Dependance of Diode I-V Characteristics on Band Gap of different Semiconductor Materials

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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 of.

Methodology:

To do this experiment, we need:

1. A simple method to identify that the band gap of a diode ‘A’ is different from that of the diode ‘B’.
2. To easily determine the band gap of a given diode.

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

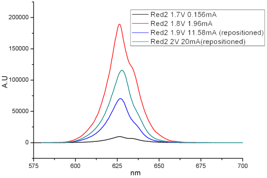
Theory

- Materials with different band gaps will emit light of different frequency and hence different colour. So different coloured LEDs are chosen.
- The peak emission wavelength of the LED is a measure of the band gap i.e.

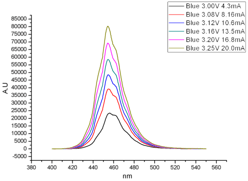
$$E_g = \frac{h * c}{\lambda} = \frac{1240}{\lambda} \tag{1}$$

Where E_g is the band gap in electron Volts (eV) and λ is the emission wavelength in nanometers (nm).

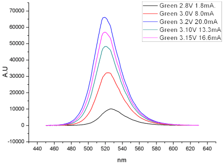
The figure on page 4 shows the spectra of different coloured LEDs driven at different current levels. As expected, the intensity of light emission increases with current as minority carrier injection increases. Notice that the white LED shows two wavelengths. Why?



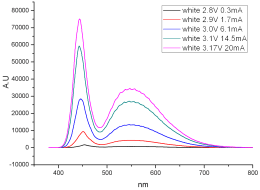
(a) Red LED



(b) Blue LED



(c) Green LED



(d) White LED

Figure: Emission Intensity v/s Wavelength of various LEDs for different currents

I-V Characteristics of an Ideal Diode

The I-V characteristics 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 the diode respectively. The saturation current I_S is given as $I_S = I_{00} e^{-\frac{E_g}{kT}}$. Assuming $qV_D \gg kT$, 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 plot V_D v/s E_g of the LED obtained from its emission spectrum and look at the correlation. This precisely, is the experiment.

Instruments and Components Required

- LEDs- Red, Green, Blue and White.
- Resistors- 100 Ω (x2).
- Potentiometers- 1 kΩ.
- Multimeters (x2), DC power Supply, CRO.
- Breadboard, connecting wires.

The Experiment

1. You will be given **four** LEDs- red, green, blue and white. Use the circuit shown in following figure.
2. Vary the 1 kΩ pot to accurately measure I_D with change in V_D. Take sufficient readings with appropriate steps of I_D and note the corresponding value of V_D.
3. Repeat steps 1 and 2 for all LEDs.

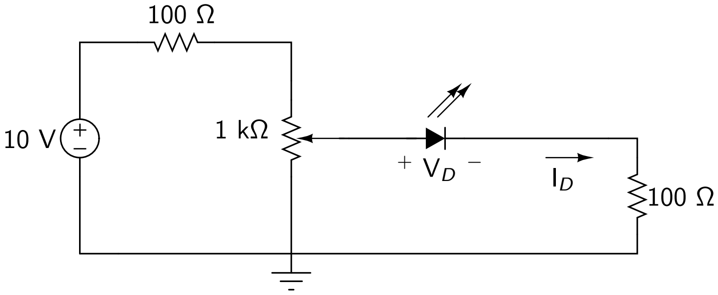


Figure: Circuit to determine LED I-V characteristics

Post Experiment Work- Obtaining Results and Interpreting Them

1. Plot a graph of I_D v/s V_D for all LEDs. Let us call this as **Plot 1**.
2. Now plot a graph of $\log I_D$ v/s V_D for all LEDs. Call this **Plot 2**. Calculate the ideality factor η of each LED from the slope. Also calculate the saturation current I_S from the y-intercept.
3. Calculate the bandgap E_g for each LED using the emission wavelengths from the figure on page 4 and putting them in equation (1).

4. From **Plot 1**, choose a constant value of I_D, say 1 mA, to define the cut-in voltage (V_γ). For each LED, find out the value of V_γ corresponding to $I_D = 1$ mA.
5. Refer back to the data you obtained in Experiment 1, for silicon diode 1N914. Find out the value of V_γ corresponding to $I_D = 1$ mA. Assume that for silicon, $E_g = 1.1$ eV.
6. Now plot a graph of V_γ v/s E_g for the LEDs as well as 1N914. For the chosen value of I_D, you should get one point (V_γ, E_g) on the graph for each diode and hence you can plot all five points (for the different diodes) on a single graph.
7. From the graph, try to find a relation between V_γ and E_g. What is the expected correlation? Do you observe any variation practically? If yes, why?

8. In addition, answer the following questions.
   (a) Google about a white LED to study what it is made of. This will help you to answer (b).
   (b) What value of E_g will you choose for the white LED? (Hint: Look at the spectrum closely. Which is the stronger emission wavelength?)

9. Additionally you may want to have some fun and do the following.
   (a) From **Plot 2**, see whether equations (2) or (3) are satisfied for the entire range of V_D.
   (b) Look at the correlation between V_γ and E_g by choosing a current level like 50 μA and/or 5 mA and see how non-ideality of the I-V affects the experiment.