Experiment - 01
Four Probe Method
(of determining resistivity of & band gap of a semi conductor)

Aim: To determine the resistivity ρ of a semi-conductor (Ge) with temperature upto (180 °C) by four-probe method and determine its band gap.

Apparatus required: Four-probe set up, oven, four probe, thermometer, Ge sample

Working Formula:

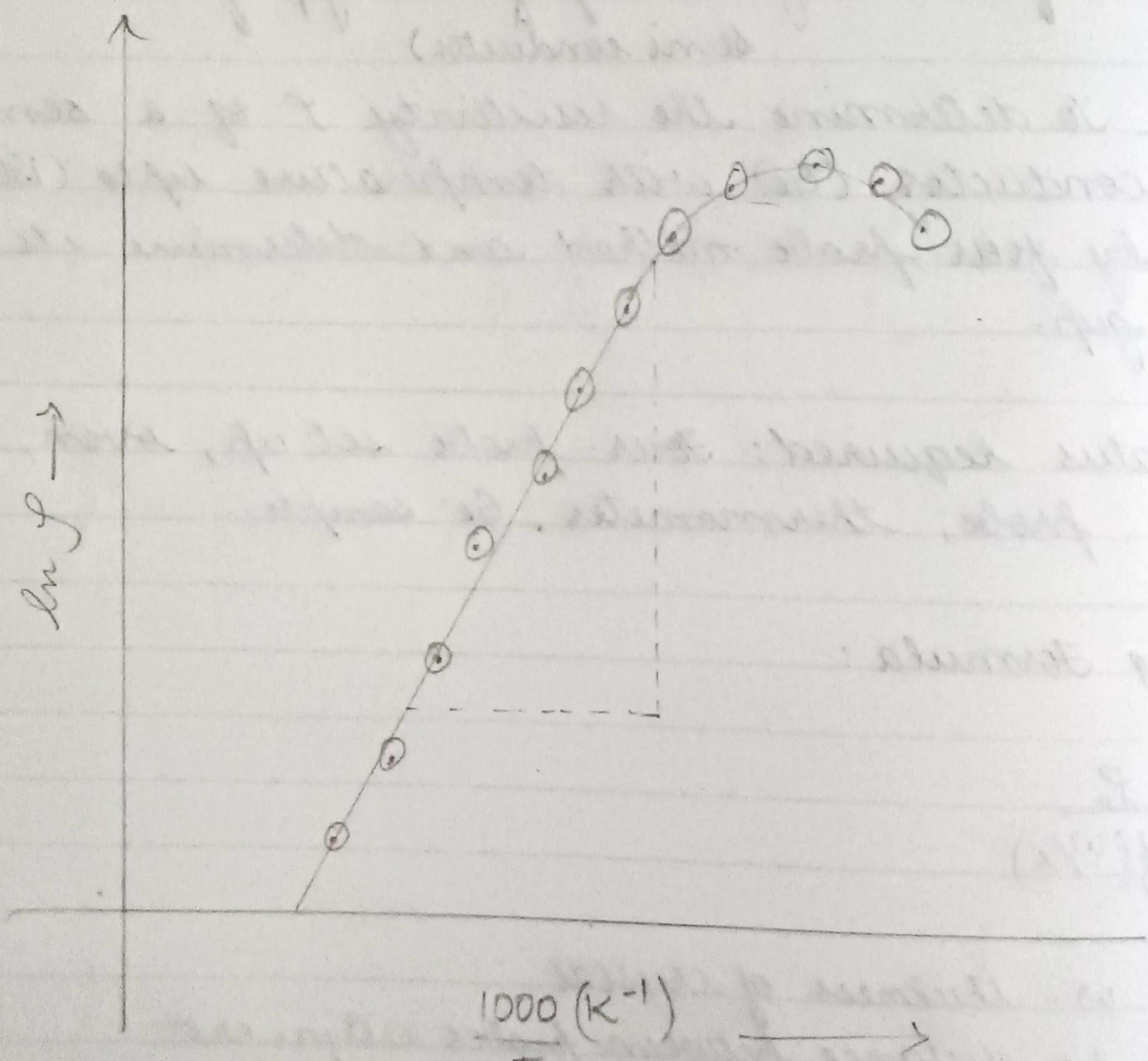
1. $$\rho = \frac{\rho_0}{f(w/s)}$$

where: w - thickness of crystal
s - distance between probes adjacent
I - current through crystal ~~adj~~
