EE236: Electronic Devices Lab
Lab 1: Diode IV Characterization

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1 Aim of the experiment

- To study the forward bias I/V characteristics of PN junction diodes and estimate the band gap of the semiconductor material which the diodes are made of.
- To calculate ideality factor, reverse saturation current and doping densities of various PN junction diodes.

2 Methodology

To perform this experiment, we need a simple method to distinguish the band gaps of two diodes made of dissimilar materials to determine the band gap of a given diode.

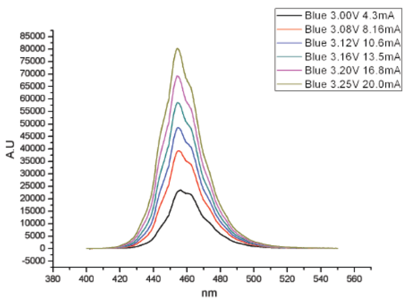
Light Emitting Diodes (LEDs) satisfy these requirements. The color of the emitted light helps us distinguish dissimilar materials, and the I/V measurements can be used to estimate the band gap of the material.

3 Theory

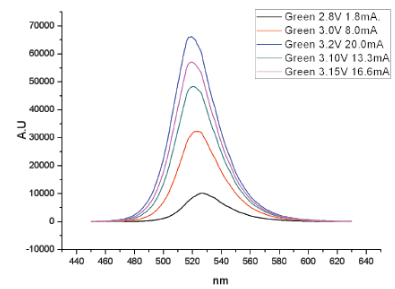
The peak emission wavelength of an LED is a measure of it's band gap:

$$E_g = \frac{hc}{\lambda} = \frac{1240}{\lambda} \tag{1}$$

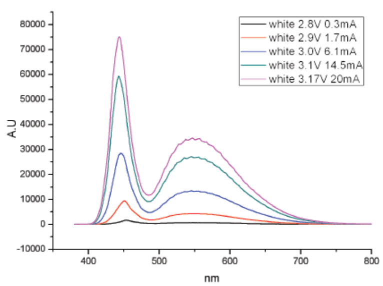
where E_g is band gap of the material in units of electron Volts (eV) and λ is the emission wavelength in nanometers (nm). Below are the Intensity vs λ curves for different LEDs:



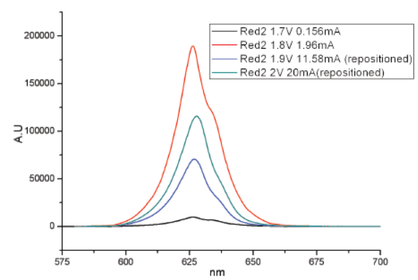
(a) Blue LED



(b) Green LED



(c) White LED



(d) Red LED

Figure 1: Intensity vs λ

As expected, the intensity of light emission increases with current as minority carrier injection increases. The white LED shows two peak wavelengths.

The I/V characteristic of a forward biased diode is given by:

$$I_D = I_{00}e^{-\frac{E_g}{kT}}(e^{\frac{qV_D}{\eta kT}} - 1) \tag{2}$$

The saturation current I_s is given as $I_s = I_{00}e^{-\frac{E_g}{kT}}$.

V_D and I_D indicate voltage across, and current flowing through the diode respectively. Assuming $qV_D >> \eta kT$, equation 2 can be rewritten in logarithmic form as

$$ln(\frac{I_D}{I_{00}} + \frac{E_g}{kT}) = \frac{qV_D}{\eta kT} \tag{3}$$

Note that for ideal diode, ideality factor, $\eta = 1$. In equations 2 and 3, assuming that I_{00} does not vary much from one material to another, then for a constant I_D, V_D will increase as the band gap increases.

