MANUAL FOR FOUR PROBE METHOD

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AIM

To determine the energy band-gap of a semiconductor sample (Silicon or Germanium) by Four Probe method.

APPARATUS

Four Probe Set-up
Four Probe Arrangement
Oven
Thermometer
Sample: Ge Crystal

THEORY

CONDUCTIVITY OF INTRINSIC SEMICONDUCTOR:

The electrical conductivity will be the sum of the contributions of both electrons and holes:

$$\sigma = (n_i\, e\, \mu_e + p_i\, e\, \mu_h) \qquad (1)$$

Where, 'e' is the electron charge, 'μ_e' and 'μ_h' are the average velocities acquired by the electrons and holes in an unit electric field and known as mobilities.

$$\sigma = e\, n_i\, (\mu_n + \mu_h) \quad \text{Since,} \quad n_i = p_i \qquad (2)$$

$$= K(T)^{3/2}\, (\mu_n + \mu_h)\, \frac{-Eg}{2KT} \qquad (3)$$

Where, K is a constant

E_g is Band-gap energy of a semiconductor

μ_n is mobility of electrones

μ_h is mobility of holes

T is temperature of the semiconductor

The factor $T^{3/2}$ and the mobilities change relatively slow with temperature compared with the exponential term, and hence the logarithm of resistivity ρ (=1/σ) varies linearly with 1/T. The width of the energy gap may be determined from the slope of the curve.

Thus we have,

$$\log_e \rho = \frac{Eg}{2KT} - \log_e K \qquad (4)$$

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 a 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. 1. 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 the crystal 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. 2. A nominal value of probe spacing which has been found satisfactory is an equal distance of 2.0mm between adjacent probes. This permit measurement with reasonable current o f 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 mechanically 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 surfaces of the semiconductor crystal may be either conducting or non - 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.

