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Aim:- To study the variation of resistivity of a Ge Crystal with temperature by Four-Probe method and hence to determine the band-gap Eg for it.

Apparatus:- A thin Ge crystal with smooth surface, a four probe arrangement, a digital electronic millivoltmeter, a constant current source (0-10mA), an oven with its power supply and a thermometer (0-200°C).

Theory:- A four-point collinear probe and the appropriate test equipment can be used to determine both the resistivity of a semiconductor specimen and its conductivity-type.

The Four Probe arrangement is shown in Figure 1. The Four Probes are equally spaced and collinear and coated with a hard conducting material (zinc, tungsten, carbide and osmium) at the tip. The probes make spring contacts with the sample and are mounted in a teflon brush for good electrical insulation from each other. Since no soldering is required for the contacts any error in resistivity measurements due to contamination of the surface, rectification and change of properties is avoided. The sample is in the form of a thin wafer with non-conducting bottom surface. A heater is used to change the temperature of the sample from room temperature to -200°C.

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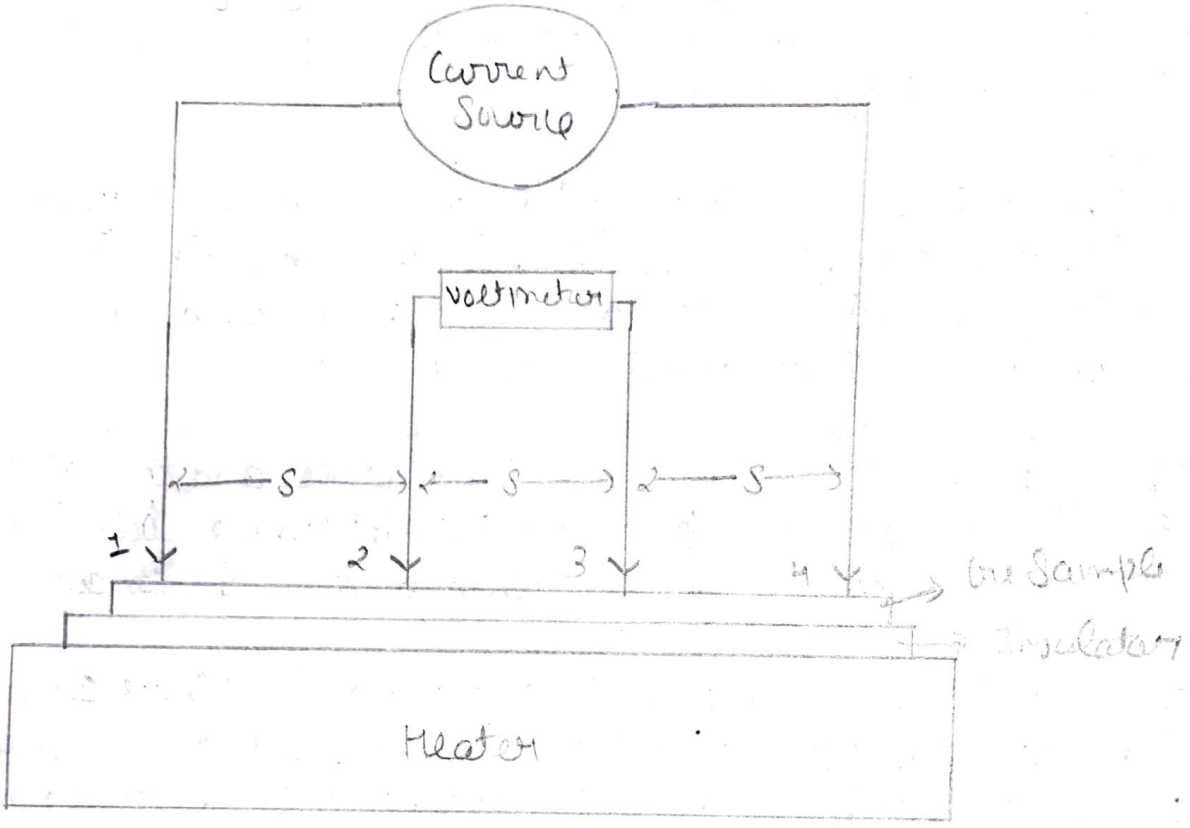

Figure 1
Four Probe Arrangement

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Procedure:-

1. Switch on the circuit (make sure that the oven is switched off).
2. Align the voltmeter/ammeter display changer switch at ammeter position and fix the value of the probe current to any fixed value (approx. 3–5 mA).
3. Align the display changer switch to voltmeter position and note the temperature and record the corresponding voltage value.
4. Switch on the oven at low heating mode.
5. As the temperature starts to increase, record all the corresponding values of the voltage at the interval of 5°C upto 150°C.
6. Switch off the oven and then switch off the circuit.
7. Calculate all the terms in the table.
8. Plot a graph between $\log_{10}\rho$ vs T^{-1}.
9. Take the slope from the linear portion of the mean graph.
10. Complete the calculation to find out the band gap for the given semiconductor.