The bandgap is also related to the intrinsic carrier concentration as:

$$n_i = 2(\frac{k_B m_e T}{2\pi\hbar^2})^{3/2} e^{-E_g/2k_BT} \tag{4}$$

The doping densities are related to n_i as:

$$N_A N_D = n_i^2 e^{V_{bi}/k_BT} \tag{5}$$

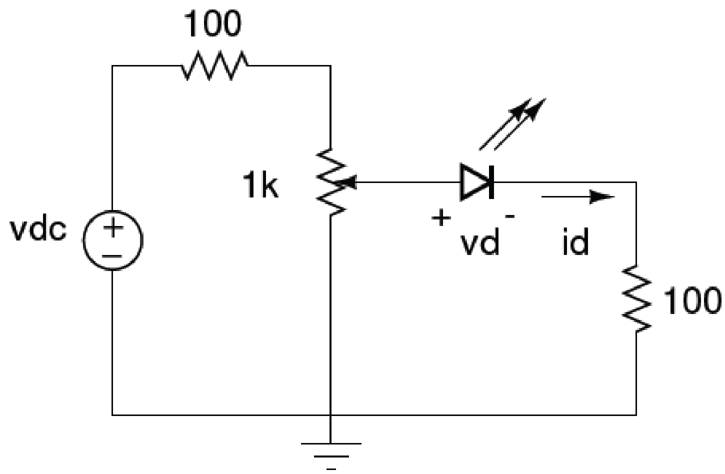
One way to test equation 3 is to measure V_D for a constant drive current I_D for different diodes (LEDs and a silicon diode) and plot V_D vs E_g of the diodes obtained from their emission spectrum and study the correlation.

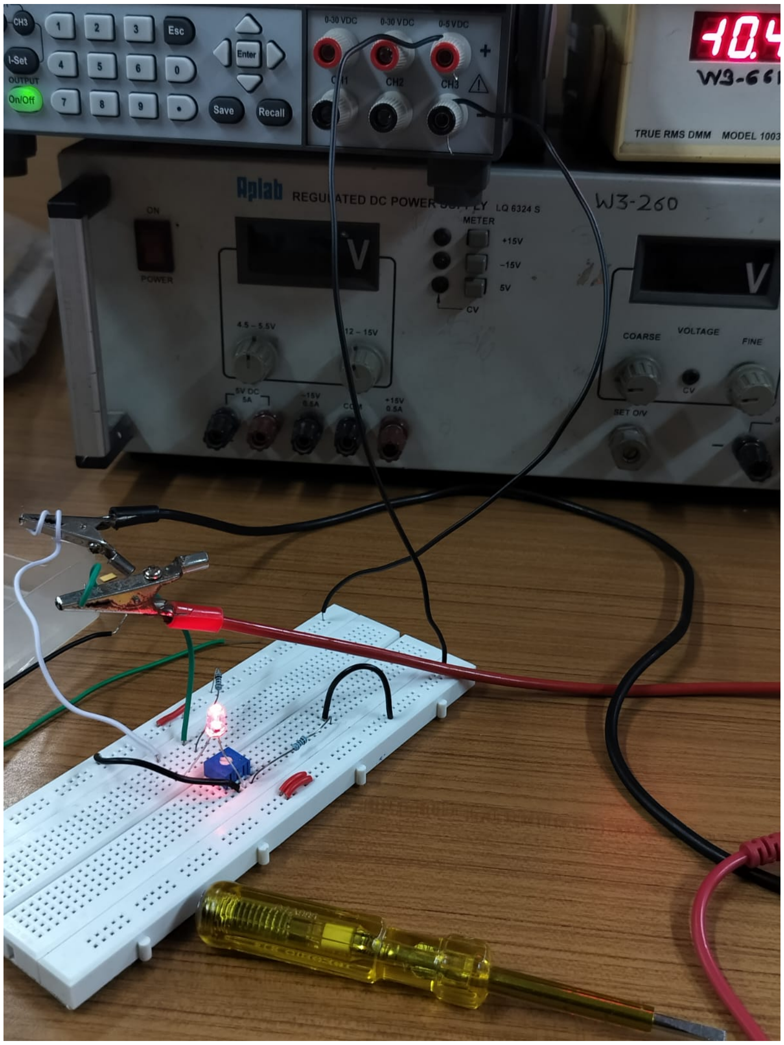
4 Design

4.1 Components used

- Silicon P-N junction diode 1N914, LEDs - Red, Green, Blue and White
- Resistors - 100Ω (×2)
- Potentiometer - 1kΩ
- Breadboard, connecting wires