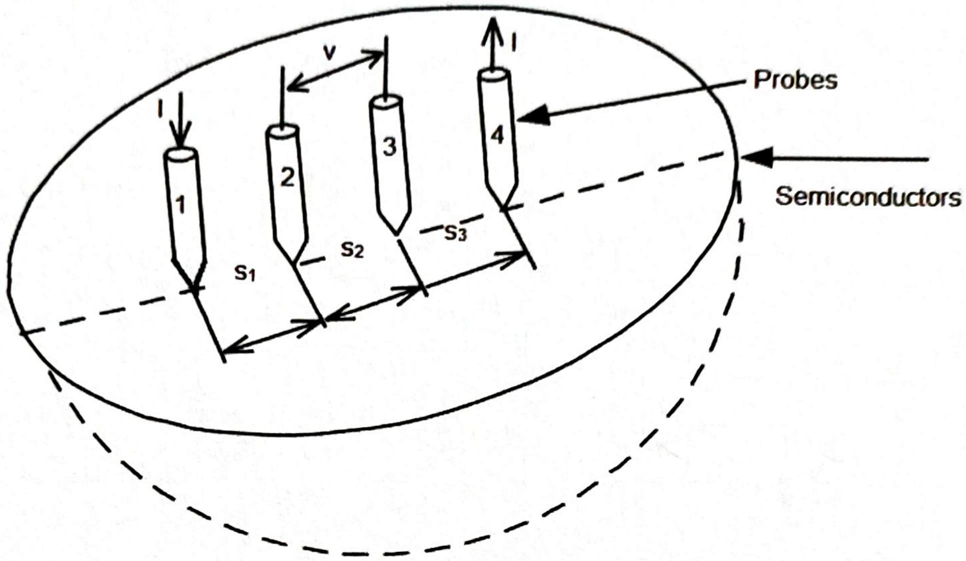


Fig 1. Model for the Four Probe resistivity measurement

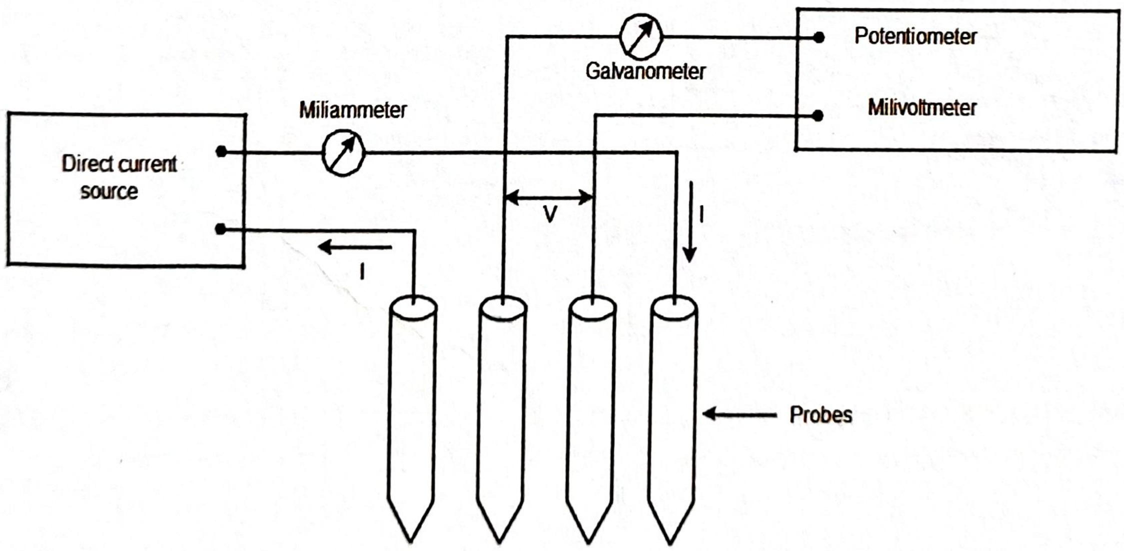
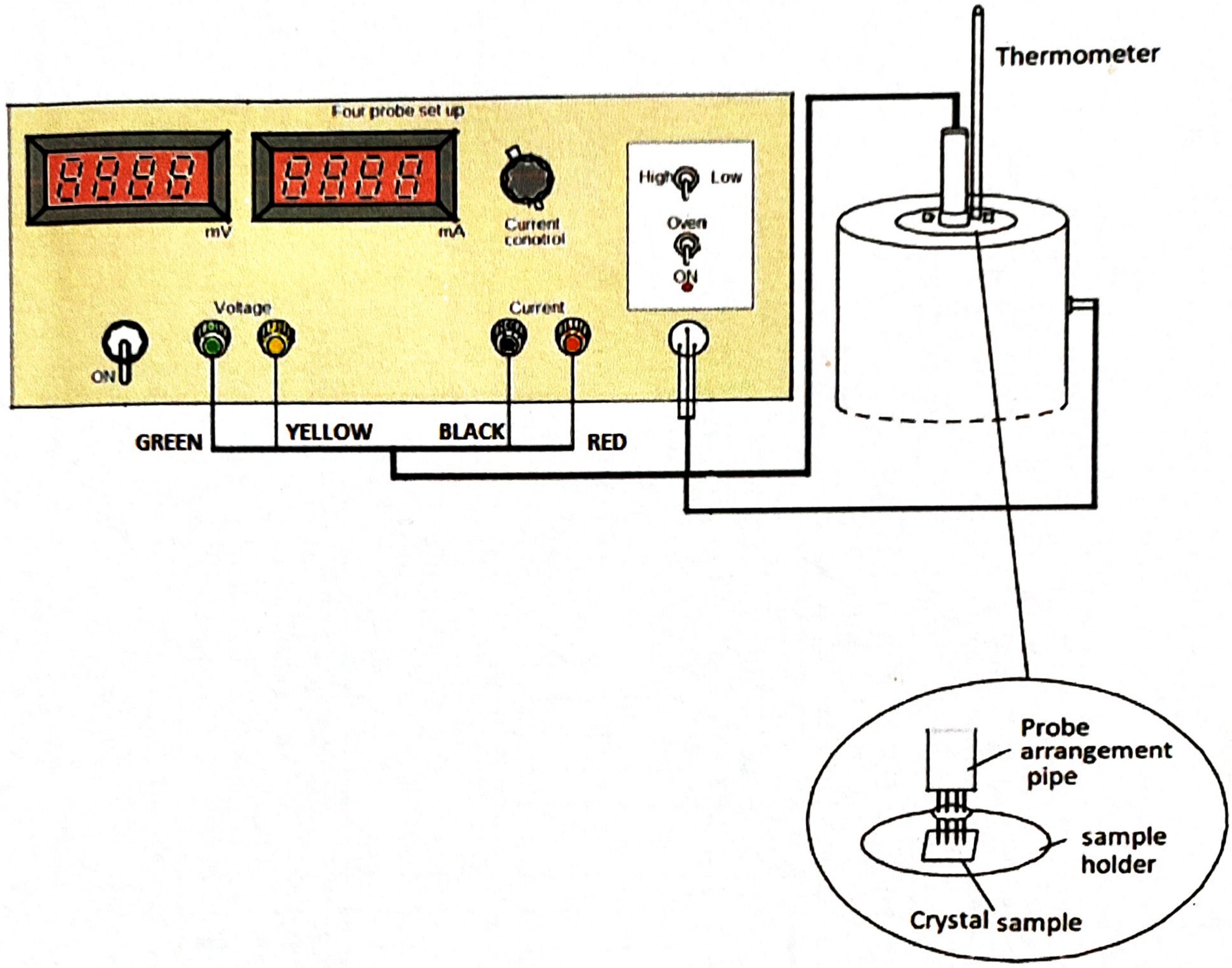


