Estimation of band gap of different semiconductor materials through diode I/V characterization

Wadhwani Electronics Lab 2021-22 (Spring Semester)

Aim of the experiment

To determine whether the forward I-V characteristics of a diode depend on the band gap of the semiconductor material with which the diode is made up of.

Methodology

To perform this experiment, we need:

- A simple method to identify that the band gap of a diode 'A' is different from that of the diode 'B'.
- To determine the band gap of a given diode.

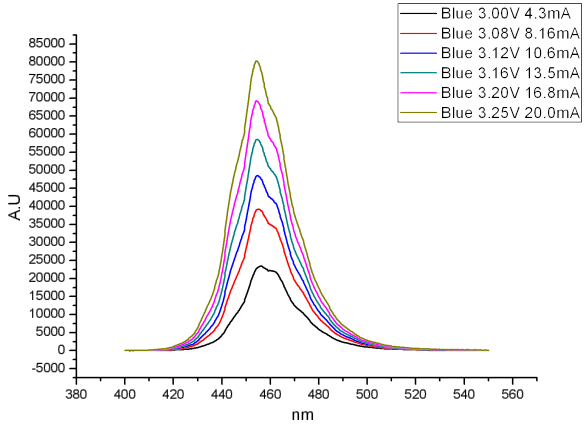
Light Emitting Diodes (LEDs) satisfy both the points mentioned above.

Background Theory

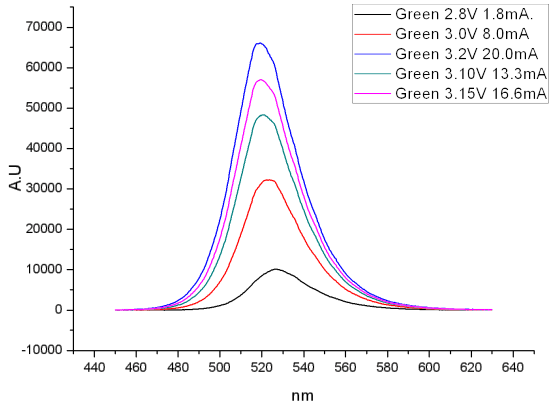
- Materials with different band gaps will emit light of different frequency and hence different colour, So LEDs of different colours have been chosen for the experiment.
- The peak emission wavelength of the LED is a measure of the band gap.

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

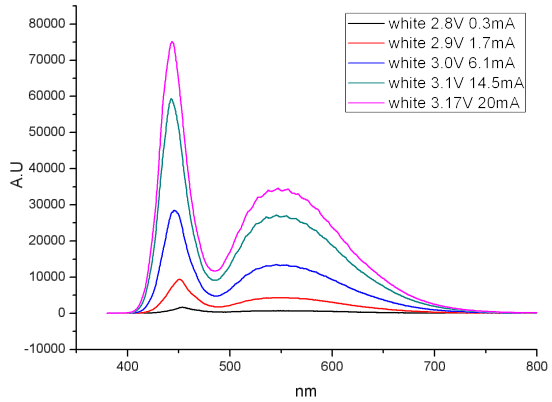
Where, E_g is the band gap of the material in electron Volts (eV) and λ is the emission wavelength in nanometers (nm). The figure on slide 4 shows spectra of different coloured LEDs driven at different current levels. As expected, the intensity of light emission increases with current as minority carrier injection increases. Notice that the white LED shows two wavelength. (Why?)



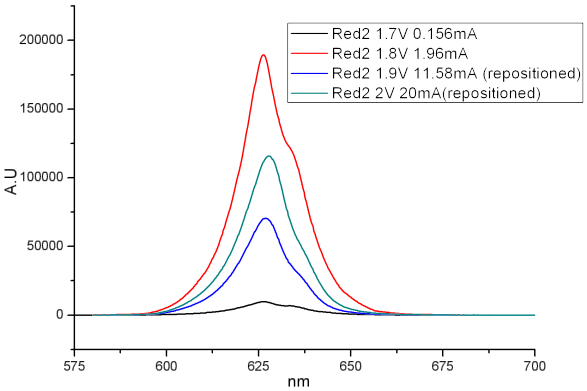
(a) Blue LED



(b) Green LED



(c) White LED



(d) Red LED

Figure: Emission intensity verses wavelength of various LEDs for different currents

The I-V characteristic of an ideal diode is given by the equation-

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

Where V_D and I_D indicate voltage across the diode and current through it respectively. The saturation current I_S is given as $I_S = I_{00} e^{-\frac{E_g}{kT}}$. Assuming $qV_D >> kT$, equation (2) can be rewritten in logarithmic form as

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

Thus for constant I_D/I_{00}, V_D is proportional to E_g. If I_{00} does not vary very much from material to material, then for a constant I_D, V_D will increase as the band gap increases. Hence one way to test equation (3) is to determine V_D for a constant value of I_D for LEDs of different colours and also a silicon diode and plot V_D v/s E_g of the diodes obtained from their emission spectrum and look at the corelation. Note that E_g of silicon diode is 1.1 eV.