4.2 Circuit





5 Results & Inferences

Here are the reading obtained for the five diodes and the corresponding I_D vs V_D curves.

5.1 Silicon Diode (1N914)

V_D (V)	I_D (A)
0.453	0.05
0.507	0.11
0.580	0.50
0.627	1.44
0.660	2.29
0.680	3.34
0.702	5.08
0.728	8.05
0.750	12.80
0.770	15.38

Table 1: I-V readings for the Diode

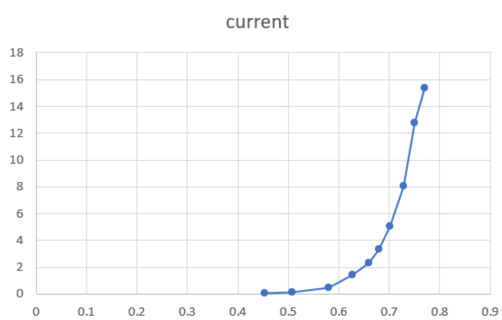


Figure 2: I_D vs V_D

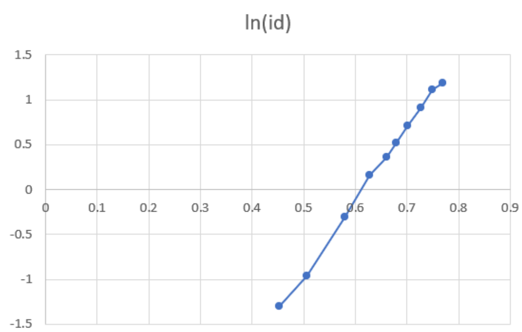


Figure 3: $ln(I_D)$ vs V_D

5.2 Blue LED

V_D (V)	I_D (A)
2.35	0.03
2.54	0.11
2.59	0.28
2.62	0.43
2.66	0.71
2.72	1.23
2.81	2.35
2.87	3.41
2.90	4.14
2.98	5.91
3.01	6.75