Fig.2 - circuit for Four Probe Method

CONNECTION DIAGRAM



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 screw of the pipe in this position. Check the continuity between the probes 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 connect the sensor lead to the RTD connector on the panel.
4. Switch 'ON' the Four Probe Setup. Connect the oven power supply using RTD connector. 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'.
5. Keep the selector switch in 'Low' position and note the rise in temperature in the thermometer.
6. As the **temperature nears 40^{0}C, set the current to a desired value (say, 5 mA)** by varying the current knob.
7. Note the rise in temperature for every **5-10^{0}C** and the corresponding change in voltage. Take temperature reading from the thermometer and the voltage readings from the milivoltmeter.

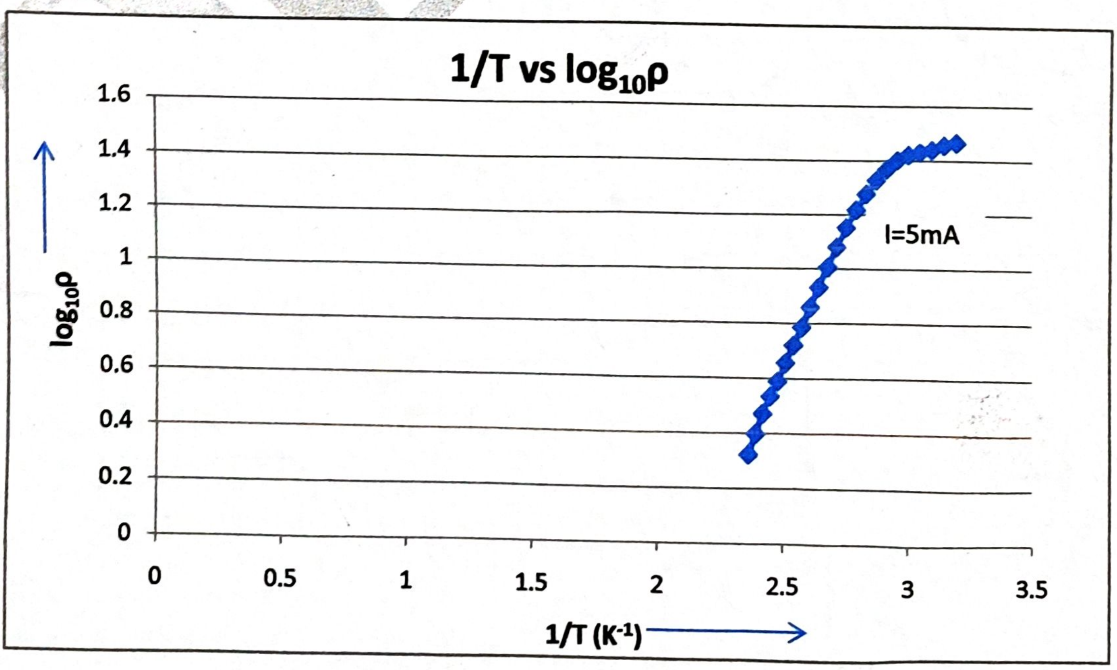
Find, $\rho = \frac{V}{I}\left(\frac{2\pi S}{G_7(\frac{W}{S})}\right)$

