Date 07/01/2022.

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"Four - Probe"

Objective :- To measure the resistivity and band gap of a semi conductor using Four-Probe method.

Apparatus :- Four-Probe apparatus, semi conducting materials.

Theory :- The purpose of 4-point probe method is to measure the resistivity of a semi-conductor sample. The four-Probe setup consists of four equally spaced metal tips with finite radius. Each tip is supported by springs on the other end to minimize excessive pressure on the crystal. A high impedence current is used through the outer probes. A voltmeter measure the voltage across the inner two probes to determine the sample resistivity and hence, the energy band gap of the semi-conductor sample.

The experimental setup measures voltage (V) and current (I) passing through the sample.

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□ Symbol used represent following Quantities.

S.No	Symbol	Quantity	SNo	Symbol	Quantity
1	h	electron Concentration	6	ρ	Corrected resistivity
2	K	Boltzmann Constant	7	ρ_0	resistivity
3	T	Temperature	8	V	potential across inner probes.
4	Eg	Band gap of semi Conductor	9	I	Current through outer probes
5	s	gap between Probes	10	w	Thickness of sample

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The resistivity is given by

$$\boxed{\rho_0 = \frac{V}{I} 2\pi s} \ \Omega\text{-m}$$

The above expression is valid only when thickness of sample is much larger than the gap between the probes. To get the correct resistivity division by a correction factor is needed.

$$\boxed{\rho = \frac{\rho_0}{f(w/s)}} \ \Omega\text{-m}$$

where $f(w/s)$ is correction factor.

Determination of band gap :- The Energy band gap (E_g) of a semiconductor is given by

$$\boxed{E_g = \frac{2K \times 2.3026 \log_{10} \rho}{T^{-1}} \ eV}$$

where $K = 8.6 \times 10^{-5}$ ev/deg

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Procedure :-

1) verify that heater is switched off
2) Connect the outer probes (yellow leads) to Current Source (in yellow sockets).
3) Connect the inner probes (Red and black) to voltmeter.
4) If you see negative voltage on display, interchange the yellow leads to reverse the direction of Current and get the positive voltage.
5) Increase Current and set it to a Constant value, say 8.03mA. Don't change the Current throughout the experiment.
6) Turn on heater and note down the voltage for several values of Temperature.
   Don't increase Temperature beyond 140°c
7) Calculate resistivity (ρ_0 and ρ) for each value of voltage
8) Plot a graph between $\log \rho$ on y-axis and $\left(\frac{1}{T}\right)$ on x-axis.
9) Evaluate the slope of linear part of graph
10) The slope is equal to $\left(\frac{E_g}{2K}\right)$.

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Observations :-

1) Current $(I) = 8.03\ mA$ (Constant)
2) Distance between Probes $(s) = 0.24\ cm = 0.0024 m$
3) Thickness of sample $(W) = 0.05\ cm = 0.0005 m$

4) Here $w/s = 0.2083$

Correction factor $f(w/s) = 6.7643$

5) $2\pi s = 2 \times 3.14 \times 0.24 = 1.5072\ cm = 0.015072 m$

6) $\rho_0 = \frac{V}{I}(2\pi s)\ \Omega\text{-}m$

7) $\rho = \frac{\rho_0}{6.7643}\ \Omega\text{-}m$

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8) **Observation Table :-**

S.No	Temperature (°C)	Temperature (K)	$\frac{10^3}{T}$ (Per Kelvin)	voltage (mV)	ρ_0 (Ω-m)	ρ (Ω-m)	$\log_{10}\rho$
1	40°C	313 K	3.19	114	0.2139	0.03162	−1.500
2	45°C	318 K	3.14	118.7	0.2228	0.03293	−1.482
3	50°C	323 K	3.10	120.5	0.2262	0.03344	−1.476
4	55°C	328 K	3.04	128	0.2402	0.03551	−1.450
5	60°C	333 K	3.00	131	0.2458	0.03633	−1.440
6	65°C	338 K	2.95	134.5	0.2524	0.03731	−1.428
7	70°C	343 K	2.91	135	0.2534	0.03746	−1.426
8	75°C	348 K	2.87	130.5	0.2449	0.03620	−1.441
9	80°C	353 K	2.83	122	0.2290	0.03385	−1.470
10	85°C	358 K	2.79	116.2	0.2181	0.03224	−1.500
11	90°C	363 K	2.75	103	0.1933	0.02857	−1.544
12	95°C	368 K	2.73	90	0.1690	0.02498	−1.602
13	100°C	373 K	2.68	74.6	0.1400	0.02069	−1.684
14	105°C	378 K	2.65	64.2	0.1205	0.01781	−1.750
15	110°C	383 K	2.61	52.4	0.0983	0.01453	−1.838