V - voltage across crystal
f(w/s) - correction factor; function dependent on w and s.

2. $$\rho_0 = \frac{V}{I} 2\pi s$$

3. $$f(w/s) = \frac{2s}{w} (\ln 2)$$

Expected graph:



4. $E_g = 2K_B \dfrac{\ln \rho}{(1/T)}$ (in eV)

E_g = slope (of $\ln \rho$ vs $1/T$ graph) $\times$ $2K_B$

where K_B - boltzmann constant = 8.617×10^{-5} eV K^{-1}.

5. Resistivity follows the relation

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

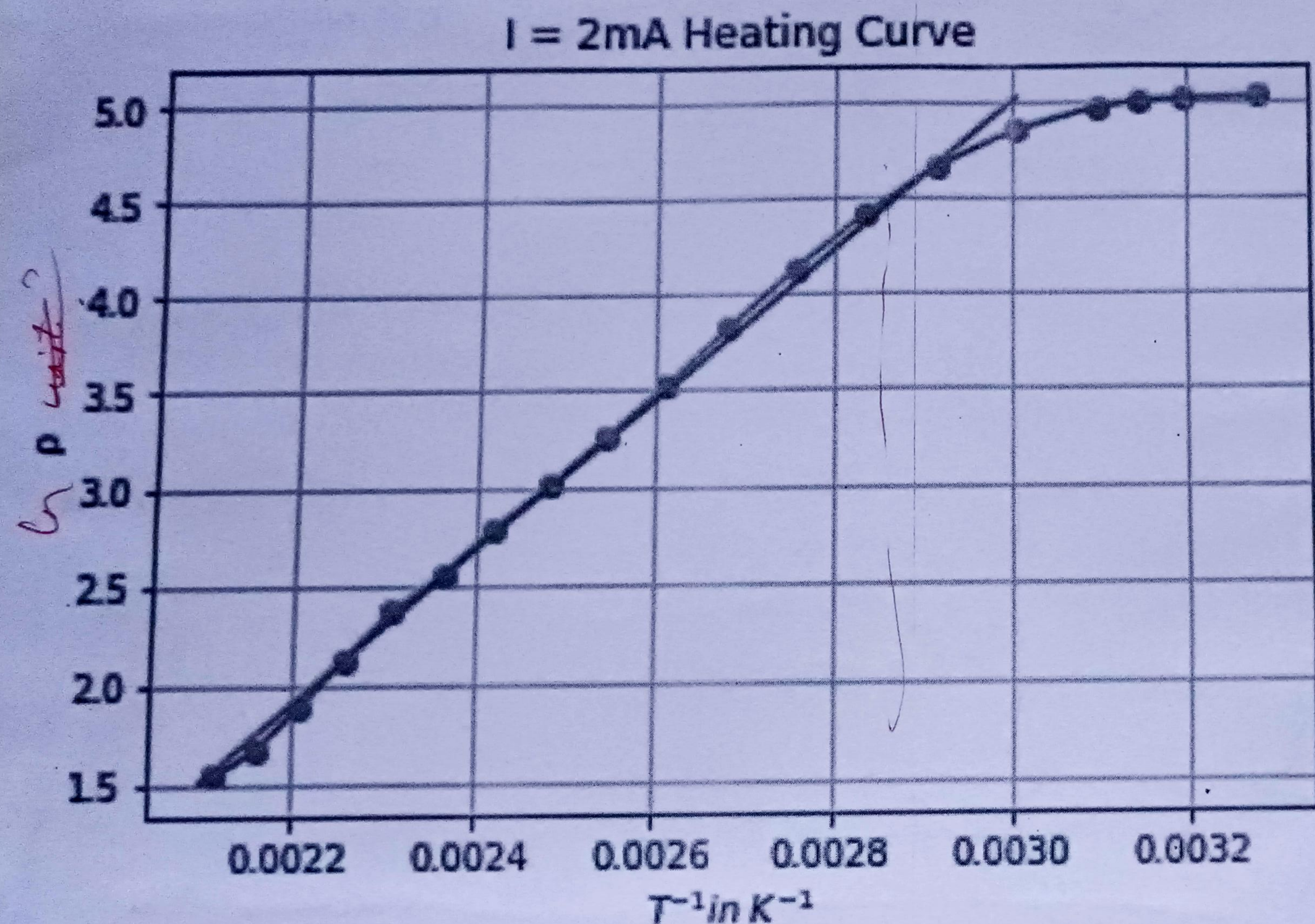
$$\ln \rho = \ln \rho_0 + \frac{E_g}{2KT}$$

