Experiment 1.2

To find the band gap of intrinsic semiconductor using four probe methods.

Apparatus Required:

A four probe arrangement (consists of a layer of zinc coated at it tips. The probes should be spaced equally), Ge or Si samples of semiconductor, oven, a constant current generator, Oven, a constant current generator, thermometer (to measure temperature), digital voltmeter, ammeter etc.

Theory:

The Resistance of a conductor of length 'l' and uniform area cross section 'a' is given as $R \propto \frac{l}{a}$

$$R = \rho\frac{l}{a} \quad \text{....(1)}$$

$$\rho = \frac{R.a}{l} \quad \text{....(2)}$$

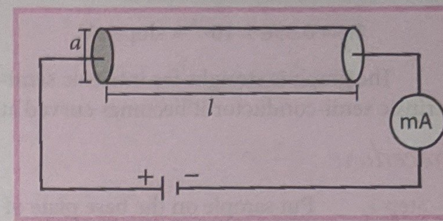

Fig. 1.6.

where ρ is constant of proportionality and known as *specific resistance or resistivity of the material.* It has units ohm-cm or ohm-*m*.

In order to calculate specific resistance or resistivity apply a constant potential across the conductor and note corresponding value of current. Plot V-I characteristics and find value of resistance of a conductor.

Using equation (2) find the value of resistivity. But equation (2) is applicable only if dimension of conductor are known.

Also in case of semi-conductor V-I characteristic will not be same for biasing in both the directions.

All the above difficulties are over come by using four probe method.

Basically in four probe, there four probes, in which outer two used for passing current and inner two probes is used for measuring potential difference between any two points on the specimen using volt meter.

If dimension of specimen are large compared to spacing between the probes then potential between two points is given as

$$V = \frac{\rho_0 I}{2\pi d} \qquad \text{or} \qquad \rho_0 = \frac{V}{I}2\pi d$$

where S is spacing between the probes. If slice is thin some correction divisor is to be applied.

For conducting bottom surface, $\rho = \frac{\rho_0}{f(W/d)}$,

where $f(W/d)$ can be calculated from table for different values of W and *d*.

Table 1.2.

S. No.	W/d	$f(W/d)$	
		For conducting bottom surface	**For non-conducting bottom surface**
1.	0.100	0.0000019	13.863
2.	0.141	0.00018	9.704
3.	0.200	0.00342	6.931
4.	0.33	0.0604	4.159
5.	0.500	0.228	2.780
6.	1.000	0.683	1.504
7.	1.414	0.848	1.223
8.	2.000	0.933	1.094
9.	3.333	0.9838	1.0228
10.	5.000	0.9948	1.0070
11.	10.000	0.9993	1.00045

Note : If any W/*d* is not found in the table, then plot a graph between W/*d* and $f(W/d)$ values. From graph obtained desired $f(W/d)$ corresponding to any W/*d*.

Further the variation of resistivity with temperature in case of a semiconductor is given as $\rho = (\text{const.}) \exp\left[\frac{E_g}{2k_B T}\right]$

Taking log of both sides, we get

$$\log_e \rho = \log_e (\text{const.}) + \frac{E_g}{2k_B T}$$

$$2.3026 \log_{10}\rho = \frac{E_g}{2k_B T} + 2.3026 \log_{10} (\text{const.})$$

$$\log_{10}\rho = \frac{E_g}{(2.3026)\cdot 2k_B} \times \frac{1}{T} + \log_{10} (\text{const.})$$

The plot of $\log_{10}\rho$ Vs $\frac{1}{T}$ will be a straight line.

$$\boxed{\text{Slope of graph} = \frac{E_g}{2.3026 \times 2k_B}}$$

$$E_g = 2.3026 \times 2k_B \times \text{slope}$$
$$= 2.3026 \times 2 \times (8.6 \times 10^{-5}\ \text{eV/K°}) \times \text{slope}$$

$$E_g = 0.396 \times 10^{-3} \times \text{slope eV.}$$

The graph is straight for intrinsic semi-conductor and for extrinsic semi-conductor it becomes curved at moderate and at higher temperature.

