International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Some Light on Determination of Energy Gap of Semiconducting Material Using P-N Junction Diode and Thermistor.

M. Venkata Ramana

Department of Physics
Anurag University, Hyderabad – 500088, India.

ABSTRACT

This paper aims at determination of energy gap of semiconducting material using p-n junction diode and thermistor and through light on the confusion and erroneous procedures being involved at the undergraduate level by following the manuals supplied along the ready-made kits. The theory involved in using both the devices was discussed.

Introduction

The measurement of the band gap of material is an important task in the semiconductor, nanomaterial and solar industries. The term “band gap” refers to the energy difference between the top of the valence band to the bottom of the conduction band. In order for an electron to jump from a valence band to a conduction band, it requires a specific minimum amount of energy for the transition which is often called as the band gap energy. Measuring this band gap energy is important in the semiconductor and nanomaterial industries in order to use them in various applications. Hence as a fundamental laboratory experiment, determination of the band gap of the semiconductor material using the p-n junction has been introduced at under-graduate level in various Science and engineering programmes in number of colleges and Universities. At the same time, few of these institutions have included another experiment with the objective of determination of energy gap of a semiconductor material using Thermistor. Almost every undergraduate Physics Laboratory text book includes this experiment including the special references given in this because of their contribution towards the energy gap determination and the physics involved therein of.

The physics behind the behaviour of p-n junction diode and the thermistor is different. More particular the principle used in determination of energy gap using these two devices is completely different. In the case of p-n junction diode, the temperature dependence of the saturation current in the reverse biased p-n junction diode plays key role where as the variation of resistivity or resistance with temperature of the sample is the factor while using the thermistor.

However, as the present laboratory experiments were done by the students using the so called kits, wherein the student doesn’t know what is inside the enclosure of the kit but could collect the readings by connecting red to red and black to black with connecting wires and the theory and the procedure is being gathered by the manuals provided by the manufacturers of these kits, there are some erroneous calculations and results have been obtained by the students which has become a practice for years together. Having the belief in what is supplied by the manufacture is allowed but when it contradicts with the physics that we learn, one needs to correct the manufacturers of these kits, how popular they may be. Erroneous science should not be taught to the next generations. Hence an attempt is made here in this paper to differentiate between these two experiments and to arrive at the correct procedure and formulae to be used for calculating the energy gap.

Theory for determination of energy gap of a semiconductor material using p-n junction diode

When a p-n junction diode is reverse biased, a small current flows which is nearly independent of the bias potential. This current is called saturation current and appears in the characteristic current-voltage relationship as I_s. The current in the circuit follows

$$I(V) = I_s \left[exp^{\left(\frac{eV}{KT}\right)} - 1 \right]$$

Where V is the applied bias voltage, T is the absolute temperature, e is the charge of electron and K is the Boltzmann constant. The saturation current is a combination of the generation current caused by thermal generation of electron hole pairs within the depletion region of the diode and the diffusion current due to minority carriers in the n and p regions diffusing across the depletion region. Even though the saturation current is voltage independent, it does depend on temperature since both the current contributions depend on thermally stimulated carriers.

The generation current comes from the electron-hole pairs that are thermally generated within the depletion region. The temperature dependence of I assumes that the depletion region behaves like an intrinsic semiconductor when the diode is reverse biased at low temperature. The conductivity and the current flow will be proportional to intrinsic carrier concentration.

The generation current dominant when the intrinsic carrier concentration is so small compared to dopant contributed carrier concentrations and the depletion region behaves like as that of intrinsic semiconductor.

The diffusion current is due to minority carriers within each region of diode diffusing to the other region. This diffusion current direction is in the reverse bias direction. The diffusion current will dominate if the minority carrier concentrations are very large. This condition is satisfied for more effectively the smaller ratio of Eg/KT.

When the diode is reverse biased, $exp^{\left(\frac{eV}{KT}\right)} \ll 1$. This leads to I(V) = - I_s. Thus the reverse saturation current is constant and independent of the applied voltage. This reverse saturation current is a function of temperature of the junction diode and can be written as

Is = npAeμ = n_i^2Aeμ as np = n_i^2

And n_i^2 can be written as

$$n_i^2 = KT^3\ exp^{-\left(\frac{E_g}{KT}\right)}$$

Where Eg is the energy gap.

Thus I_s = $KT^3\ exp^{-\left(\frac{E_g}{KT}\right)}$Aeμ = Aeμ $KT^3\ exp^{-\left(\frac{E_g}{KT}\right)}$ = C $T^3\ exp^{-\left(\frac{E_g}{KT}\right)}$ where C is a constant equal to Aeμ K

From this we can write

log I_S = log (C T^3) $- \frac{E_g}{KT}$

The value of log (C T^3) is nearly constant and hence

log I_S = constant $- \frac{E_g}{KT}$

This represents a straight line when log I_s is taken on Y-axis and 1/T on X-axis.

