FYSC23

# Semiconductor lab

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# Abstract

# Contents

# 1 Introduction

Semiconductors are becoming more and more important for our society. One important application of semiconductors is light emitting diodes (LEDs) [1] which are used in e.g. displays and lighting, but also have application in medicine. LEDs also show a much better efficiency than earlier lightbulbs, thus decreasing energy consumption [1], something which is becoming increasingly more important. The basic part of the LED, the pn-junction, is also used in solar cells and can be used to produce energy from light [1].

# 2 Theory

## 2.1 Bandgap

The bands in solid state materials are energy continuum that arises in solid state materials due to the number of atoms close to each other [1]. The valance band is the highest band under the Fermi energy and where the electrons are bound to the atoms. The conduction band is the lowest band above the Fermi energy, and where electrons can move freely [1]. The bandgap is the energy difference between the valance band and the conduction band and can be used to describe different materials. For conductors the bandgap is zero and electrons are free to move, for insulators the bandgap is large and a lot of energy is needed to excite an electron from the valance band to the conduction band, and for semiconductors the bandgap exist but is smaller than for insulators [1]. The definition of the size of the bandgap for insulators and semiconductors is a bit arbitrary, but is usually said to be around 3 eV [1].

## 2.2 Semiconductors

Semiconductors, as stated in the previous section, have a bandgap under 3 eV but above 0 eV. This is a bandgap which can quite easily be excited and opens up for many applications [1]. One example is exciting the bandgap using light from the sun to produce energy. Applying a voltage to a semiconductor can also excite the bandgap. If an electron is excited from the valance band to the conduction band, a hole is left in the valence band which behave as a positive charge [1]. An excited electron will thermalize in the conduction band and lose energy to phonons and then eventually recombine with a hole in the valance band [1].

## 2.3 Doping

Doping is a process where impurities are added to a semiconductor to change its properties. Usually the impurity atom either have one more electron than the semiconductor atom, or one less electron [1]. If the impurity has one more electron it is called a donor and if it has one less it is called and acceptor. If it is a donor that is added the doping is called n-type, and for an acceptor it is called a p-type. The effect on the semiconductor is mainly that the bandgap will change, by adding either a donor state just below the conduction band or an acceptor state just above the valance band [1]. If a semiconductor is cooled sufficiently it will experience a freeze-out, where the effects from the doping will disappear, thus reverting the bandgap to the original size [1].

### 2.4 Pn-junction

A pn-junction arises when connecting a p-type and an n-type semiconductor. The electrons in the donor states in the n-type will combine with the holes in the acceptor states in the p-type, creating a depletion zone. This zone will be negative on the p-side and positive on the n-side creating an electric field, stopping further diffusion of electrons and holes [1]. The electric field will create a drift current from the p-side to the n-side, while the abundance of electrons on the n-side will create a diffusion current from the n-side to the p-side. In equilibrium these currents will be equal. If a forward bias is applied the n-side electrons will have a lower potential barrier to overcome and the diffusion current will increase [1]. For a reverse bias, the potential barrier will increase and the diffusion current decreases.

### 2.5 LED

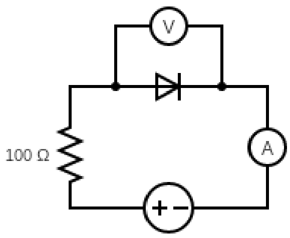
An LED is a pn-junction where the recombination of electrons and holes emit light. This light is directly proportional to the bandgap energy [1]. Thus, by using specific semiconductors and doping the bandgap energy can be controlled and thus the light that is emitted. Thus, an LED and a solar cell diode are very similar, and an LED will produce a current when light is shone on it [1], if the light is energetic enough.