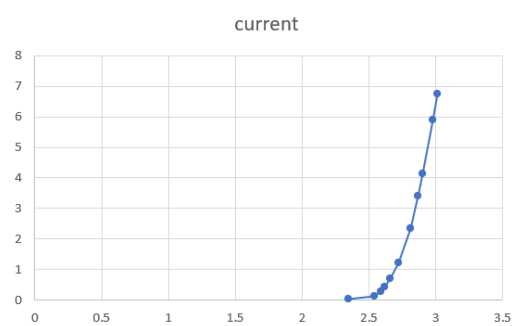


Figure 4: I_D vs V_D

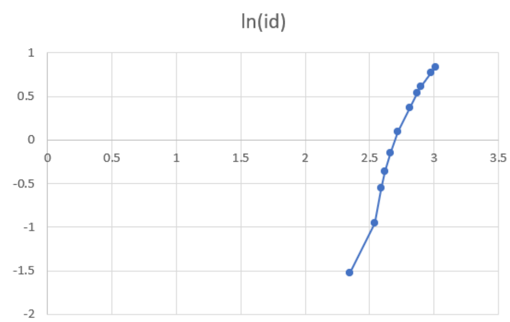


Figure 5: $ln(I_D)$ vs V_D

5.3 Green LED

V_D (V)	I_D (A)
2.02	0.02
2.21	0.11
2.22	0.12
2.24	0.16
2.26	0.23
2.20	0.38
2.37	0.71
2.56	2.39
2.73	4.68
2.88	7.41

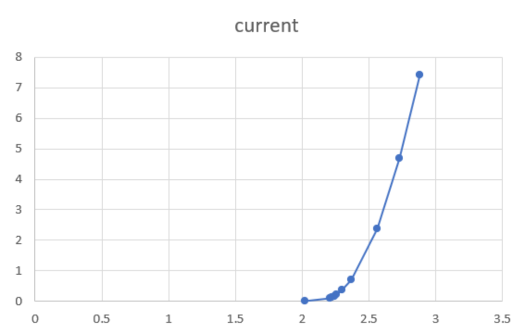


Figure 6: I_D vs V_D

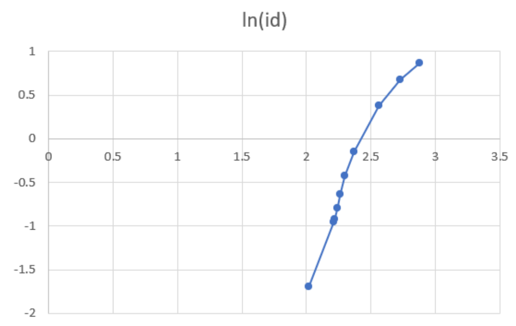


Figure 7: $ln(I_D)$ vs V_D

5.4 Red LED

V_D (V)	I_D (A)
1.67	0.06
1.73	0.17
1.76	0.34
1.79	0.58
1.81	0.84
1.82	1.06
1.84	1.33
1.90	2.80
1.91	3.17
1.92	4.00
1.98	7.19
2.03	10.43

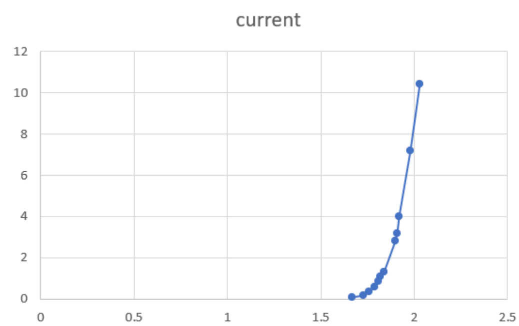


Figure 8: I_D vs V_D

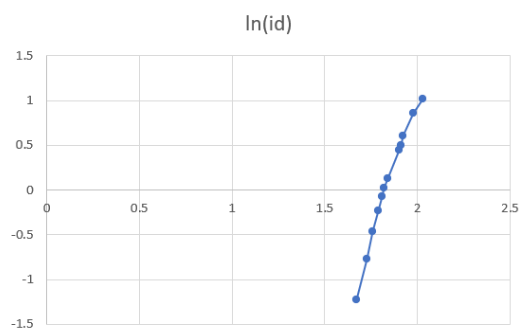


Figure 9: $ln(I_D)$ vs V_D

5.5 White LED

V_D (V)	I_D (A)
2.51	0.05
2.53	0.08
2.56	0.16
2.57	0.21
2.58	0.27
2.59	0.34
2.60	0.45
2.62	0.63
2.64	0.96
2.66	1.34
2.68	1.62
2.72	2.48
2.77	4.06
2.82	5.62
2.87	7.38