∴ Graph between ρ and $1/T$ gives slope = $E_g/2K$
and y intercept = $\ln \rho_0$

$$x \text{ intercept} = -\frac{\ln \rho_0}{E_g} \times 2K_B.$$

Precautions:

1. The surface of the semiconductor should be flat.
2. All the four probes should be collinear.
3. The adjustment of 4-point probes should be done gently, as the semiconductor chip is brittle.
4. The voltage should be measured using inner probes only using a high impedance multivoltmeter
5. Temperature of the oven should not exceed the limits set by manufacturer of the prober and chip set.


I = 2mA Heating Curve
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ρ
unit?
ln
0.0022
0.0024
0.0026
0.0028
0.0030
0.0032
T⁻¹ in K⁻¹

Observations:

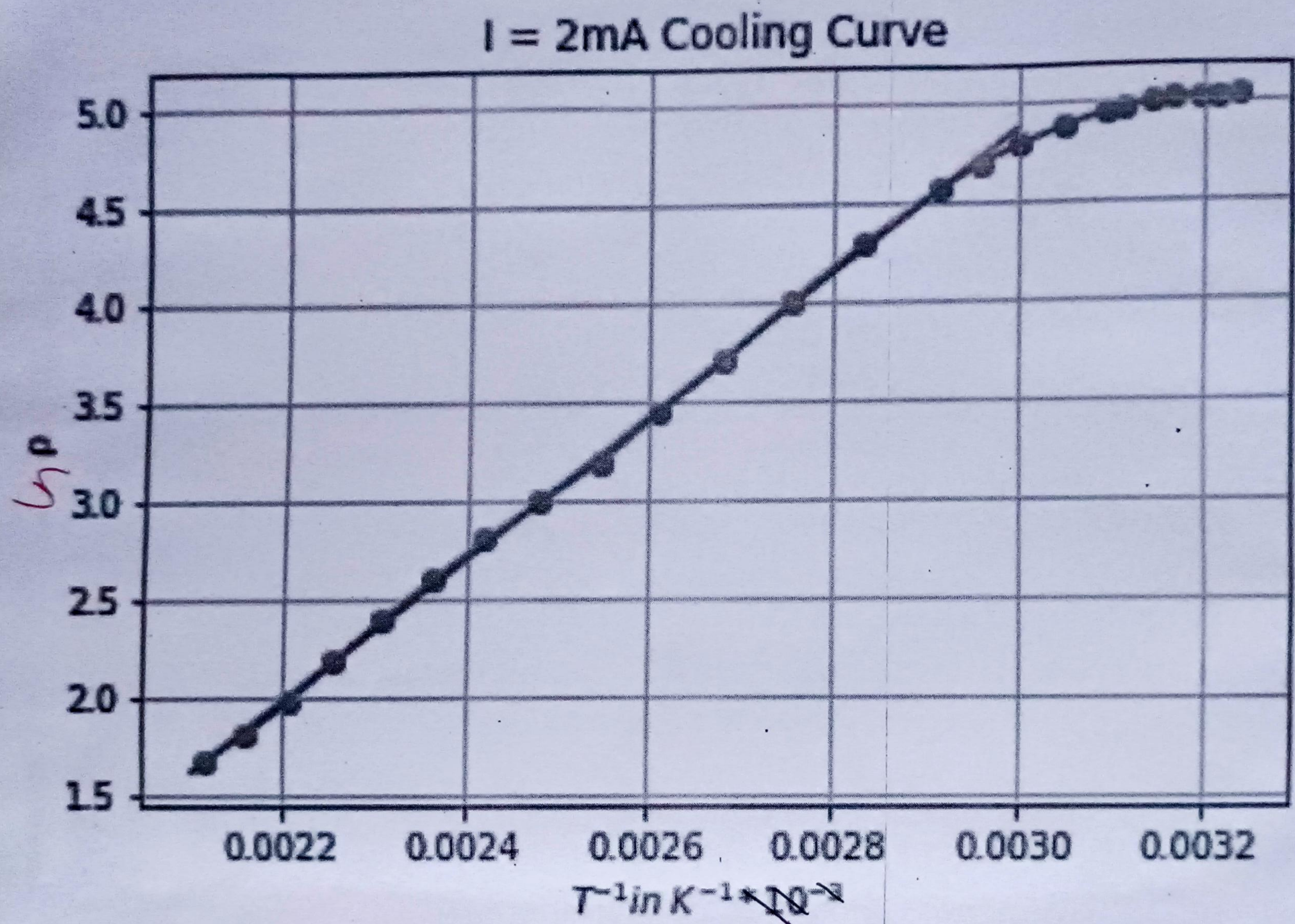
$w = 0.71$ mm, $\delta = 0.2$ mm. LC of Voltmeter = 0.1 mV

I Current = 2mA

LC of Ammeter = 0.01 mA.

S.No.	T(°C)	T(K)	V(mV) Heating	V(mV) Cooling	V(mV) Mean	ρ_0 (ΩM)	ρ	$T^{-1}(K^{-1})$ ×1000	ln ρ
1.	32	305	95.2	–	–	598.16	153.18	3.279	5.032
2.	36	309	–	94.1	–	591.25	151.40	3.236	5.020
3.	38	311	–	93.9	–	589.99	151.08	3.215	5.018