From the slope of the graph, we can determine the Eg.

$E_g = \frac{slope\ of\ the\ graph\ between \log Is\ and\ (\frac{1}{T})}{5.036}$ eV

In general, for convenience the X-axis will be taken as 1000/T and for obtaining the slope, the Excel or Origin will be used and a straight line will be fitted to the data.

Theory for determination of energy gap of a semiconductor material using Thermistor

For the other experiment i.e with the thermistor, the procedure will be essentially same with slight modifications. The thermistors are semiconductor devices with high negative temperature coefficient. The high degree of sensitivity, nearly equal to 5% change per degree rise in temperature, makes them to use in temperature measurement and control of temperature.

The thermistor is made up of a semiconducting material whose resistance decreases following the relation

$R_T = R_0\ exp^{\left(\frac{Eg}{2KT}\right)}$

Where R_T is the resistance at temperature T in Kelvin degrees and R_0 is the resistance at 0 Kelvin. Here E_g and K are the energy gap and Boltzmann constant.

We can write

ln R_T = ln R_0 + $\left[\frac{Eg}{2K}\right]\left[\frac{1}{T}\right]$

If we plot a graph taking ln R_T on Y-axis and $\left[\frac{1}{T}\right]$ on X-axis, it will be a straight line with slope $\left[\frac{Eg}{2K}\right]$.

If we plot a graph taking $\log_{10} R_T$ on Y-axis and $\left[\frac{1}{T}\right]$ on X-axis, it will be a straight line with slope $\left[\frac{Eg}{2.303*2\ K}\right]$ or $\left[\frac{Eg}{4.606\ K}\right]$.

The energy gap is calculated using the slope of the straight line obtained from the straight line fit of the data as

E_g = 4.606 x K x (slope of the graph)

The substitution of value of Boltzmann constant and converting into eV, we get

E_g (eV) = 3.96 x 10^{-4} x (slope of the graph)

Note on performing experiment

In the case of thermistor, we measure the resistance either by connecting a Ohmmeter or by connecting an ammeter and then converting the current into resistance. In the case of reverse biased p-n junction diode a micro-ammeter is connected and the current is measured. Here current will not be converted into resistance as principle involved is the variation of reverse saturation current with temperature. In the case of thermistor, the resistance variation with temperature and in the case of reverse biased p-n junction diode the saturation current variation with the temperature is to be plotted, of course, after taking the logarithms. The temperature of the device in both the cases will be conventionally varied, in the ready-made kits, by keeping the device in coconut oil bath and by heating the oil with the help of an electric heater which is built–in in most cases.

Reasons for error that creep in

Most of the ready-made kits use Germanium p-n junction diode. The energy gap value will be around 0.7eV. The value obtained from these experiments will be generally higher than the expected 0.7eV Due to the fact that the sample temperature is higher than the thermometer reading, there will be more EHP formation. This causes the Fermi Level to be different than expected. The increase in temperature causes Fermi Level to shift towards the conduction edge. Further, the $T^{(3/2)}$ term in the reverse bias current will also has the influence with variation in temperature.

Conclusions

The energy gap of semiconducting material can be determined using p-n junction diode and thermistor, following almost same procedure and with same ready-made kit. When p-n junction diode is used, the equation of saturation current

$$\log I_S = \text{constant} - \frac{E_g}{KT}$$

should be used and a graph for log I_s on Y-axis and 1/T on X-axis should be plotted. From the slope of the graph, E_g will be determined using

$$E_g = \frac{slope\ of\ the\ graph\ between \log Is\ and\ (\frac{1}{T})}{5.036}\ \text{eV}$$

When thermistor is used, we measure the resistance of the thermistor at diferent temperatures and graph between $\log_{10} R_T$ and $\left[\frac{1}{T}\right]$ will be plotted. The energy gap is calculated using the slope of this line by using

E_g (eV) = 3.96 x 10^{-4} x (slope of the graph)

REFERENCES

A.Vasudeva, A Manual of practical engineering physics, S.Chand, 2003, 211.

John R. Taylor and Chris D. Zafiratos, Modern Physics for Scientists and Engineers, Prentice-Hall (1991), pp. 513-519.

Robert A. Levy, Principles of Solid State Physics, Acadenic (1968), pp. 381

Thriveni D, Nagaraja K P, Rohith P S, Sajida K. M. and Veekshitha B. V. Study of Energy Gap of Semiconductor: A Graphical and Least Square Fit Approach E- ISBN: 978-1-68576-432-6, July 2023

Vinay kumar Singh, Volume 4, Issue 12 Journal of Emerging Technologies and Innovative Research, 12,4,2017, p1200 .

G. Busch, Early history of the physics and chemistry of semiconductors from doubts to fact in a hundred years, Eur. J. Phys., Vol. 10, No. 4, pp. 254–263, 1989.

J. Orton, The Story of Semiconductors. Oxford: Oxford University Press, 2004, p. 359.