LABORATORY MANUAL FOR

ENERGY BAND GAP EXPERIMENT

Background Semiconductors, PN junction diode, Forward and reverse biasing, Band gap, Fermi level.

Aim: To determine the Energy Band Gap of a Semiconductor by using PN Junction Diode.

Apparatus: Energy band gap kit containing a PN junction diode placed inside the temperature controlled electric oven, microammeter, voltmeter and connections brought out at the socket, a mercury thermometer to mount on the front panel to measure the temperature of oven.

Formula Used: The reverse saturation current, I_s is the function of temperature (T) of the junction diode. For a small range of temperatures, the relation is expressed as,

$$log_{10} I_s = Constant - \frac{5.036 \ X \ 10^3 E_g}{T}$$

Where, T is temperature in Kelvin (K) and E_g is the band gap in electron volts (eV).

Graph between $10^3/T$ as abscissa and $\log_{10} I_s$ as ordinate will be a straight line having slope = 5.036 E_g
Hence band gap,

$$E_g = \frac{Slope \ of \ line}{5.036}$$

Theory: A semi-conductor (either doped or intrinsic) always possesses an energy gap between its valence and conduction bands (fig.1). For the conduction of electricity, a certain amount of energy is to be given to the electron so that it can jump from the valence band to the conduction band. The energy so needed is the measure of the energy gap (E_g) between the top and bottom of valence and conduction bands respectively. In case of insulators, the value of E_g varies from 3 to 7 eV. However, for semiconductors, it is quite small. For example, in case of germanium, E_g = 0.72 eV and in case of silicon, E_g = 1.1 eV.

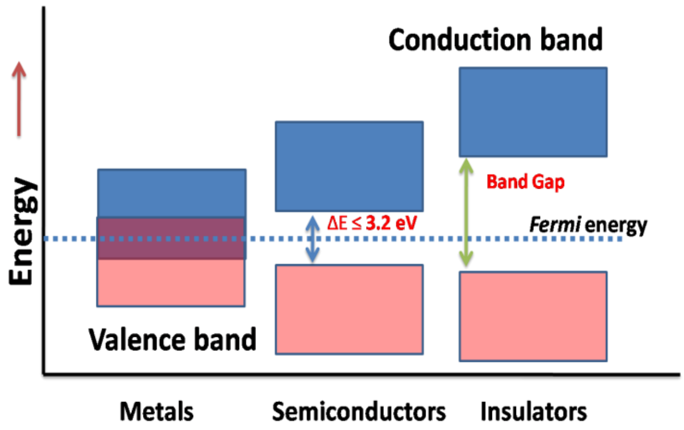

Fig.1. Energy Gap in Metals, Semi-conductors and Insulators

In semi-conductors at low temperatures, there are few charge carriers to move, so conductivity is quite low. However, with increase in temperature, more number of charge carriers get sufficient energy to be excited to the conduction band. This lead to increase in the number of free charge carriers and hence increase in conductivity. In addition to the dependence of the electrical conductivity on the number of free charges, it also depends on their mobility. The mobility of the charge carriers, however decreases with increasing temperature. But on the average, the conductivity of the semiconductors rises with rise in temperature.

To determine the energy band gap of a semi-conducting material, we study the variation of its conductance with temperature. In reverse bias, the current flowing through the PN junction is quite small and internal heating of the junction does not take place.

When PN junction is placed in reverse bias as shown in fig.2(a), the current flows through the junction due to minority charge carriers only. The concentration of these charge carriers depend on band gap E_g.

The saturation value, I_s of reverse current depends on the temperature of junction diode and it is given by the following equation,

$$I_s = A\,(N_n\, e\, v_n + N_p\, e\, v_p)\, e^{\frac{-E_g}{kT}}$$

Where, N_n (N_p) is the concentration of electrons (holes) in N(P)-type region,

v_n and v_p are the drift velocities of electrons and holes respectively,

A is the area of junction,

k = 1.38 x 10^{-23} J/K, is Boltzman's constant and T is absolute temperature of junction.

Taking log of both sides of above equation, we have

$$log_e I_s = log_e\, A\,(N_n\, e\, v_n + N_p\, e\, v_p) - \frac{E_g}{kT}$$

Or $$2.303\, log_{10} I_s = 2.303\, log_{10}\, A\,(N_n\, e\, v_n + N_p\, e\, v_p) - \frac{E_g}{kT}$$

Or $$log_{10} I_s = C - \frac{E_g}{2.303\, kT}$$

Where C is a constant, which is equal to the first term of RHS of above equation. On substituting the value of k and converting the units of E_g from eV to Joule, we get

$$log_{10} I_s = C - \frac{1.6\ x\ 10^{-19}\ E_g}{2.303\ x\ 1.38\ x\ 10^{-23}\ T}$$

Or $$log_{10} I_s = C - \frac{5.036\ X\ 10^{3} E_g}{T}$$

Which can be expressed as,

$$log_{10} I_s = C + (-5.036\, E_g)\frac{10^3}{T}$$

This represents the equation of straight line having negative slope (5.036 E_g) for graph drawn between $\log_{10} I_s$ and $10^3/T$. Therefore, by knowing the slope of the line, E_g can be determined through following formula,

$$\text{Slope} = 5.036\ E_g$$

$$E_g = \frac{Slope\ of\ graph\ drawn\ between\ log_{10}\, I_s \text{ and } \frac{10^3}{T}}{5.036}$$

Procedure: The experimental setup is shown in fig.2(b).