Observations and calculations:-

using:-

$$\rho = \frac{V}{I} \times \frac{2\pi s}{F(t/s)} \quad -(1)$$

Since t and s are known for the sample and V and I are measured in the experiment, ρ can be evaluated.

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Observation Table

S.No.	Temperature °C | K	voltage (mV) heating	voltage (mV) cooling	Mean V(mV)	Resistivity $\rho = \frac{V}{I} \times D$ (Ωcm)	$\frac{1000}{T}$ (K^{-1})	$\log_{10}\rho$
1.	25 | 298	193.1	–	193.1	10.04	3.35	1.00
2.	30 | 303	189.4	–	189.4	9.84	3.30	0.99
3.	35 | 308	188.7	–	188.7	9.79	3.25	0.99
4.	40 | 313	184.6	–	184.6	9.59	3.20	0.98
5.	45 | 318	180.5	177.8	179.1	9.31	3.15	0.96
6.	50 | 323	179.4	173.4	176.4	9.17	3.10	0.96
7.	55 | 328	175.2	166.1	170.6	8.87	3.05	0.94
8	60 | 333	167.2	156.1	161.8	8.41	3.00	0.92
9.	65 | 338	158.1	142.8	150.4	7.82	2.95	0.89
10.	70 | 343	146.6	129.1	137.8	7.16	2.91	0.85
11.	75 | 348	133.0	116.9	124.9	6.49	2.87	0.81
12.	80 | 353	119.6	101.4	110.5	5.74	2.83	0.75
13.	85 | 358	106.4	89.7	98.0	5.09	2.79	0.70
14.	90 | 363	93.3	77.9	85.6	4.94	2.75	0.69
15.	95 | 368	80.8	67.9	74.3	3.86	2.71	0.58
16.	100 | 373	70.4	58.4	64.4	3.34	2.68	0.52
17.	105 | 378	60.6	50.4	55.5	2.88	2.64	0.45
18.	110 | 383	53.3	43.8	48.5	2.52	2.61	0.40
19.	115 | 388	45.2	33.4	39.3	2.04	2.57	0.30
20.	120 | 393	39.6	38.3	38.9	2.02	2.54	0.30
21.	125 | 398	34.5	29.1	31.9	1.65	2.51	0.21
22.	130 | 403	29.9	25.9	27.9	1.45	2.48	0.16
23.	135 | 408	26.5	24.1	24.8	1.28	2.45	0.10
24.	140 | 413	23.0	20.5	21.7	1.12	2.42	0.04
25.	145 | 418	21.2	18.6	19.9	1.03	2.39	0.01
26.	150 | 423	17.8	17.1	17.4	0.90	2.36	-0.04

The formula for the variation of resistivity and temperature can be obtained by taking the inverse of both the sides of given equation.

$$\rho = \rho_0 e^{E_g/2KT}$$

$$\ln\rho = \ln\rho_0 + \frac{E_g}{2KT}$$

$$\log_{10}\rho = \log_{10}\rho_0 + \frac{E_g}{2KT \times 2.303} \quad \text{(11)}$$

Thus a graph between $\left(\frac{1}{T}\right)$ and $\log_{10}\rho$ would be a straight line. From the slope of this line, the band gap E_g can be determined.

Distance between the probes, $s = 0.5\text{ mm} = 0.05\text{ cm}$

Thickness of crystal, $t = 0.05\text{ cm}$

From standard table $f(t/s) = 1.504$

Least count of thermometer $= 0.2^\circ C$

Current, $I = 4\text{ mA}$

Temperature $= 19.8^\circ C$

voltage, $V = 169.2\text{ mV}$

From equation, the straight line portion of graph between $\log_{10}\rho$ and $\frac{1}{T}$ has a slope equal to

$$\text{slope} = \frac{E_g}{2 \times 2.303 \times 10^{-3} \times K}$$

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$E_g = \text{Slope} \times 0.606 \times K \times 10^3$

where $K = 1.38 \times 10^{-23}\ J/K = 8.625 \times 10^{-5}\ eV/K$

$E_g = 0.3973 \times \text{Slope} = 0.3973 \times 1.74$

$= 0.69\ eV$

Result :-

(i) Resistivity ρ for the given semiconductor decrease with increasing temperature.