OBSERVATION TABLE

Current = 5mA
Distance between probes (S) = 0.22 cm
Thickness of the crystal = 0.07cm
G_7 (W/S) from Table/Graph = 4.2

TABLE 1

Sl. No.	Temperature (°C)	Voltage (mV)	Temperature(T) (K)	ρ (Ω.cm)	1/T ($\times10^{-3}$ K^{-1})	$\log_{10}(\rho)$
1.	40	444	313	29.21076	3.194888	1.465543
2.	45	435	318	28.61865	3.144654	1.456649
3.	50	418	323	27.50022	3.095975	1.439336
4.	55	409	328	26.90811	3.04878	1.429883
5.	60	400	333	26.316	3.003003	1.42022
6.	65	383	338	25.19757	2.95858	1.401359
7.	70	355	343	23.35545	2.915452	1.368388
8.	75	323	348	21.25017	2.873563	1.327362
9.	80	287	353	18.88173	2.832861	1.276042
10.	85	251	358	16.51329	2.793296	1.217834
11.	90	216	363	14.21064	**2.754821**	**1.152614**
12.	95	183	368	12.03957	2.717391	1.080611
13.	100	154	373	10.13166	2.680965	1.005681
14.	105	130	378	8.5527	2.645503	0.932103
15.	110	110	383	7.2369	2.610966	0.859553
16.	115	93	388	6.11847	2.57732	0.786643
17.	120	80	393	5.2632	2.544529	0.72125
18.	125	69	398	4.53951	2.512563	0.657009
19.	130	59	403	3.88161	2.48139	0.589012
20.	135	52	408	3.42108	2.45098	0.534163
21.	140	45	413	2.96055	2.421308	0.471372
22.	145	38	418	2.50002	2.392344	0.397943
23.	150	32	423	2.10528	**2.364066**	**0.32331**