Simulation Exercise: Model files and other circuit components to be used

- Diode 1N914, LEDs- Red, Green, Blue, and White
- Resistors - 100Ω- 2 nos.
- Potentiometers -1 kΩ

Simulation Exercise

- Write ngspice netlist for the circuit diagram shown in the figure below to measure I/V characteristics of RED, BLUE GREEN, and WHITE LED and the diode 1N914.
- Run the simulation and plot all the characteristics on the same plot. Call this Plot 1. What is your observation from this plot?

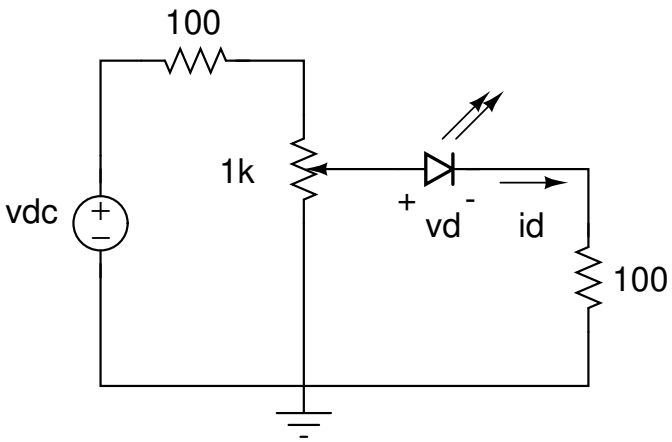


Figure: Hardware model

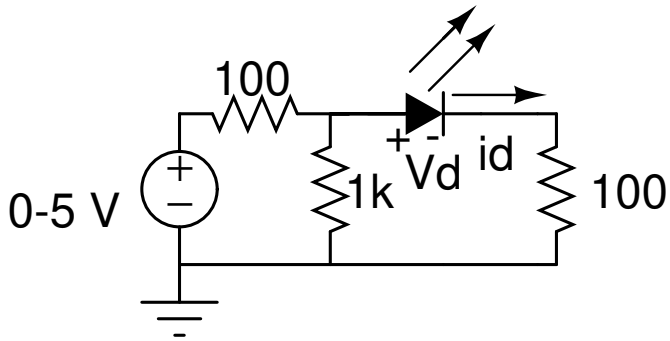


Figure: Simulation model

Simulation Exercise—— Continued

- Now plot a graph of $\ln I_D$ v/s V_D for all the diodes. Call this **Plot 2**. The slope of the graph is given by

$$\frac{\ln I_{D2} - \ln I_{D1}}{V_{D2} - V_{D1}} = \frac{1}{\eta V_T} \tag{4}$$

  Calculate the ideality factor η of each diode from the slope. Also calculate the saturation current I_S from the y-intercept.
- Calculate the bandgap E_g for each LED using the emission wavelengths from figure in page 4 and putting them in equation (1). Assume that for silicon(1N914), $E_g = 1.1$ eV.
- From **Plot 1**, choose a constant value of I_D, say 1 mA. For each diode, find out the value of V_D corresponding to $I_D = 1$ mA.

Simulation Exercise—— Continued

- Now plot a graph of V_D v/s E_g for all the diodes. For the chosen value of I_D, you should get one point (V_D, E_g) on the graph for each diode and hence you can plot all five points (for the different diodes) on a single graph.
- From the graph, try to find a relation between V_D and E_g. What is the expected correlation? Do you observe any variation? If yes, why?

Find out the Answers for the following questions

1. What is the material a White LED is made of? What value of E_g will you choose for it?
   Note: Look at the spectrum closely and look for the stronger emission wavelength.
2. Are the equations (2) and (3) satisfied for the entire range of V_D?
3. Look at the correlation between V_γ and E_g by choosing a current I_D of 50μA and 5mA and see how non-ideality of I-V affects the experiment.