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

Wadhwani Electronics Lab 2018

Aim of the experiment

- To study the forward bias I/V characteristics of a diode and estimate the band gap of the semiconductor material which the diode is made of.
- To measure and contrast the I/V characteristics of a silicon (Si) pn junction diode and a Schottky diode. Please note that:
  - A semiconductor pn junction diode is formed by a junction of a P-type with N-type semiconductor (such as Si)
  - A Schottky junction is formed by a metal with silicon (metal-semiconductor contact)
- To explore simple applications of various diodes and appreciate their versatility

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 both 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.

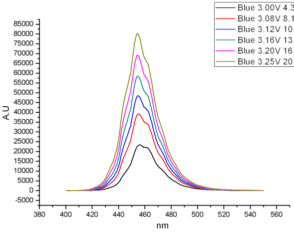
Theory

- 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. Read supporting document for detailed theory.
- The peak emission wavelength of the LED is a measure of the band gap:

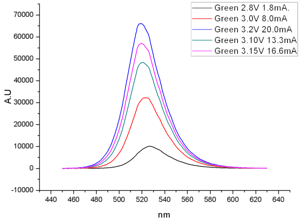
$$E_g = \frac{hc}{\lambda} = \frac{1240}{\lambda} \tag{1}$$

  E_g: band gap of the material in units of electron Volts (eV)
  λ: emission wavelength in nanometers (nm)

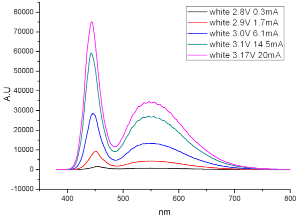
- The figure on slide 4 shows spectra of different coloured LEDs driven at various current levels. As expected, the intensity of light emission increases with current as minority carrier injection increases. Notice that the white LED shows two peak wavelengths. (Why?)



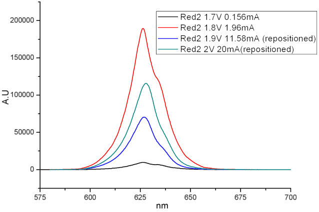
(a) Blue LED



(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:

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

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

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

Note that for ideal diode, ideality factor, η=1. If 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 1.1eV (to calibrate the plot).

Components required

- Silicon diode 1N914, Schottky diode BAT85, Zener diode, 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 6 diodes. The learning objective here is that not everything in life needs to be glamorous :) The boring tasks are equally important!

Experiment - Part 1

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 (except the Zener diode!).

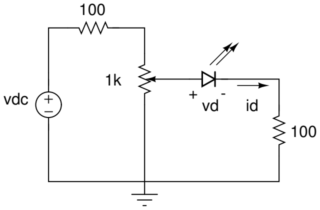


Figure: Circuit to measure I/V characteristics of a semiconductor diode

While tabulating data, you are advised to simultaneously plot I/V in the lab, to quickly identify if the measurement is as expected. (Excel or Libre office Calc will do)

Experiment - Part 2

- Connect the circuit as shown in the figure below. Connect V_s to one channel of the DSO and connect the other channel to V1, V2, and V3 one by one and record the DSO screenshots.
- Now observe V1 and V2 on the two channels. What difference do you notice? Record the DSO screenshot.

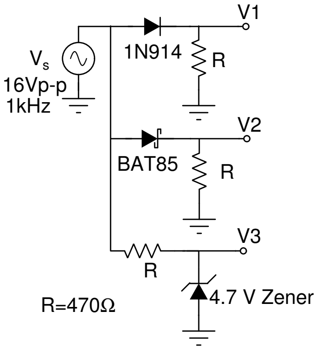


Figure: Circuit diagram for Part 2

Documenting and Interpreting Results

1. Plot a graph of I_D v/s V_D for all six diodes. Let us 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. (You need not use the data of Schottky diode for further analysis).
3. Calculate the bandgap 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.

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 50μA and 5mA and see how non-ideality of I/V affects the experiment.

8 What is the difference between the I/V characteristics of 1N914 and that of the Schottky diode?

9 Explain your observations (waveforms) in Part-2.

10 Can you predict the I/V characteristic of the Zener diode simply by observing the waveform? Justify your approach.

11 State some applications of all the diodes that you used today.

12 All the three diodes (Si, Schottky, Zener) look more or less identical. How will you identify them quickly?

13 **Advanced (AA):** Design, construct and demonstrate a circuit that gives visual indication (alarm) when the input voltage exceeds 6V. You can use only the components given to you.