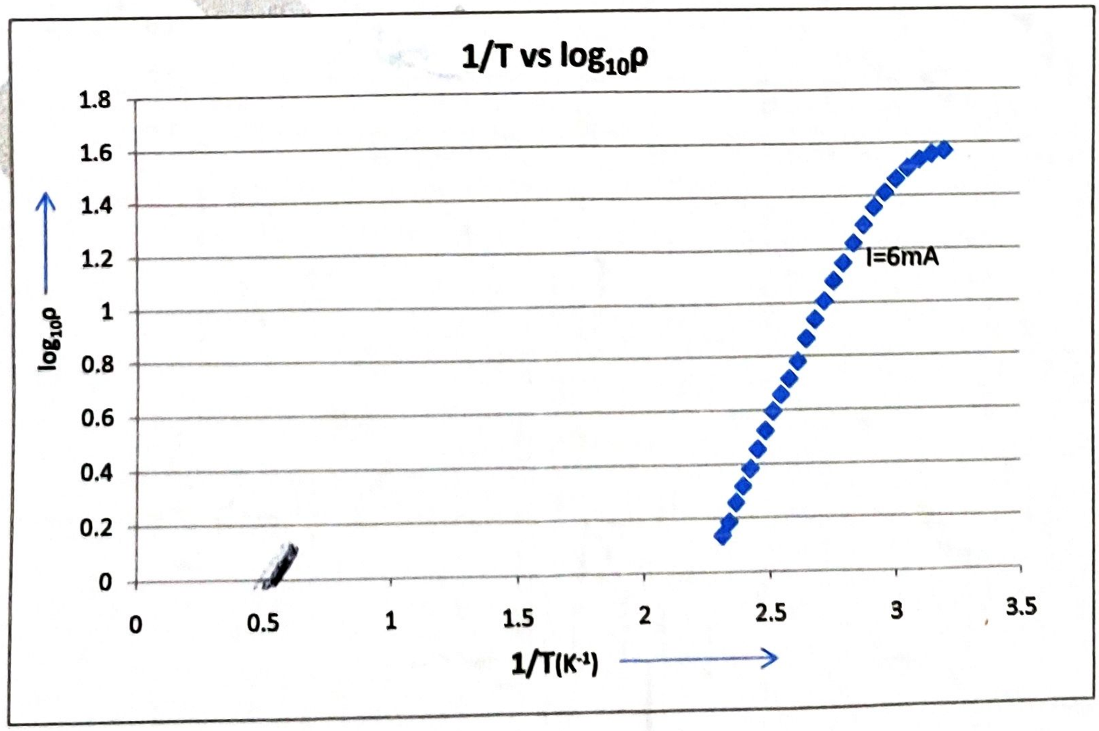


GRAPH-1

Current = 6mA
Distance between probes = 0.22cm
Thickness of the crystal = 0.07cm
G_7(W/S) from Table/Graph = 4.2

TABLE 2

Sl. No.	Temperature (°C)	Voltage (mV)	Temperature(T) (K)	ρ (Ω.cm)	1/T ($\times 10^{-3}$ K^{-1})	$log_{10}(\rho)$
1.	40	677	313	37.11314	3.194888	1.569528
2.	45	658	318	36.07156	3.144654	1.557165
3.	50	626	323	34.31732	3.095975	1.535513
4.	55	583	328	31.96006	3.04878	1.504608
5.	60	532	333	29.16424	3.003003	1.464851
6.	65	473	338	25.92986	2.95858	1.4138
7.	70	416	343	22.80512	2.915452	1.358032
8.	75	357	348	19.57074	2.873563	1.291607
9.	80	305	353	16.7201	2.832861	1.223239
10.	85	257	358	14.08874	2.793296	1.148872
11.	90	220	363	12.0604	2.754821	1.081362
12.	95	185	368	10.1417	2.717391	1.006111
13.	100	158	373	8.66156	2.680965	0.937596
14.	105	134	378	7.34588	2.645503	0.866044
15.	110	110	383	6.0302	2.610966	0.780332
16.	115	95	388	5.2079	2.57732	0.716663
17.	120	83	393	4.55006	2.544529	0.658017
18.	125	72	398	3.94704	2.512563	0.596272
19.	130	61	403	3.34402	2.48139	0.524269
20.	135	52	408	2.85064	2.45098	0.454942
21.	140	44	413	2.41208	2.421308	0.382392
22.	145	38	418	2.08316	2.392344	0.318723
23.	150	33	423	1.80906	2.364066	0.257453
24.	155	28	428	1.53496	2.336449	0.186097
26	160	25	433	1.3705	2.309469	0.136879