4.	40	313	94.2	93.8	94.0	590.62	151.24	3.195	5.019
5.	43	316	–	92.5	–	581.20	148.83	3.165	5.003
6.	45	318	92.8	91.4	92.1	578.68	148.19	3.145	4.998
7.	48	321	–	88.8	–	557.95	142.88	3.115	4.962
8.	50	323	90.0	87.2	88.6	556.69	142.56	3.096	4.960
9.	55	328	–	81.1	–	509.57	130.49	3.049	4.871
10.	60	333	80.0	74.3	77.2	484.75	124.13	3.003	4.821
11.	65	338	–	67.5	–	424.12	108.61	2.959	4.688
12.	70	343	66.2	59.3	62.8	394.27	100.96	2.915	4.615
13.	80	353	51.2	45.1	48.2	302.54	77.47	2.833	4.350
14.	90	363	38.6	33.8	36.2	227.45	58.25	2.755	4.065
15.	100	373	28.6	25.0	26.8	168.39	43.12	2.681	3.764
16.	110	383	21.1	19.4	20.3	127.23	32.58	2.611	3.484
17.	120	393	16.2	15.1	15.7	98.33	25.18	2.545	3.226
18.	130	403	12.5	12.4	12.5	78.23	20.03	2.481	2.997
19.	140	413	9.8	10.2	10.0	62.83	16.09	2.421	2.778
20.	150	423	7.9	8.3	8.31	50.89	13.03	2.364	2.567
21.	160	433	6.6	6.8	6.7	42.10	10.78	2.309	2.378
22.	170	443	5.2	5.5	5.4	33.62	8.61	2.257	2.153
23.	180	453	4.1	4.5	4.3	27.02	6.92	2.208	1.934
24.	190	463	3.3	3.8	3.6	22.31	5.71	2.160	1.734
25.	200	473	2.9	3.3	3.1	19.48	4.99	2.114	1.607

