Experiment No. 13(ii)

Object : To determine the energy band gap of a given extrinsic semi-conductor (Germanium) material by thermal variation using four probe method.

Apparatus : *Four probe arrangement (spring type), four probe set up, oven with supply, germanium or silicon crystal chip with non-conducting base and a sensitive thermometer.*

Description of the Apparatus

Four Probe Arrangement with Oven : In four probe method four spring type contacts are used to avoid contact resistance. In fact soldered probes contact or direct soldering to the body of the sample effects the sample properties by heating effect and contamination. Four electrodes probe arrangement consists of four spring type collinear equally spaced probes coated with zinc at the tips (Fig. 13.3). The probes are mounted in a teflon bush for good electrical insulation. The outer probes (1, 4) are used to pass current *I* through the specimen of known conductivity sample *S'*. The constant current source *I* used in the experiment is specially designed for this method to provide 100% protection from crystal burn due to excess current. In this source the value of current can be changed by the potentiometer included for that purpose. The current *I* is usually low, of the order of milliampere and is measured by a milliammeter of 0-10 mA range. The inner pair probes (2, 3) measure voltage *V* by a digital electronic millivoltmeter specially designed for this purpose. However, any pair of electrodes may be used to pass current *I* while the remaining pair may be used to measure voltage *V*. The whole arrangement is mounted on a suitable stand and leads are provided for current and voltage measurements (usually green leads are provided for current and orange leads for voltage measurement). At the top of the four probe arrangement stand a hole is provided for inserting a thermometer to measure the oven temperature. A good quality thermometer of generally 0-200°C range is used to measure the oven temperature. Variation of temperatures of crystal from room temperature to about 175°C is studied in a small oven the supply for which is built-in inside the set up. The supply has three different output voltages for the oven to change the rate of heating.

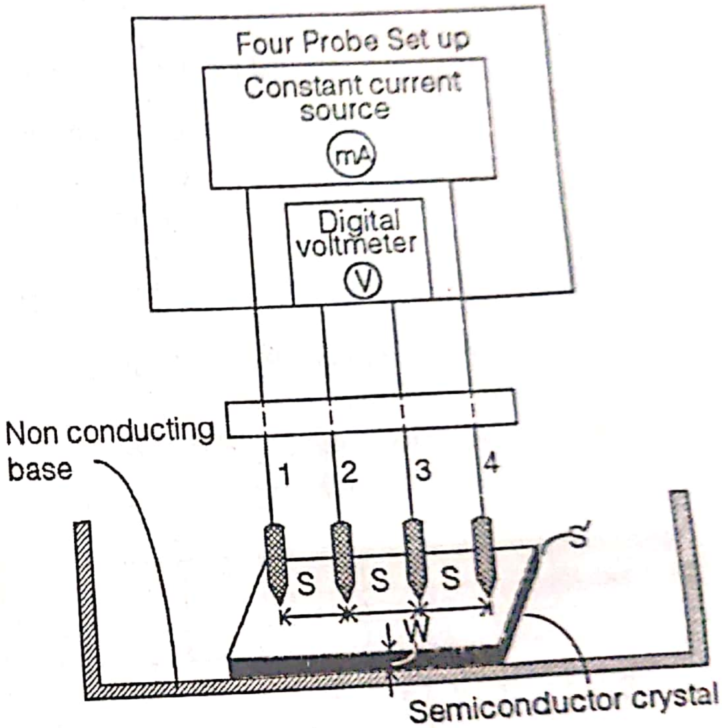

Fig. 13.3

Assumptions for four probe technique : The four probe technique is based on the following assumption :

1. The surface of the sample on which the four electrodes probe rest is flat, uniform, having no leakage, adequately large and crystal should be of big size.
2. The spring type contacts between the probes are point contacts and lie in a straight line.
3. The resistivity of the crystal is considered to be uniform in the area of measurement.
4. The bottom surface of the sample chip is non-conducting.

5. The contacts between the probes and the surface are point contacts.
6. The thickness of the sample in chip shape should be less than the half the distance between the probes or probe spacing (S).
7. If there is minority carrier injection into the semi-conductors by current carrying electrode probes most of the carrier recombine near the electrode probes so that there effect on the conductivity become negligible.

Theory and Formula Used

If the current I is passed through the outer probes and V the potential difference measured across the inner probes, then the resistivity of the sample is given by

$$\rho_0 = \frac{V}{I} \times 2\pi S \qquad \text{......(1)}$$

where S is the distance between the two successive probes.

