Experiment No. 3

Object: **(1)** To measure resistivity of semiconductor at different temperatures by Four Probe Method.
(2) To determine Band Gap of the semiconductor.

Apparatus Used: The Four Probe Set-Up (Model DEP-03 # 70) consists of the following:
(i) Four Probes Arrangement: It has four individually spring loaded probes. The probes are collinear and equally spaced. Whole arrangement is mounted on a suitable stand.
(ii) Sample: n-type Ge Single Crystal chip.
Thickness = 0.50mm.

(iii) Oven: For the variation of temperature from room temperature to 200˚C.
Maximum Operating Temperature for Ge: 120˚C

(iv) Thermometer (0-200˚C): For measuring temperature.

(v) Four Probe Set-Up: Consisting of
(a) Constant current Generator (0-20 mA) with 10 μA resolution
(b) Oven power supply (0-64 V)
(c) Digital voltmeter (0-200 mV & 0-2 V) and ammeter (0-20 mA).
(d) Main ON/OFF Switch.

Formula Used:
The resistivity of sample is given by

$$\rho = \rho_0 / G_7(W/S)$$

where, intrinsic resistivity of material $\rho_0 = (V / I) \times 2\pi S$ and $G_7(W/S)$ is a correction factor which depends on the distance between probes S (here S=2mm) and thickness of the crystal (W here W=0.5mm). For Ge,
$G_7(W/S) = 2S/W (\log_e 2)$

The resistivity of semiconductor varies with temperature as

$$\rho = \rho_0 \exp (E_g/2k_B T)$$

we can write,

$$E_g /2k_B = \log_e\rho / (1/T)$$

where, V= voltage, I= Current, T=Temperature of sample, Boltzmann constant $k_B = 8.6 \times 10^{-5}$ eV/deg and E_g = Energy band gap.

Theory:

By Ohm's law, the electric field intensity, $\vec{E}$ at a point in a material is proportional to the current density, $\vec{J}$ that it induces at that point. The proportionality constant is called electrical resistivity, ρ of the material. That is,

$$\vec{E} = \rho\vec{J}$$

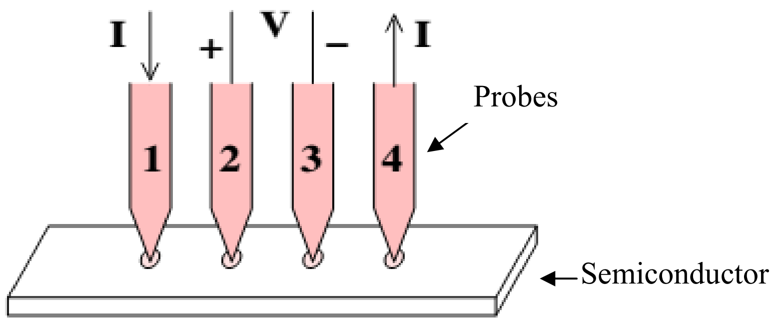

Fig. 1: Four probe experiment arrangement

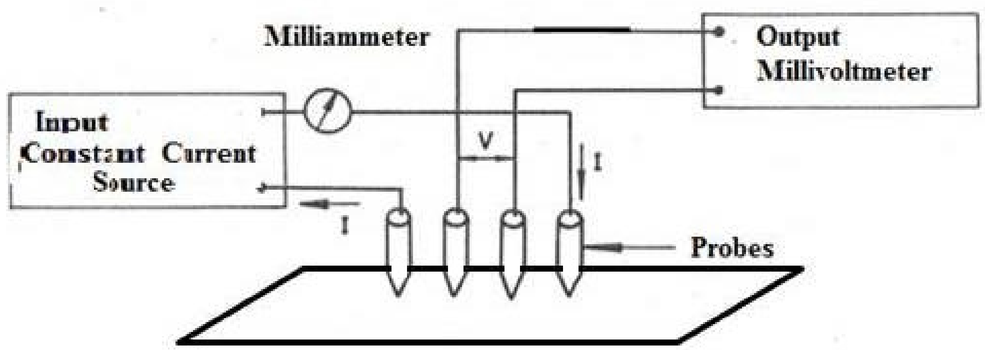

Fig. 2: Circuit used for resistivity measurements

For a sample with a long wire like geometry with uniform cross-sectional area, ρ can be measured by simply passing a known current through the sample and measuring the voltage drop across it. This simple method has however several disadvantages. For example, it cannot be applied to samples with non-regular shapes, there could be errors due to contact resistance of the measuring leads, soldering the contact leads itself can be difficult for some samples etc. Also in case of semiconductors, the soldering process may results in injection of impurities into the sample thereby affecting its intrinsic electrical resistivity. Some of the above difficulties can be overcome by employing a technique called four probe method. In the four probe method, four pointed, collinear, equally spaced probes are placed in pressure contact with the plane surface of the sample (Figure 1). A current is injected into the sample through the outer two probes (1 & 4). The resulting electric potential distribution is measured via the two inner probes (2 & 3). The voltage drop, V across probes 2 & 3 for a current I through probes 1 & 4, is given by a simple expression, if certain conditions are satisfied. The surface of the sample is assumed to be flat with no surface leakage. The diameter of the contact point between each probe and the sample should be small compared to the distance between the probes. Also the thickness, W of the sample is assumed to be much smaller than the distance, S between two probes. Under such conditions, resistivity of the sample is given by

