Aim: **To determine the energy band gap of a semiconductor (germanium) using four probe method.**

Apparatus: Probes arrangement (it should have four probes, coated with zinc at the tips. The probes should be equally spaced and must be in good electrical contact with the sample), Sample (germanium or silicon crystal chip with non-conducting base), Oven (for the variation of temperature of the crystal from room temperature to about 2000C), A constant current generator (open circuit voltage about 20 V, current range 0 to 10 mA), Millivoltmeter (range from 100mV to 3V, electronic is better.), power supply for oven, thermometer

Theory:

Four Probe Method

Many conventional methods for measuring resistivity are unsatisfactory for semiconductors because metal-semiconductor contacts are usually rectifying in nature. Also there is generally minority carrier injection by one of the current carrying contacts. An excess concentration of minority carriers will affect the potential of other contacts and modulate the resistance of the material.

The method described here overcomes the difficulties mentioned above and also offers several other advantages. It permits measurements of resistivity in samples having a wide variety of shapes, including the resistivity of small volumes within bigger pieces of semiconductor. In this manner the resistivity of both sides of p-n junction can be determined with good accuracy before the material is cut into bars for making devices. This method of measurement is also applicable to silicon and other semiconductor materials. The basic model for all these measurements is indicated in Fig.

Four sharp probes are placed on a flat surface of the material to be measured, current is passed through the two outer electrodes, and the floating potential is measured across the inner pair. If the flat surface on which the probes rest is adequately large and thecrystal is big the semiconductor may be considered to be a semi-infinite volume. To prevent minority carrier injection and make good contacts, the surface on which the probes rest, maybe mechanically lapped.

The experimental circuit used for measurement is illustrated schematically in Fig. A nominal value of probe spacing which has been found satisfactory is an equal distance of 2.0 mm between adjacent probes. This permit measurement with reasonable current of n-type or p-type semiconductor from 0.001 to 50 ohm. cm. In order to use this four probe method in semiconductor crystals or slides it is necessary to assume that :

1. The resistivity of the material is uniform in the area of measurement.

2. If there is minority carrier injection into the semiconductor by the current - carrying electrodes most of the carriers recombine near the electrodes so that their effect on the conductivity is negligible. (This means that the measurements should be made on surface which have a high recombination rate, such as mechanical lapped surfaces).

3. The surface on which the probes rest is flat with no surface leakage.

4. The four probes used for resistivity measurements contact the surface at points that lie in a straight line.

5. The diameter of the contact between the metallic probes and the semiconductor should be small compared to the distance between probes.

6. The boundary between the current-carrying electrodes and the bulk material is hemi spherical and small in diameter.

7.The surface of the semiconductor is either conducting or not conducting.

(a) A conducting boundary is one on which a material of much lower resistivity than semiconductor (such as copper) has been plated.

(b) A non-conducting boundary is produced when the surface of the crystal is in contact with an insulator.

Experimental Procedure

1. Put the sample on the base plate of the four probe arrangement. Unscrew the pipe holding the four probes and let the four probes rest in the middle of the sample. Apply a very gentle pressure on the probes and tighten the pipe in this position. Check the continuity between the probes for proper electrical contacts.

CAUTION: The Ge crystal is very brittle. Therefore, use only the minimum pressure

required for proper electrical contacts.

2. Connect the outer pair of probes (red/black) leads to the constant current power supply and the inner pair (yellow/green leads) to the probe voltage terminals.

3. Place the four probe arrangement in the oven and fix the thermometer in the oven through the hole provided.

4. 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 5 mA).

5. Now put the digital panel meter in voltage measuring mode. In this position LED facing mV would glow and the meter would read the voltage between the probes.

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'.

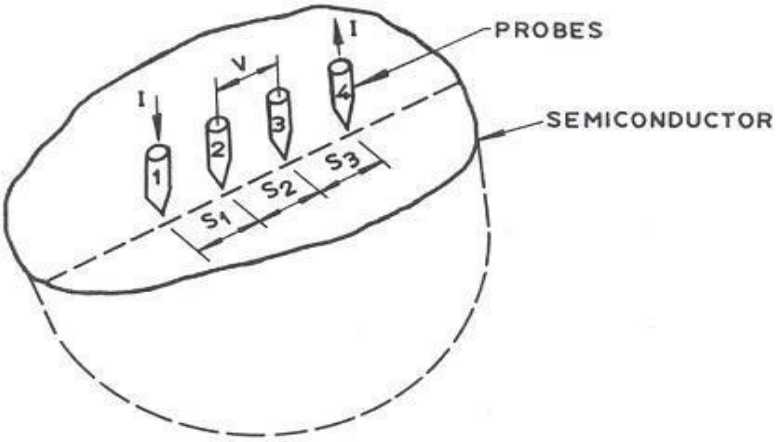

Fig-Model for the Four probe resistivity measurement.

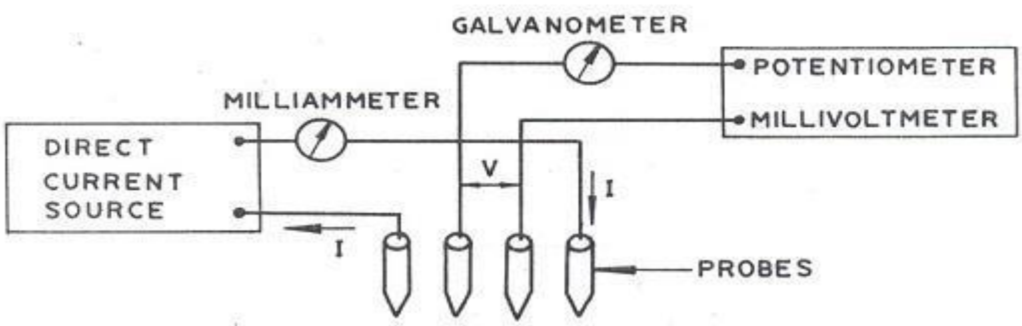

Fig-Circuit used for resistivity measurement.

TABLE I

S. No.	W/S	G_6 (W/S)	G_7 (W/S)
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

Observation table:

Current (I)=   mA(constant) Distance

between probes (S) =2 mm

Thickness of the crystal (W) = 0.5mm

G7 (W/S)=   (may be obtained from Table-I or by drawing graph)

Take K, Boltzmann const=8.617X10^{-5}ev/K

Sr. No.	Temp.(°C)	Temp.(K)	1/Temp (K^{-1})	Voltage(v)	$\rho_0 = \frac{V}{I} \times 2\pi S$ (ohm. cm.)	$\rho = \frac{\rho_0}{G_7(W/S)}$ (ohm.cm.)	$Log_{10}\rho$

Calculation

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

Since the thickness of the crystal is small compared to the probe distance a correction factor for it has to be applied. Furtherthe bottom surface is non-conducting in the present case, following equation will be applied

$$G_7(W/S) = 1 + 4\frac{S}{W}\sum_{n=1}^{n=\infty}\left[\frac{1}{\sqrt{\left(\frac{S}{W}\right)^2 + (n)^2}} - \frac{1}{\sqrt{\left(2\frac{S}{W}\right)^2 + (2n)^2}}\right]$$

The function G7 (W/S) may be obtained from Table-I for the appropriate value of
(W/S). Thus ρ may be calculated for various temperature.

Plot a graph for $\quad Log_{10}\rho \quad$ vs. $\quad T^{-1} \times 10^{-3}$

Using Eq. (7) $\quad Log_e\rho = \dfrac{E_g}{2kT} - \log_e K$