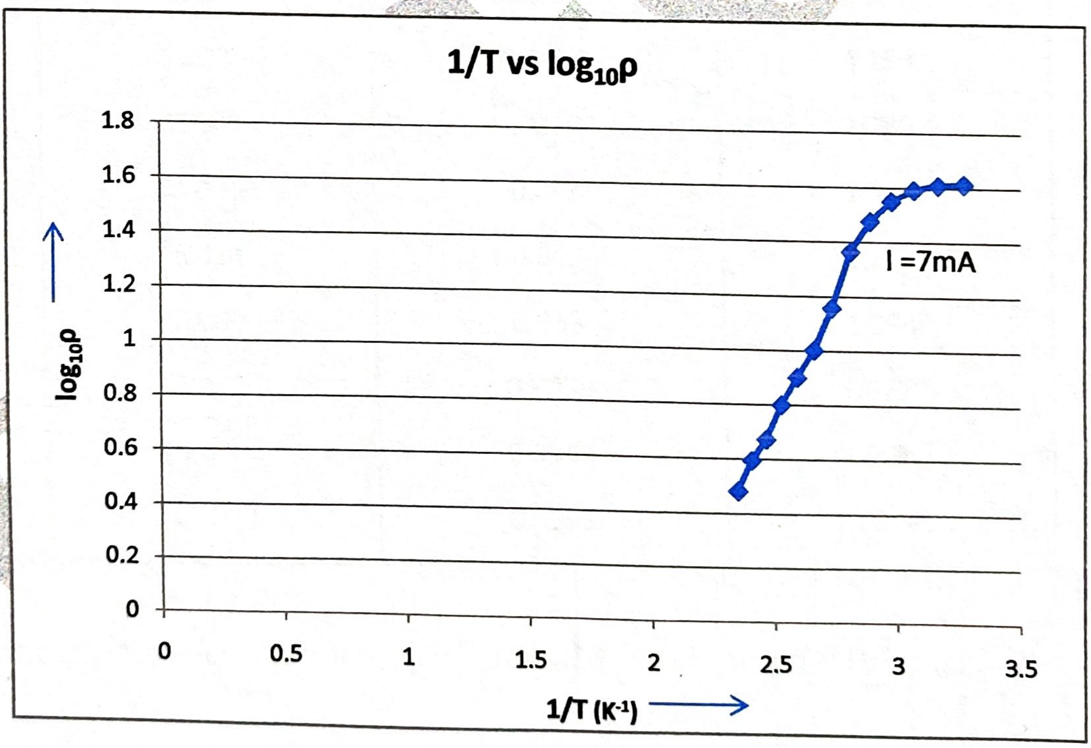


GRAPH-2

Current = 7mA
Distance between probes = 0.22 cm
Thickness of the crystal = 0.07cm
G_7 (W/S) from Table/Graph = 4.2

TABLE 3

Sl. No.	Temperature (°C)	Voltage (mV)	Temperature(T) (K)	ρ (Ω.cm)	1/T (×10⁻³ K⁻¹)	$log_{10}(\rho)$
1.	43	994	316	40.86334	3.164556962	1.611334
2.	53	954	326	39.21894	3.067484663	1.593496
3.	63	866	336	35.60126	2.976190476	1.551465
4.	73	730	346	30.0103	2.89017341	1.47727
5.	83	564	356	23.18604	2.808988764	1.365227
6.	93	350	366	14.3885	2.732240437	1.158016
7.	103	245	376	10.07195	2.659574468	1.003114
8.	113	194	386	7.97534	2.590673575	0.901749
9.	123	154	396	6.33094	2.525252525	0.801468
10.	133	115	406	4.72765	2.463054187	0.674645
11.	143	96	416	3.94656	2.403846154	0.596219
12.	153	74	426	3.04214	2.34741784	0.483179



GRAPH-3

NOTE: The readings are for reference purpose only. The readings will vary from sample to sample

CALCULATION

We have, $\rho = \rho_0/G_7$ (5)

and, $\rho_0 = \frac{V}{I} 2\pi S$ (6)

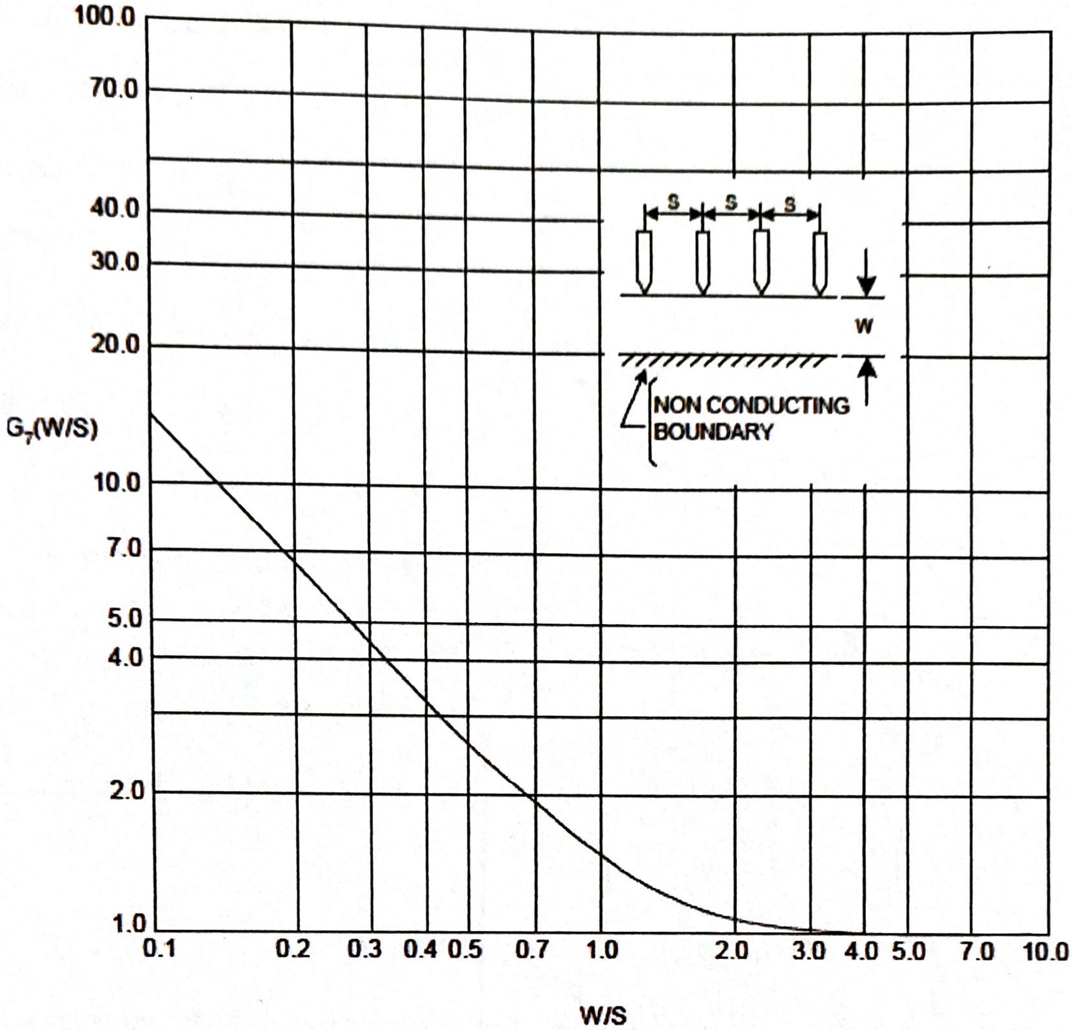
Where, ρ_0 is the resistivity of the crystal