If probe spacing is 0.159 cm, then

$$2\pi S = 1 \qquad and \qquad \rho_0 = \frac{V}{I}$$

As the thickness of the crystal is very small compared to the probe distance the equation (1) is not applicable directly, but a correction factor for it is to be applied. For a thin slice non-conducting bottom surface, the resistivity may be expressed as

$$\rho = \frac{\rho_0}{F(W/S)}$$

where W is the thickness of the semi-conducting material and S the probe spacing. The value of function F(W/S) is obtained either from table A or from the graph shown in fig. 13.4. In table A, the value of F(W/S) for different combination of W/S is given. If any W/S value is not found in the table, then the desired value of F(W/S) corresponding to any value of (W/S) can be obtained from the graph shown in fig. 13.4.

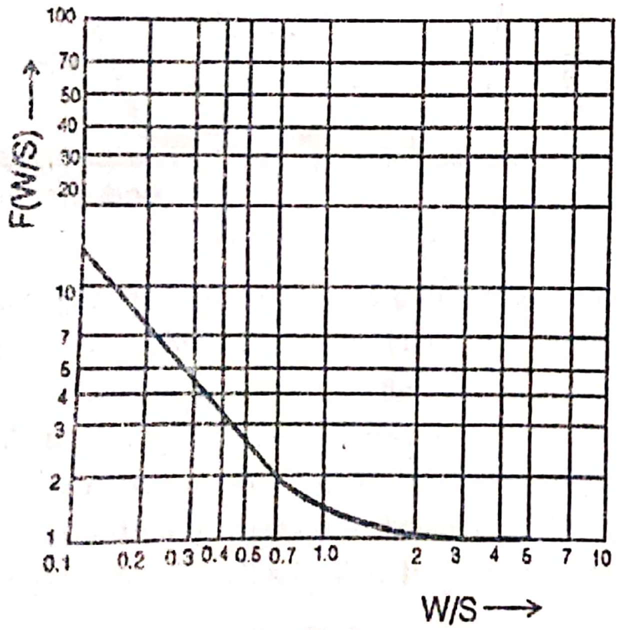

Fig. 13.4

Table A

S.No.	W/S	F(W/S)
1.	0.100	13.863
2.	0.141	9.704
3.	0.200	6.931
4.	0.333	4.159
5.	0.500	2.780
6.	1.000	1.504
7.	1.414	1.223
8.	2.000	0.094
9.	3.333	1.0228
10.	5.000	1.0070
11.	10.000	1.00045

We know that the forbidden energy band gap E_g of semi-conductor is related with the resistivity as

$$\log_e \rho = \frac{E_g}{2kT} \qquad or \qquad E_g = 2k\frac{2.3026 \log_{10}\rho}{(1/T)}$$

where k is the Boltzmann's constant equals to 8.6×10^{-5} eV/deg. and $\log_e \rho = 2.3026 \log_{10} \rho$. Thus, the slope of the graph between $\log_{10} \rho$ and $10^3/T$ gives

$$\frac{\log_{10} \rho}{1/T} = \frac{E_g}{2k} \quad or \quad E_g = 2k \times 2.3026\left(\frac{\log_{10} \rho}{1/T}\right)$$

Thus, the determination of energy band gap involves the plotting of a graph between $\log_{10} \rho$ and $(1/T) \times 10^3$ and calculating its slope.

Procedure

1. First of all the four probe arrangement is taken out of the oven and keep it on a plane surface. Now the sample crystal is put on the circular base plate of the arrangement in such a way that its non-conducting surface lies towards the plate side and four probes are in the middle of the sample crystal. To make the proper contact of the probes with the sample crystal apply slight pressure on their pipes and screws are tightened.
2. Now check the continuity between the sample crystal and four probes with the help of multimeter. For proper contacts the resistance between the outer probes leads (usually green leads are used) and inner probes leads (usually orange leads are used) should be nearly equal and of the order of 1 KΩ to 3.5 KΩ. If the contacts are not proper, tighten the screws (three in number) provided on the top of the base stand till the probes touch the sample crystal.
3. Now keep the four probe arrangement on the oven properly and again check the continuity between the probes as described above.
4. Now insert the thermometer in the hole provided in four probe arrangement. Connect the outer probe leads to the output terminals of the constant current source and the inner probes leads to the input terminals of the digital millivoltmeter of the four probe set up. Now connect the set up to the A.C. mains and put the switch to 'ON' position.
5. In the four probes set up, put the selector switch on current position and adjust current to zero value with the help of current adjustment knob. Now change the selector switch in the voltage position and adjust zero value in digital voltmeter by shorting the voltage terminals.
6. Again change the selector switch of the set up towards current position and apply some current say about 5 mA by means of current adjustment knob and keep this current value constant by undisturbing current adjustment knob for one set of observation. Now change the selector switch again towards voltage position.
7. Connect the oven with the oven supply and adjust its switch to lower position (L-position, the temperature range in this position is 40° to 50°C).
8. As the oven is switched on its temperature rises. Note down the voltage in digital voltmeter and corresponding temperature in thermometer. When the temperature rises above 45°C put the oven supply switch in medium position (M position, the temperature range in this position is upto 80°C or 90°C). Keep on recording the voltage in digit voltmeter and corresponding temperature in thermometer. Again above 90°C, the oven supply switch is adjusted to higher position (H position, the temperature in this position is above 90°C).
9. The voltages for different values of temperatures keeping current constant are recorded upto the temperature of about 160°C.
10. Repeat the above procedure for different values of current.

