on one of the other scope channels while still driving the laser. Trigger the scope from the channel displaying the output of the signal generator.

When you have correctly set the laser drive, remove the current- and volt-meters from the laser circuit (they may affect its frequency response).

Measure the peak-to-peak value of the **a.c. component** of the receiver voltage at several different drive frequencies (up to about 100 kHz) to determine the frequency response of your photonic system (i.e. a plot of V_{out}/V_{in} versus frequency). Hence estimate the –3-dB bandwidth of the system. What do you think is the main factor determining the bandwidth?

Using the same bias and peak-to-peak voltage settings, switch the signal generator to give a square wave. At low frequency (e.g. 1 kHz), measure the extinction ratio of the received signal (express your answer in dB). Increase the frequency of the square wave and observe what happens to the received signal. Record some representative oscilloscope traces. How do these results relate to the system bandwidth measured above?

Task 4: Measure the loss of the fibre

The fibre pigtail from the laser is a step-index plastic optical fibre (POF) with a core diameter of approximately 1 mm and a numerical aperture of 0.47. Would you expect this fibre to be single-mode or multi-mode? Why?

Using the same experimental arrangement as in Task 3, modulate the laser with a 1 kHz sine wave, with offset and peak-to-peak voltages that give a clear, undistorted sine wave at the output of the of the photodiode circuit (i.e. as set up in Task 3). Measure the amplitude of the received signal.

You are provided with a longer piece of optical fibre with connectors on each end (often referred to as a fibre patchcord). Using the coupling sleeve, connect one end of this patchcord to the fibre pigtail from the laser. Connect the other end to the photodiode. Measure the amplitude of the received signal for the drive conditions used for the previous measurement.

The nominal length of the fibre patchcord is 10 m. Assuming this value is accurate, estimate the attenuation of the POF in $dB.m^{-1}$.

Task 5: Transimpedance amplifier

Replace the simple load resistor receiver circuit with the transimpedance amplifier shown in Figure 3, using a 741 op-amp. You should obtain the same output voltage amplitude as with the simple circuit if you use $R_f = R_L$. Check that this is correct.

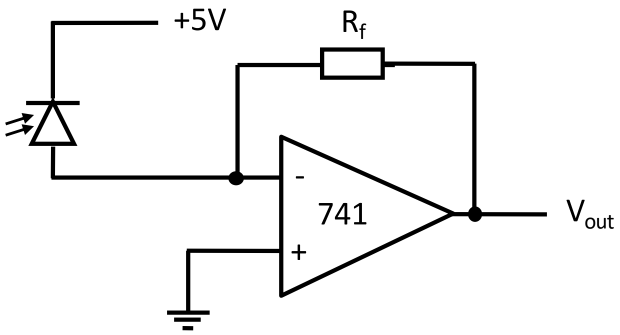

Figure 3: Transimpedance receiver circuit

Drive the laser with a square wave as in Task 3. You should observe ringing on the signal at the rising and falling edges of the square wave. This can be reduced by placing a compensation capacitor, C_f, in parallel with R_f. A value for C_f of a few hundred picofarads or so should be suitable (try changing the value to see the effect and to obtain the best response). Think about why the ringing occurs and why C_f reduces it.

Assessment

For this lab, you will be assessed using a Moodle quiz which requires you to upload plots of the results you obtained during the lab and answer a few questions. Graphs should be carefully plotted, with axes properly labelled, etc., and scope captures should be clearly labelled to indicate the conditions under which they were measured. The marks for this report make up 3% of the ELEC0020 module mark.

Your will be required to upload the following results:

- A single figure showing the VI plots for both the LED and laser (Tasks 1 and 2).
- A single figure showing the LI plots for both the LED and laser (Tasks 1 and 2).
- A single figure showing the frequency response plot for the photonic system using the laser as the transmitter (Task 3).
- A single figure showing scope captures of the receiver voltage when the laser is driven with a square wave (at 2 or 3 different frequencies) (Task 3).
- The value of the fibre loss that you measured (Task 4).
- A single figure showing scope captures of the output of the TIA circuit, with and without compensation capacitor (Task 5)

References

1. https://www.gov.uk/government/publications/laser-radiation-safety-advice/laser-radiation-safety-advice, accessed January 2022.