Teacher's Signature :



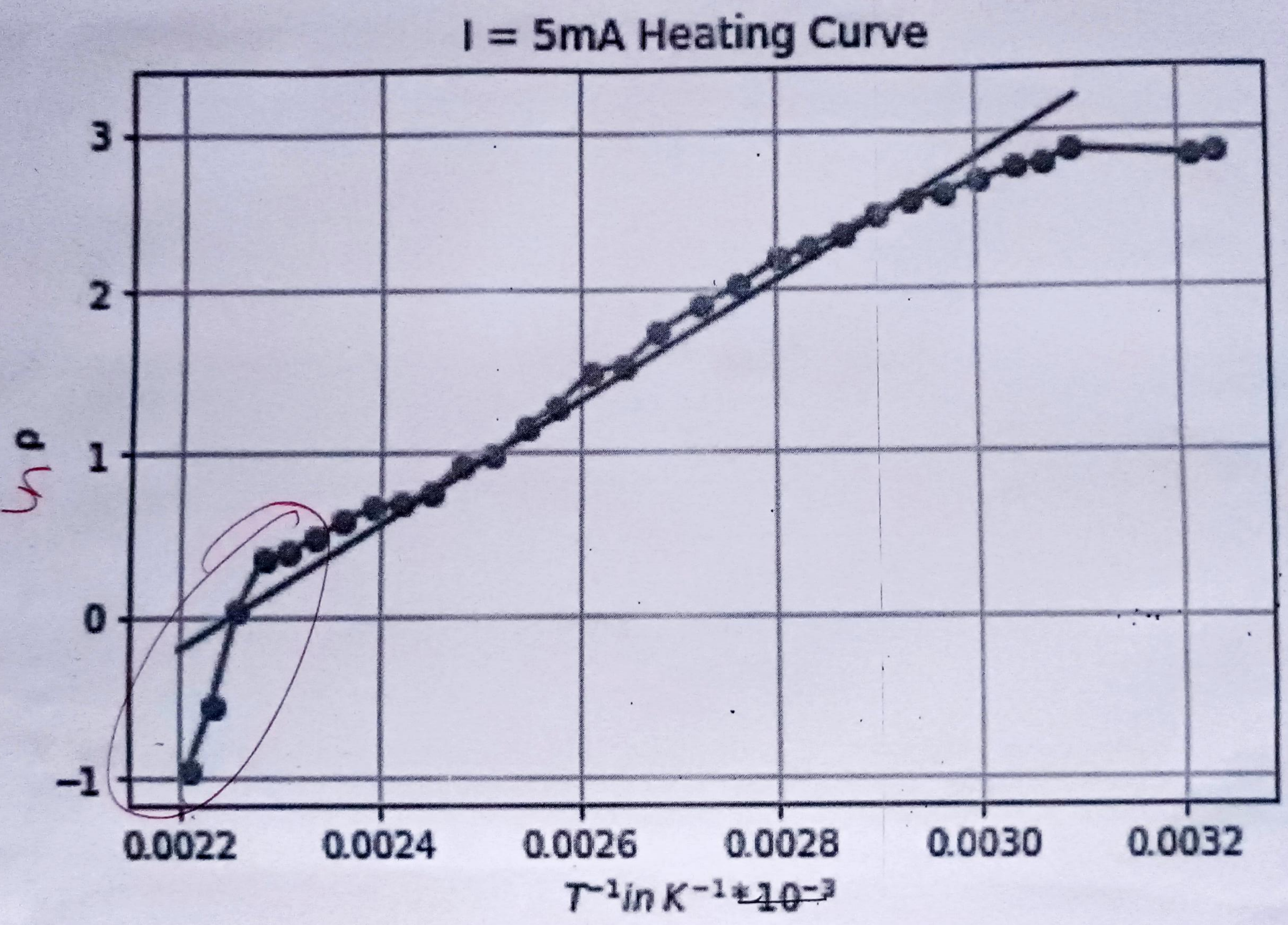
I = 2mA Cooling Curve
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ρ
0.0022
0.0024
0.0026
0.0028
0.0030
0.0032
$T^{-1} in\ K^{-1} * \cancel{10^{-3}}$