(ii) The band-gap E_g of Ge Crystal $= 0.69eV$

Actual value $= 0.67eV$

Precautions and Source of Error

1. Current should be constant while performing the experiment.
2. Reading should be taken not only while heating the sample but also while cooling.
3. The sample should be heated to a temperature near about 180 - 200°C.
4. The four Probe should be lie in a straight line.

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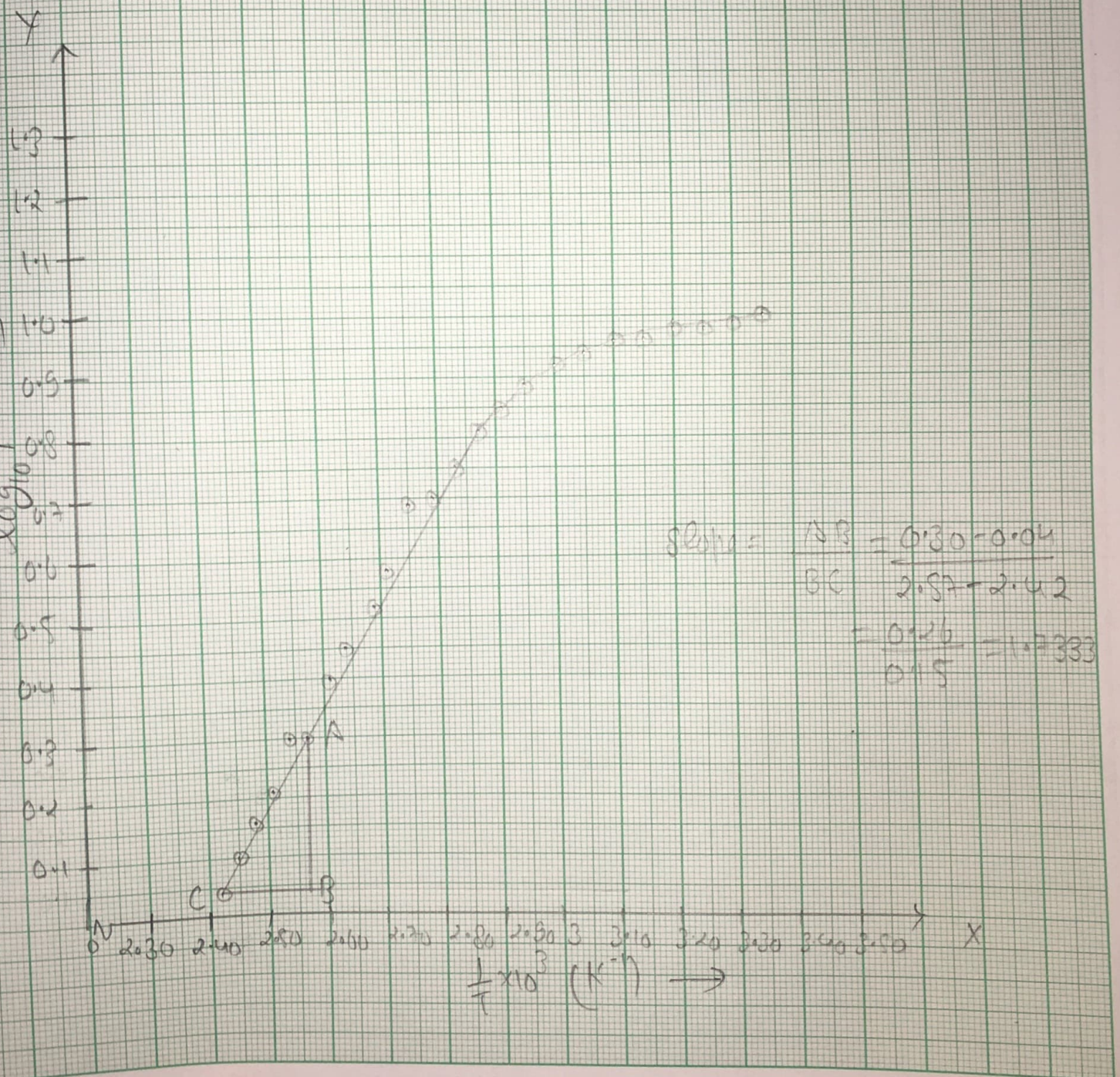
Scale

X axis 1 box = 0.01 K^{-1}

Y axis 1 box = 0.01



$$\text{Slope} = \frac{AB}{BC} = \frac{0.30 - 0.04}{2.57 - 2.42} = \frac{0.26}{0.15} = 1.7333$$