Diode IV Characterization and Band Gap of Semiconductors

Electronic Devices Lab : Experiment 1

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Think it. Make it. Prove it.

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.

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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.

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Theory

- Materials with different band gaps will emit light of different wavelengths i.e. different colours. Hence LEDs of different colours have been chosen for the experiment.
- The peak emission wavelength of the LED is a measure of the band gap:

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

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

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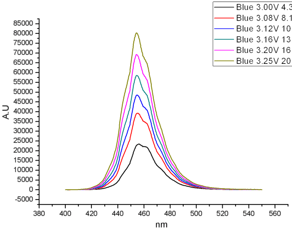
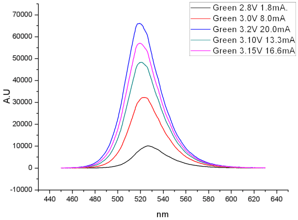
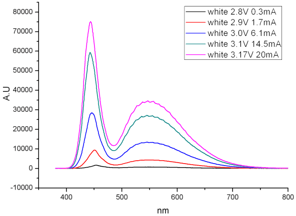


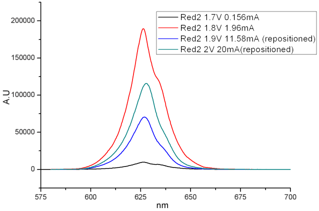
(a) Blue LED



(b) Green LED



(c) White LED



(d) Red LED

Figure: Intensity v/s wavelength of 4 coloured LEDs for various currents

Theory - continued

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

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

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 $qV_D \gg \eta kT$, equation 2 can be rewritten in logarithmic form as

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

Note that for ideal diode, ideality factor, $\eta = 1$.

Theory - continued

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.

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 v/s E_g of the diodes obtained from their emission spectrum and study the correlation.

Note that E_g of silicon is 1.1 eV (to calibrate the plot).

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Components required

- Silicon P-N junction diode 1N914, LEDs - Red, Green, Blue and White
- Resistors - 100Ω ($\times 2$)
- Potentiometer - $1k\Omega$
- Breadboard, connecting wires

Warning: This experiment involves measuring I/V characteristics of 5 diodes. The learning objective here is that not everything in life needs to be glamorous :) The boring tasks are equally important!

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Experiment Setup

1. Make the connections as per the circuit diagram. Start with 1N914 diode. Notice the role of the $1k\Omega$ pot, that can be used to vary the voltage to be applied to the diode.
2. Vary V_D in suitably small steps, and measure and tabulate I_D and V_D for each step.
3. Repeat step 2 for all the diodes.

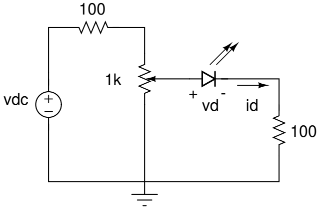

Figure: Circuit to measure I/V characteristics of a semiconductor diode

You are advised to simultaneously plot I/V in the lab,
to quickly identify if the measurement is as expected.

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1. Plot a graph of I_D v/s V_D for all five diodes. Call this plot as **Plot1**.
2. Now plot a graph of log I_D v/s V_D for all the diodes. Call this plot as **Plot2**. Calculate the ideality factor η from the slope and the saturation current I_S from the y-intercept for each diode.
3. Calculate the band-gap E_g for each LED using the emission wavelengths from the emission spectrum on slide 4 and putting them in equation 1. Note that for 1N914 diode, $E_g = 1.1\ eV$.
4. From **Plot1**, choose a constant value of I_D, say 1 mA to define the cut-in voltage, (V_γ). For each diode, find V_γ corresponding to $I_D = 1\ mA$.
5. Now plot V_γ v/s E_g. What is the expected correlation?
   Do you observe any variation practically? Justify your observations.

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Documenting and Interpreting Results

6. Are equations 2 and 3 satisfied for the entire range of V_D?
7. Observe the correlation between V_γ and E_g by choosing a current I_D of 50 μA and 5 mA and see how non-ideality of I/V affects the experiment.
8. Calculate the intrinsic doping densities of all the LEDs. Assuming density of states are approximately same for all the semiconductor materials, we have:

$$n_i \propto e^{-E_g/2KT}$$

9. Calculate the doping densities of 1N914 and all the LEDs using:

$$V_{bi} = KT \ \ln\left(\frac{N_A N_D}{n_i^2}\right); \qquad \text{Assume} \quad N_A = N_D$$

10. Tabulate E_g, I_s, V_{TH}, n_i and $N_{A,D}$ for all the LEDs and 1N914.
11. State some applications of all the diodes that you used today.