Expt. No. ____________ Page No. ____________

II Current = 5mA

S.NO	T°(C)	T(K)	V(mV) Heating	Cooling	Mean	ρ_0 (Ωm) unit	ρ (Ωm) unit	$T^{-1}(K^{-1})$ ×1000	$\ln(\rho)$
1	37	310	-	15.4	-	38.685	9.906	3.226	2.293
2	40	313	-	17.2	-	43.206	11.064	3.195	2.404
3	43	316	-	18.0	-	45.216	11.579	3.165	2.449
4	45	318	-	18.6	-	46.723	11.965	3.145	2.482
5	47	320	-	17.0	-	12.704	10.292	3.125	2.392
6	50	323	27.2	17.6	22.4	56.26	17.368	3.236	2.855
7	53	326	25.2	16.0	20.6	51.75	16.854	3.215	2.825
8	56	329	24.4	15.4	19.9	49.99	14.409	3.096	2.668
9	60	333	22.5	15.0	18.8	47.10	13.251	3.067	2.584
10	64	337	21.0	13.7	17.4	43.58	12.801	3.040	2.550
11	68	341	20.0	12.2	16.1	40.44	12.061	3.003	2.490
12	72	345	18.4	10.8	14.6	36.68	11.161	2.967	2.412
13	76	349	16.3	9.6	13.0	32.53	10.357	2.933	2.338
14	80	353	15.0	8.8	11.9	29.89	9.392	2.899	2.240
15	84	357	13.9	7.7	10.8	27.13	8.330	2.865	2.120
16	89	362	11.8	6.5	9.2	22.98	7.655	2.833	2.035
17	94	367	10.5	5.5	8.0	20.10	6.945	2.801	1.938
18	100	373	8.9	4.4	6.7	16.70	5.885	2.762	1.773
19	105	378	7.2	3.9	5.6	13.94	5.146	2.725	1.638
20	110	383	6.9	3.5	5.2	13.06	4.278	2.681	1.453
21	115	388	5.6	3.0	4.3	10.80	3.570	2.646	1.273
22	120	393	4.9	2.7	3.8	9.55	3.345	2.611	1.207
23	125	398	4.1	2.4	3.3	8.16	2.766	2.577	1.017
24	130	403	3.9	2.2	3.1	7.66	2.444	2.545	0.894
25	135	408	3.3	2.0	2.7	6.66	2.091	2.513	0.737
26	140	413	3.1	1.7	2.4	6.03	1.962	2.481	0.674
	145								

Teacher's Signature : ____________


I = 5mA Heating Curve
ln ρ
3
2
1
0
−1
0.0022
0.0024
0.0026
0.0028
0.0030
0.0032
$T^{-1} in K^{-1} * \cancel{10^{-3}}$