## 3 Experiment

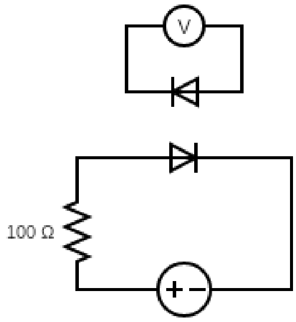
During the first part of the lab, we measured the intensity of a white diode at different voltages. The white diode was a violet diode, covered in a phosphorus layer that emitted a white spectrum. The voltage was controlled through a DC source, as shown in Figure 1a. Twelve measurements were taken of the voltage from the DC source, the voltage across the diode, the current through the circuit, and the intensity. The measurements were taken evenly between 1 to 9 V. The intensity of the diode was evaluated through an glass fibre cable placed directly above the diode. The intensity was displayed in a computer program called AvaSoft, where counts for different wavelengths were shown. The intensity was determined by evaluating the intensity at the largest peak. The integration time used was 70 ms, which involved averaging every 10th measurement.

In the second part, the same circuit was used; however, this time a yellow diode was employed instead. The fibre optic cable was taped directly onto the diode. One measurement was taken of the voltage from the DC source, the voltage across the diode, the current through the circuit, and the intensity. A screenshot was also captured of the spectrum in the AvaSoft program. Keeping the same voltage from the DC source, the diode was placed in liquid nitrogen, and a similar measurement was taken.

In the last part, another circuit was used, as seen in Figure 1b. This time, neither an ammeter nor a voltmeter was used in the main circuit. Instead, a separate circuit was implemented with a diode and a voltmeter connected in parallel. The integration time was changed to 2 ms. The DC source was turned on until the diode in the main circuit shone brightly. The other circuit was then placed close to the main circuit to check if the diode in the smaller circuit registered any voltage. This procedure was repeated for all combinations of red, green, and blue diodes.




(a) This sktch shows the circuit for part 1 and part 2.



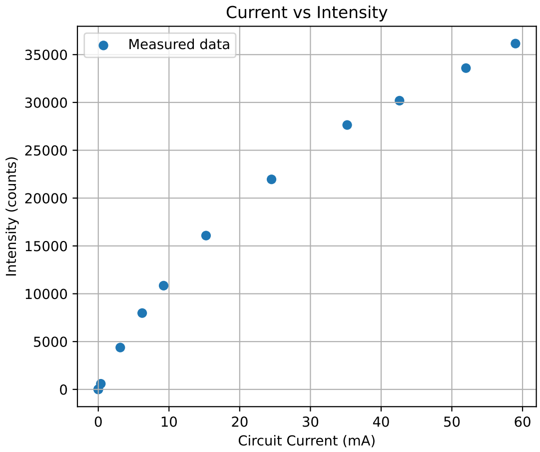

(b) This sktch shows the circuit for part 3, with the two different diodes.

Figure 1: Above one can see the circuits used in this lab. Both circuits used an resistor with 100 .