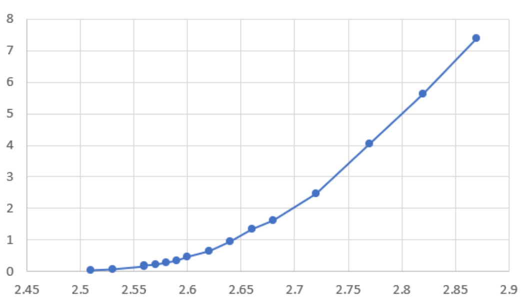


Figure 10: I_D vs V_D

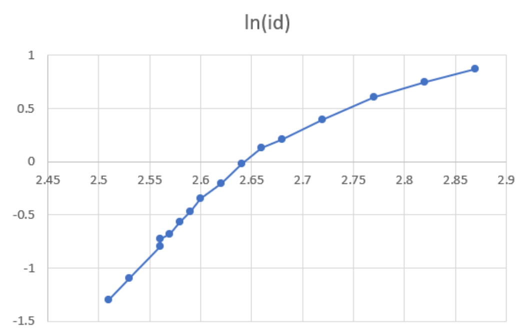


Figure 11: $ln(I_D)$ vs V_D

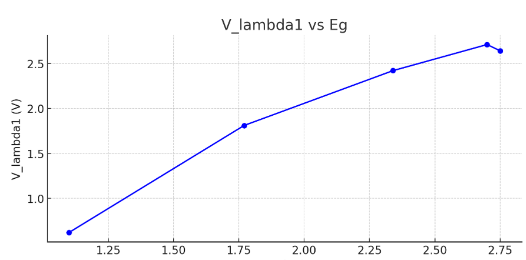
The ideality factor (η) can be calculated from the slope of the $ln(I_D)$ vs V_D curve and the saturation current from the y-intercept as laid out in equations 2 and 3. E_g is calculated from the corresponding Intensity vs Wavelength curve by taking the peak wavelength and using equation 1. N_i and the doping concentrations are calculated from equations 4 and 5 using the cut-in voltage at 1 mA as the V_{bi}.

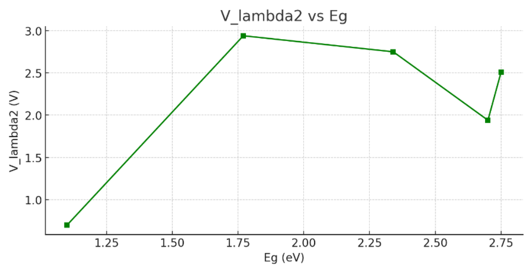
For the five diodes, the relevant parameters as calculated are therefore:

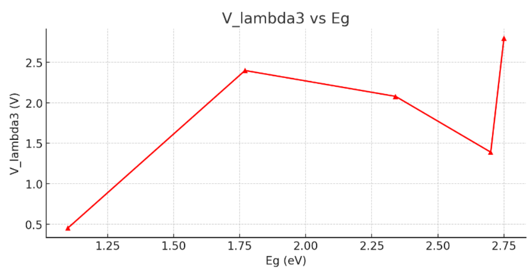
Type	η	I_s	E_g	$V_{\gamma 1}$	$V_{\gamma 2}$	$V_{\gamma 3}$	n_i	N_A/N_D
1N914	4.739	$6.73 * 10^{-3}$A	1.1eV	0.62V	0.70	0.453	1.48E+16	2.38E+21
Red	6.124	$9.83 * 10^{-6}$A	1.77eV	1.81V	2.94	2.40	3.54E+10	5.49E+25
Green	12.885	$5.76 * 10^{-4}$A	2.34eV	2.42V	2.75V	2.08V	5.84E+5	1.19E+26
Blue	10.429	$4.10 * 10^{-5}$A	2.70eV	2.71V	1.94	1.39	5.56E+2	3.08E+25
White	6.369	$9.59 * 10^{--8}$A	2.75eV	2.64V	2.51	2.80	2.11E+2	3.03E+24

where, $V_{\gamma 1}$, $V_{\gamma 2}$ and $V_{\gamma 3}$ are the cut-in voltages at I_D of 1 mA, 0.05 mA and 5 mA respectively.

The cut-in voltages vs E_g curves are:







As can be clearly seen, the V_λ vs E_g curves are not always linear as expected from equation (3).

5.6 Conclusion

In this experiment we studied the I-V characteristics of various commonly used diodes and calculated the relevant parameters to characterise the diode. These diodes are commonly used for lighting and in circuits for making rectifiers.

5.7 Experiment completion status

Completed.