$$\rho = \rho_0 / G_7(W/S) \qquad (1)$$

where ρ_0 is computed as

$$\rho_0 = \left(\frac{V}{I}\right) 2\pi S \qquad (2)$$

and the correction factor $G_7(W/S)$ is given as,

$$G_7\left(\frac{W}{S}\right) = \left(\frac{2S}{W}\right) \ln 2 \qquad (3)$$

Also the temperature variation of resistivity of a semiconductor is given by,

$$\rho = \rho_0 \exp\left(\frac{E_g}{2K_B T}\right) \qquad (4)$$

Taking logarithm of both sides of the above equation,

$$ln\rho = \frac{E_g}{2x10^3 K_B}\left(\frac{10^3}{T}\right) + ln\rho_0 \qquad (5)$$

The factor 10^3 above is inserted for convenience. Thus a plot of 'ln ρ' as a function of $10^3/T$ is a straight line with the slope being equal to,

$$slope = \frac{E_g}{2x10^3 K_B} \qquad (6)$$

Therefore, the band gap of semiconductor is

$$E_g = 2x10^3 K_B (slope) \qquad (7)$$

Procedure:

(1) Connect the outer pair of probes leads labelled as current generally Red & Black, to the constant current power supply and the inner pair of probes leads labelled as voltage generally Yellow & Green, to voltage terminals.

Note: Make sure the polarity of leads are correct

(2) Switch on the AC mains of Four Probe Set-up and put the digital panel meter in the current measuring mode through the selector switch. In this position LED facing mA would glow. Adjust the current to a desired value (Say 1.2 mA).

(3) Now put the digital panel meter in voltage measuring mode. In this position LED facing mV or V would glow depending upon the position of switch and the meter would read the voltage between the probes.

(4) Connect the oven power supply. Rate of heating may be selected with the help of a switch –Low or High as desired. Switch on the power to the Oven. The glowing LED indicates the power to the oven is 'ON'.

Note: Oven temperature should not exceed 120°C

(5) Measure the inner probe voltage V, for various temperatures.

Observations:

Constant Current (I) = 1.2 (mA)
Distance between probes (S) = 2 mm
Thickness of the crystal (W) = 0.5 mm

(a) Table for resistivity measurement for temperature in increasing order

S. No.	Temperature in increasing order (K)	Voltage (V)	ρ_0	$\rho = \rho_0 / G_7(W/S)$ (Ohm-cm)	T^{-1} x (10^3)	$\log_e \rho$
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						

(b) Table for resistivity measurement for temperature in decreasing order

S. No.	Temperature in decreasing order (K)	Voltage (volts)	ρ_0	$\rho = \rho_0 / G_7(W/S)$ (Ohm-cm)	T^{-1} x (10^3)	$\log_e \rho$
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						

Calculations:

$$G_7(W/S) = 2S/W\ (\log_e 2) \qquad \text{(For Ge)}$$

In our case

$$G_7(W/S) = 5.54$$

$$\rho_0 = (V / I) \times 2\pi S$$

$$\rho_0 = (V / I) \times 1.256$$

$$\rho = \rho_0 / G_7(W/S)$$

$$E_g / 2k_B = \log_e\rho / (1/T) = 10^3 \times \log_e\rho / (10^3/T)$$

Plot graph 1 between ρ and T ; and graph 2 between $\log_e\rho$ and $(10^3/T)$ and find the slope from graph 2

Slope = ……….

Band gap is

$$E_g = 2x10^3 k_B(slope)$$

E_g = ……..eV

Results: Graph 1 shows the variation of ρ vs T and the Band Gap of the given semiconductor is found to be = ...eV

Percentage Error: $$\frac{\text{Standard value of band gap} - \text{Calculated value of band gap}}{\text{Standard value of band gap}} x100$$

Sources of error and precautions:

(i) The probes must be gently placed otherwise Germanium crystal can break.
(ii) Temperature must be measured carefully.
(iii) An insulating sheet must be placed between the Germanium sample and base on which it is kept.
(iv) The surface on which the probes rest should be flat with no surface leakage.
(v) The diameter of the contact point between the metallic probes and the semiconductor crystal chip should be small compared to the distance between the probes

Viva-Voice:

1. What is the band gap of semiconductor?
2. How do you differentiate between a conductor, an insulator and a semiconductor in relation to energy gap?
3. Why a semiconductor behaves as an insulator at zero degree Kelvin?
4. What is the advantage of Four Probe method over the other conventional methods?
5. Can we use an ordinary millivoltmeter instead of electronic millivoltmeter or potentiometer to measure the inner probe voltage? why?
6. Explain the behaviour of the $\log_{10}(\rho)$ vs.1/T curve.
7. What do you know about intrinsic and extrinsic semi-conductor?

8. What are maximum operating temperature limits for Ge and Si semiconductors and why we don’t exceed this limit?
9. What are direct and indirect band gaps of semiconductors?
10. How resistivity varies with temperature for semiconductor, insulator and conductor?
11. What do you meant by resistivity and conductivity?
12. How resistivity varies with thickness and cross section of material?
13. What give rise to resistivity in semiconductor, insulator and conductor?
14. Difference between resistivity and specific resistance.
15. Are you a conductor or semiconductor?

References:

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4. Electrons and Holes, W. Shockley, D van Nostrand NY 1950.
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