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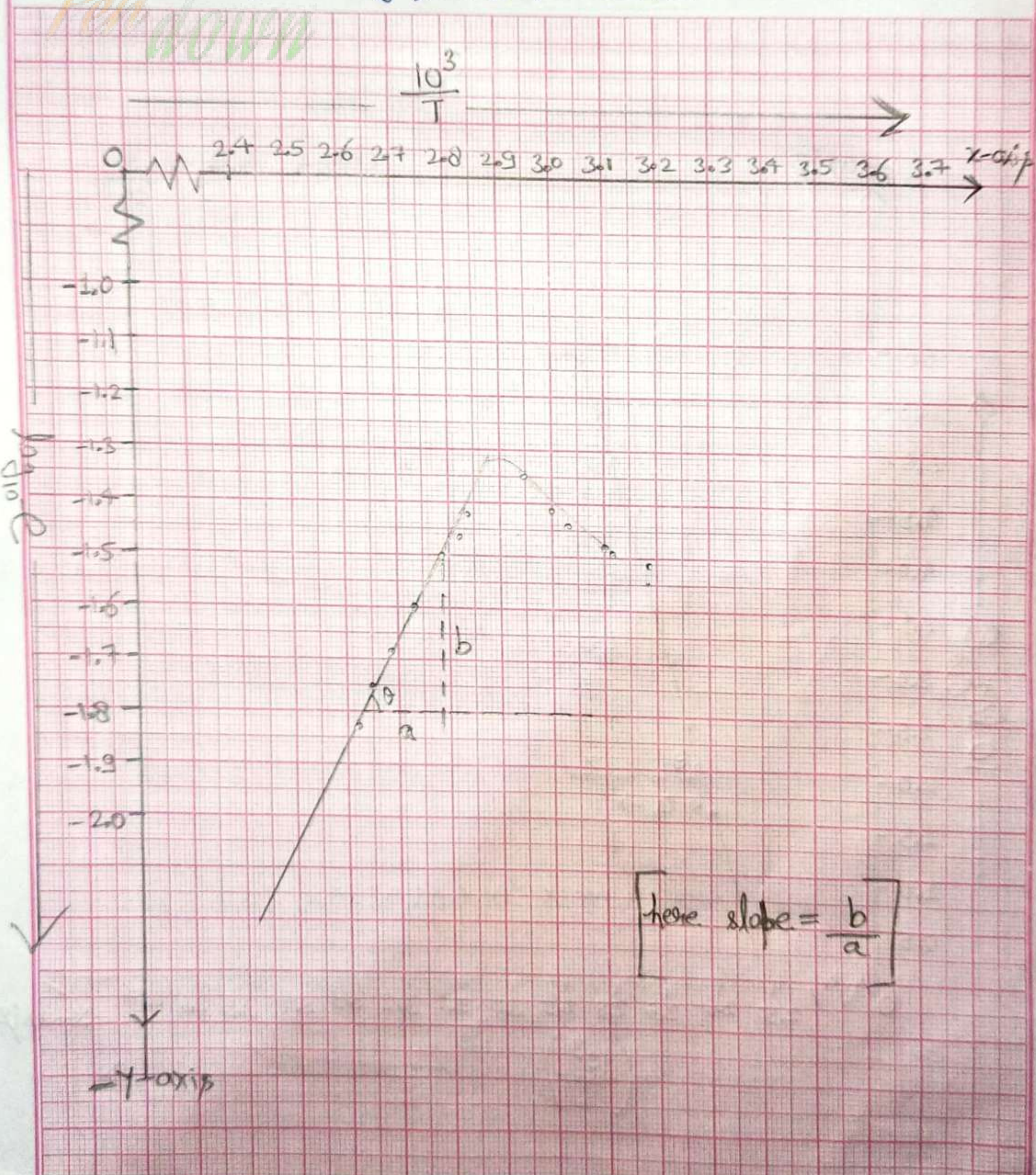
Graph between $\log_{10} e$ and $\left(\frac{10^3}{T}\right)$

Scale :- on x-axis → 1 big square (1cm) = 0.1 unit = 0.1 (Per kelvin)

on y-axis → 1 big square (1cm) = 0.1 unit



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Calculations:-

1) slope of graph between $\log_{10} e$ and $\left(\frac{10^3}{T}\right)$ is (say m) :-

$$m = \frac{b}{a} = \frac{(1.8 - 1.5)}{(2.79 - 2.62)} = \frac{0.3}{0.17}$$

$$\boxed{m = 1.76}$$

2) $$E_g = \left(\frac{2K \times 2.3026 \log_{10} e}{T^{-1}} \times \frac{10^3}{10^3} \right) eV$$

$$E_g = \underline{2K \times 2.3026 \times 10^3} \times \left(\frac{\log_{10} e}{10^3 T^{-1}} \right) eV$$

$$E_g = (2 \times 8.6 \times 10^{-5} \times 2.3026 \times 10^3 \times 1.76) \quad eV$$

$$\boxed{E_g = 0.697\, eV}$$

Note:- from graph

$$\left[m = \frac{b}{a} = \frac{\log_{10} e}{10^3 T^{-1}} \right]$$

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Result :-

The bandgap of semiconductor Germanium is 0.697 eV.

Source of error (s) and Precautions :-

1) Ensure the Contacts of four points probe and make sure Current and voltage not always remains zero.
2) Ensure all Connections to be tight and Equipment is working properly.
3) For more Correctness take values of $\log_{10} e$ upto 2 decimal places and mark the points in graph properly with suitable scale.

Comments on Results :-

The Theoretical value of Energy band gap of Germanium is 0.7 eV and our calculated value is 0.697 eV that is very close to theoretical value. so the Result is Reliable and Experimental setup is properly working.

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