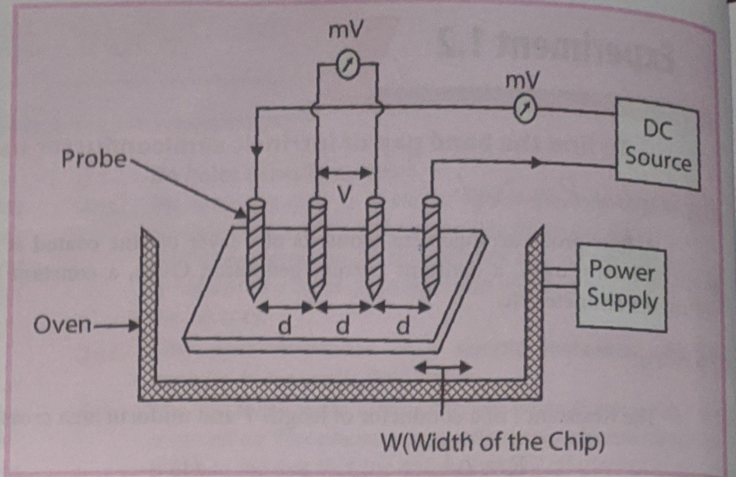

Fig. 1.7.

Procedure :

Step 1. Put sample on the base plate of four probe arrangement and lower the probes carefully so that there is a good contact between the probes and wafer. To ensure proper electrical contact check continuity between the probes.

Step 2. The outer pair of probes is connected to current source and inner pair of probes is connected to the voltmeter. The oven is connected to power supply.

Step 3. Set a constant current in constant current supply and note down its value.

Step 4. Now increase the temperature of oven and note down corresponding value of voltage for every 5°C rise in temperature.

Step 5. Take 10-15 observations. It is observed that as the temperature increases voltage decreases.

Observation :

Distance between probes = ... cm, Thickness of semi-conductor water = ... cm

Current, I = ... mA

Table 1.3. *To measure voltage with rise in temperature.*

S. No.	Temperature (°C)	Temperature (K)	Voltage (volts)
1.			
2.			
3.			
4.			
:			
:			
15.			

Find ρ_0 corresponding to different values of voltage using relation $\rho_0 = \frac{V}{I} \cdot 2\pi S =$ .... ohm-cm

Then find ρ corresponding to different temperatures using relation $\rho = \frac{\rho_0}{f(W/d)}$

Table 1.4.

S. No.	Temperature (°C)	$\frac{1}{T} \times 10^3$	ρ	$\log_{10}\rho$
1.				
2.				
3.				
4.				
:				
:				
15.				

Calculations :

Plot a graph between $\log_{10}\rho$ and $10^3/T$

From graph, Slop $= \dfrac{\Delta y}{\Delta x}$

As, $E_g = 0.396$ slope eV. [$\because$ graph is plotted between $\log_{10}\rho$ & $10^3/T$]

$\therefore E_g = 0.396 \times \dfrac{\Delta y}{\Delta x}$ eV

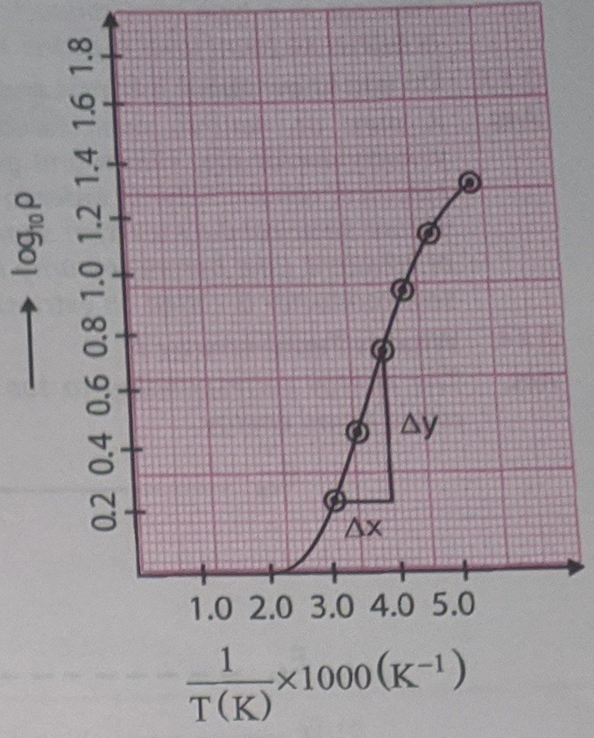

Fig. 1.8.

Result:

The band gap of given semiconductor is = ... eV

Precautions :

(i) Resistivity of the material should be uniform, in the area of measurement.
(ii) The surface on which probe rests should be flat.
(iii) Current through the sample should be kept constant.
(iv) Exert minimum pressure to make electrical contact of probe with the wafer.
(v) Temperature should be measured carefully.
(vi) Current should not be large enough to cause heating.