1. Insert the thermometer in the hole of the oven.
2. Switch ON the instrument using ON/OFF toggle switch provided on the front panel.
3. Keep the temperature control switch to the high side.
4. Adjust the voltage at 1V DC.
5. Switch ON the oven using ON/OFF toggle switch provided on the front panel. Temperature starts increasing and the reading of microammeter also starts increasing.
6. When temperature reaches to 90°C or 100°C, switch OFF the oven and note down the reading of microammeter (µA).
7. As the temperature starts falling, note down the readings of microammeter after every 5°C or 10°C drop in temperature.
8. Repeat the whole procedure for 2V and 3V DC.
9. Plot graph between $\log_{10} I_s$ and $10^3/ T$ for different voltages.

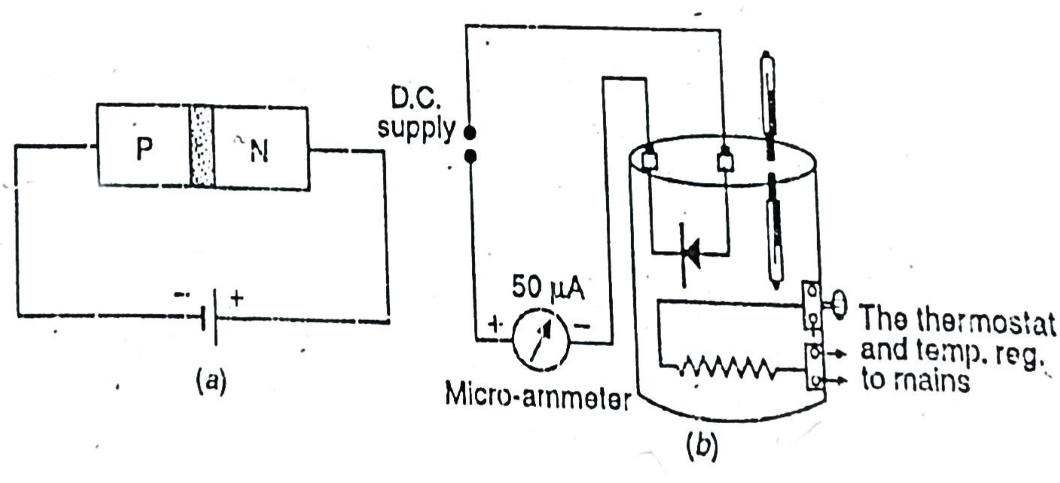

Fig. 2 (a) Reverse biased PN junction Diode (b) Experimental Setup

Observations:

S.No.	Temp. (°C)	Current I_s (μA)			Temp. (K)	10^3/ T	$\log_{10} I_s$
		V = 1V	V = 2V	V = 3V			
1.	30						
2.	40						
3.	50						
4.	60						
5.	70						
6.	80						
7.	90						
8.	100						

Calculations:

Taking 10^3/ T along X-axis and $\log_{10} I_s$ along Y-axis, plot a graph between $\log_{10} I_s$ and 10^3/ T for three different voltages. The graph will be a straight line as shown in fig.3. Determine the slope of straight line from this graph and then calculate band gap using formula,

$$\text{Band gap } (E_g) = \frac{Slope}{5.036} = \_\_\_\_\_\_\_\_ \text{ eV.}$$

Take average of three values of band gap.

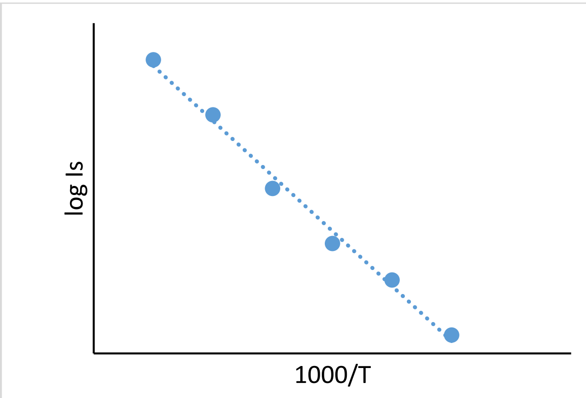

Fig.3. Variation of $\log_{10} I_s$ v/s 10^3/T

Result:

The band gap (E_g) of the given semiconductor is found to be _______ eV.

Precautions:

The following precautions should be taken while performing the experiment:

1. The diode must be reverse biased.
2. Do not exceed the temperature of the oven above 100℃ to avoid over heating of the diode.
3. The voltmeter and ammeter reading should initially be at zero mark.
4. Bulb of the thermometer should be inserted well in the oven.
5. Readings of microammeter should be taken when the temperature is decreasing.
6. Readings of current and temperature must be taken simultaneously.

Sample viva voce questions:

1. What is PN junction diode?
2. What do you understand by band gap of a semi-conductor?
3. What do you mean by valence band, conduction band and forbidden band?
4. How many types of semi-conductors are there?
5. What are P-type and N-type semi-conductors?
6. Define doping and dopant.
7. Why P-type (N-type) semi-conductor is called Acceptor (Donor)?
8. What do you mean by Fermi energy level?
9. What is the position of Fermi level in an intrinsic semi-conductor and in a p-type or n-type semi-conductor with respect to the positions of valence and conduction bands?
10. What do you mean by forward biasing and reverse biasing?
11. Why diode is reverse biased in determining the band gap of semi-conductor?
12. What is the shape of graph between $\log_{10} I_s$ and $10^3/T$? How do you find band gap energy from this graph?
13. Why conductivity of metals decreases with increase in temperature?
14. Why conductivity of a semi-conductor increases with increase in temperature?

References:

- Solid State Electronic Devices by Streetman and Banerjee
- B.sc Practical Physics by Geeta Sanon

Note: Soft copy of this manual will be available on http://www.nitj.ac.in/physics/