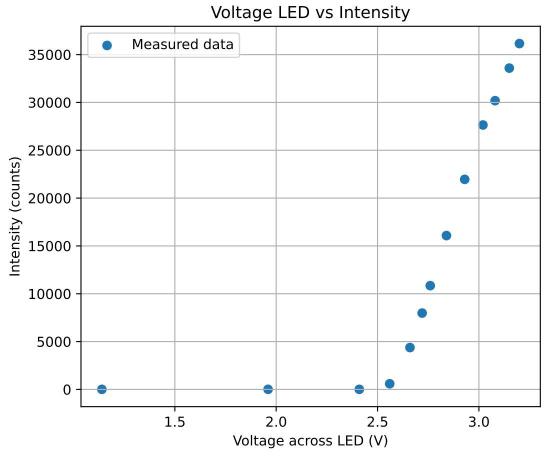
# 4 Result

## 4.1 Part 1

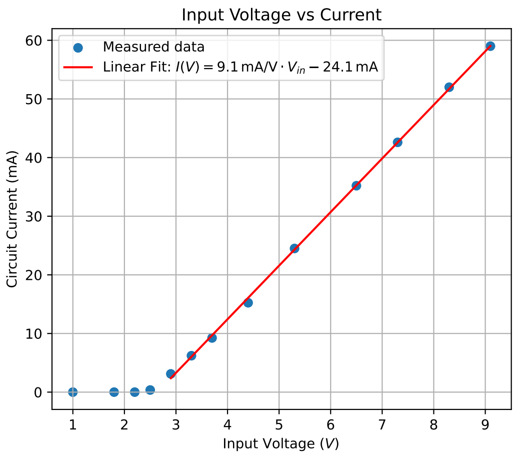
In the first part the peak which was measured from the white diode was located at 454.17 nm. Using the data obtained from the measurements Figure 2 was obtained. From the linear fit in Figure 2a one can see that that the linear fit intersects the x-axis at $V_{\text{in}} = 2.7\,\text{V}$. This means that a voltage under this value would yield no current output, which can be seen in the figure. Thus, one can conclude that the forward bias is $V_{\text{in}} = 2.7\,\text{V}$.




(a) This plot displays the itensity of the LED over the current in the circuit.




(b) This plot displays the itensity of the LED over the voltage across the LED in the circuit.




(c) This plot displays the current in the circuit over the voltage from DC-source. A linear fit was used for the non-zero measurements, since this fit would be used to calculate the forward bias.

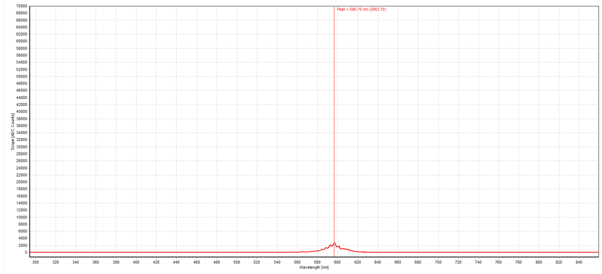
Figure 2: Plots of the measurements.

## 4.2 Part 2

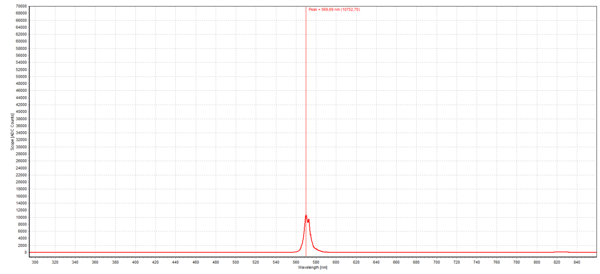
The measurements from the circuit before was combined with the measurements from the program, as seen in Figure 3, in Table 1. Notably the wavelength of the peak shifted, and the intensity increased when the diode was submerged in liquid nitrogen.

Table 1: This table shows the measurements.

| Measurement | $V_{in}$ (V) | $V_{LED}$ (V) | $I_{circuit}$ (mA) | $\lambda_{peak}$ (nm) | Intensity (counts) |
|---|---|---|---|---|---|
| Room temperature | 5.0 | 2.06 | 30.8 | 596.70 | 2663.70 |
| Liquid nitrogen | 5.0 | 4.44 | 7.7 | 569.69 | 10757.70 |



(a) This was the output from the program at room temperature.



(b) This was the output from the program when submerged in liquid nitrogen.

Figure 3: This figure display the output from AvaSoft at the different measurements.

### 4.3 Part 3

The result from the different diode constellations as detectors and emitters can be seen in Table 2. The table shows that shorter wavelength diodes can excite longer wavelength diodes, but not the other way around.

Table 2: This table displays which combinations of detectors and emitters yielded an voltage output from the diode in the smaller circuit.

| Detector/Emitter | Red | Green | Blue |
|---|---|---|---|
| Red | Output | No output | No output |
| Green | Output | Output | No output |
| Blue | Output | Output | Output |

## 5 Discussion

### 5.1 Part 1

At which wavelength does the LED shine? Is the light emission uniform in the visible wavelength range for a White LED? Why/why not? How does the current depend on the voltage? Can you explain qualitatively why the LED behaves like this? Why does the voltage need to be applied in one specific direction for the LED to shine? How does the light depend on the current/voltage applied? Why? When using different LED colours, do they behave the same (if enough time is available)? Why/why not?

### 5.2 Part 2

## 6 Conclusion

# References

[1] Philip Hofmann. *Solid State Physics: An Introduction.* Wiley-VCH, 2nd edition, 2015.