Observations

Thickness of the crystal, $W = \ldots$ *cm*

The distance between the probes, $S = \ldots$ *cm*

Value of current, $I = \ldots$ *mA*

S.No.	Temperature of the sample In (°C) T(°C)	In Kelvin T(K)	Corresponding Voltage V (Volts)	Resistivity $\rho_0 = \frac{V}{I} \times 2\pi S$ (Ohm-cm)	Corrected resistivity $\rho = \frac{\rho_0}{F(W/S)}$ (Ohm-cm)	$\log_{10} \rho$	$\frac{1}{T(K)}$
1.	20°C	293	...	...	...	...	...
2.	25°C	298	...	...	...	...	...
3.	30°C	303	...	...	...	...	...
4.	35°C	338	...	...	...	...	...
5.	40°C	343	...	...	...	...	...
6.	.	.	.	.	.	.	...
.	.	.	.	.	.	.	.
	160°C	437	...	...	...	...	...

Calculation

First of all the resistivity ρ_0 corresponding to temperature in Kelvin is found by using the relat

$$\rho_0 = \frac{V}{I} \times 2\pi S$$

the values of I and S are taken from observations.

Now, corrected resistivity ρ for probes on a thin slice with a non-conducting bottom surface and for the thickness W of the crystal is determined by using the relation

$$\rho = \frac{\rho_0}{F(W/S)}$$

The value of function, F(W/S) may be obtained from the table A or graph (Fig 13.4) for appropriate value of W/S. Hence, calculate ρ corresponding to different values of temperatures.

Now a graph between $(1/T) \times 10^3$ and $\log_{10} \rho$ is plotted. The graph will be a straight line (Fig. 13.5). The slope of the curve will be

$$\frac{AB}{BC} = \frac{\log_{10} \rho}{(1/T) \times 10^3} = \ldots$$

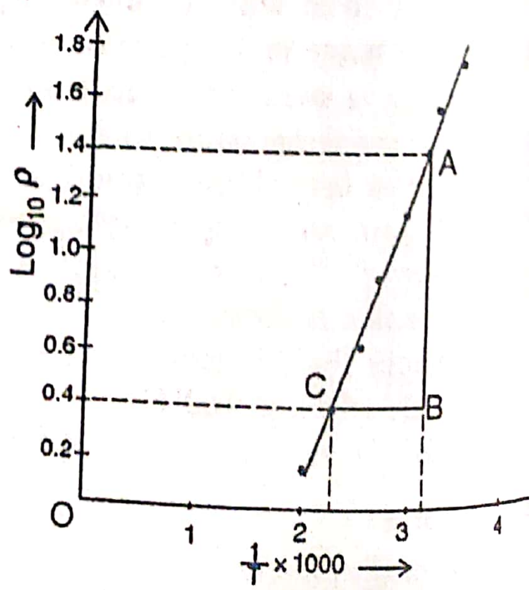

Fig. 13.5

Therefore, the forbidden energy band gap of semi-conductor (Germanium) is calculated as

$$E_g = 2k\frac{\log_e \rho}{(1/T)} = 2k\frac{2.3026 \log_{10} \rho}{(1/T)}$$

or

$$E_g = 2 \times 8.6 \times 10^{-5} \times 2.3026 \left(\frac{AB}{BC}\right) \times 1000\ eV$$

or

$$E_g = 0.396\left(\frac{AB}{BC}\right) eV$$

The percentage error in the experimental result is calculated by the following formula

$$\text{Percentage error} = \frac{\text{standard value} \sim \text{calculated value}}{\text{standard value}} \times 100$$

$$= \ldots \%$$

Result : *Forbidden energy band gap for semi-conductor (germanium) is,* $E_g = \ldots\ eV$

Standard Result : *Standard value of forbidden energy band gap of semi-conductor (germanium) is,*

$$E_g = \ldots\ eV$$

Percentage Error : *The percentage error* $= \ldots \%$

Precautions and Sources of Error

1. *The resistivity of the sample crystal should be uniform in the area of the measurement.*
2. *The sample surface should be uniform and having no leakage.*
3. *The sample should be placed with non-conducting surface towards bottom.*
4. *There should be proper contact between the probes and sample crystal surface.*
5. *Current should be constant for one set of observation.*
6. *The current through the sample should not be large enough to cause heating.*