V is the given voltage
I is current passing through crystal
S is the distance between the probes
G_7 can be calculated from the TABLE 4 (for this case $G_7 = 4.2$; since (W/S)=0.318)

TABLE 4

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

Thus, ρ can be calculated for different temperatures which are shown in TABLE (1), (2) & (3).



Calculation of ρ for TABLE 1 ,SL. No. 1

From Eq. 6, $\rho_0 = \frac{V}{I} 2\pi S$

or, $\rho_0 = (V/(5 \times 10^{-3})) \times 2 \times 3.14 \times 0.22$

or, $\rho_0 = 276.32 \times V$

Now, From Eq. 5, $\rho = \rho_0 / G_7$

or, $\rho = (276.32 \times V)/4.2$

or, $\rho = (276.32 \times 444 \times 10^{-3})/4.2$

or, $\rho = 29.21$ ohm.cm

[**N.B.** Similarly, calculate the value of ρ for all different temperature and corresponding voltages shown in TABLE (1), (2) & (3)]

Now plot the graph between 1/T vs $\log_{10} \rho$ and find the slope.

Calculation of slope from GRAPH-1

Slope $=(1.152-0.323)/(2.754\times10^{-3} - 2.364\times10^{-3})$

Therefore, slope = 2092

Calculation of E_g

Now, from Eq.(4), $\log_e \rho = \frac{Eg}{2KT} - \log_e K$

The slope of the curve is given by,

$$E_g/2K = [\log_e \rho/(1/T)]$$

$$\text{or, } E_g = [\log_e \rho/(1/T)] \times 2K$$

$$\text{or, } E_g = 2092\times2.302\times2\times8.6\times10^{-5} \quad [\text{Since, } \log_e\rho = \log_{10}\rho\,]$$

Hence, E_g **= 0.82eV**

[Similarly calculate E_g for TABLE (2) & (3)]

RESULT

We get the value for energy bandgap of Ge crystal as 0.82eV, which is near to the standard value 0.74eV.

PRECAUTION

1. The Ge crystal is very brittle. Therefore, use only the minimum pressure required for proper electrical contacts.
2. Take the reading carefully as temperature may vary soon.
3. After taking reading at a desired current take some time to cool down the oven. In the time of cooling the oven calculate the value of ρ to save the time.

PACKAGE CONTAINS

ITEM	QUANTITY
Four Probe Set-up	1
Four Probe Arrangement	1
Oven	1
Thermometer	1
Sample: Ge Crystal	1
Manual	1