S.NO	$T^\circ(C)$	T(K)	V(mV)			ρ_0	ρ	$T^{-1}(K^{-1})$	ln ρ
			Heating	Cooling	Mean	(Ω m)	(Ωm)	$\times 10^3$	
27	145	418	3.0	1.5	2.3	5.65	1.447	2.392	0.370
28	150	423	2.0	1.4	1.7	4.27	1.094	2.364	0.089
29	155	428	1.8	1.2	1.5	3.77	0.965	2.336	-0.036
30	165	438	1.6	1.0	1.3	3.27	0.836	2.283	-0.179
31	170	443	1.6	0.9	1.3	3.14	0.804	2.257	-0.218

Calculations

I ~~Set I~~:

Correction term: $f(w/s) = \frac{2s}{w}(\ln 2)$

I Set 1: I = 2mA.

a) Heating curve

Best fit slope = 3.8873×10^3

Best fit x intercept = 1.7114×10^{-3}

Best fit y intercept = -6.6527

Band gap = slope $\times 2K_B$ = $3.8873 \times 10^3 \times 2 \times 8.617 \times 10^{-5}$ eV K^{-1}

= 0.6699 eV.

Error calculation:

Error in best fit slope: 58.4586

Error in best fit y-intercept: 0.1476.

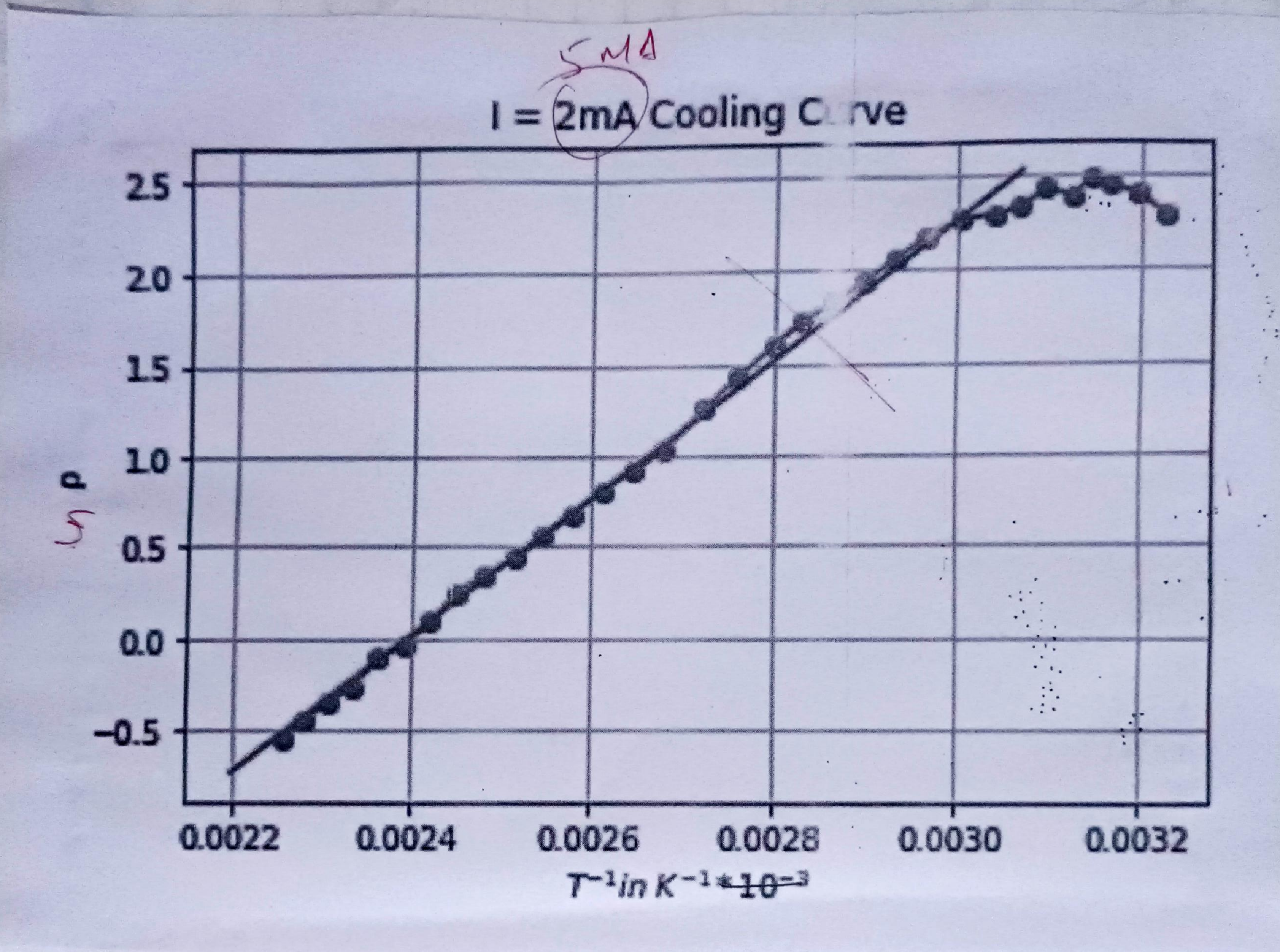
Error in E_g:

$\frac{\partial E_g}{E_g} = \frac{\partial m}{m} \times \frac{\partial 2}{2} \times \frac{\partial K_B}{K_B} = \frac{\partial m}{m}$

relative error: $\left(\frac{\text{Theo} - \text{Obs}}{\text{Theo}}\right)$ = ~~0.009~~ ~~0.96 eV~~

= 0.0001 eV.

Error in E_g = 58.4586



5mA
I = 2mA Cooling Curve
ln ρ
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
0.0022
0.0024
0.0026
0.0028
0.0030
0.0032
T⁻¹ in K⁻¹ * ~~10⁻³~~

b) Cooling curve

Best fit slope = 3.6062×10^{3}
Best fit x-intercept = 1.6522×10^{-3}
Best fit y-intercept = −5.9582
Band gap = ~~0.0008~~ 0.6215 eV.

Error in slope: ±0.6879
Error in y-intercept: ±0.0522
Error in band gap: ~~±0.6879 eV.~~ 0.0724eV

II Set 2: I = 5mA
a) Heating curve
Best fit slope : 3773.0 ~~×10~~
Best fit x-intercept : 0.0023
Best fit y-intercept : −8.5031
Band gap : 0.6502 eV

Error in slope: ~~3773.0~~ 157.0024
Error in y intercept: ±0.4126
Error in band gap: ~~157.0024 eV~~ 0.0295 eV.

b) Cooling curve
Best fit slope: 3740.07
Best fit x intercept: 0.0024
Best fit y intercept: ~~a~~ −8.9566
Band gap: 0.6446 eV

Teacher's Signature :

Error in slope = 47.0477 check

Error in y intercept = 0.125.

Error in band gap = ~~47.0477~~ 0.0379 eV.

Result:

1. For $I = 2mA$,

~~Band gap =~~

(a) Heating curve

Band gap = $(0.6999 \pm \cancel{58.4586}\ 0.0001)$ eV

(b) Cooling curve

Band gap = $(0.6215 \pm \cancel{20.6879}\ 0.0724)$ eV

Use slope to report the result.

2 For $I = 5mA$

(a) Heating curve

Band gap = (0.6502 ± 0.0295) eV

(b) Cooling curve

Band gap = (0.6446 ± 0.0379) eV

The temperature dependence of the resistivity of semiconductor chips ~~is~~ as shown in the graph. The resistivity of decrease exponentially with increase in temperature T.

The material used was found to be Germanuim, as the calculated band gap is approximately 0.67eV, ie band gap of Ge.

what Material

Expt. No. ____________ Page No. ____________

Sources of Error:

1. All the four probes may not be collinear
2. The surface of the semiconductor may not be flat
3. ~~There might be error in reading temperature~~ P ^.
4. There might be fluctuations in voltage.

Discussion ρ Vs T Semiconductor.

- As temperature increases, ~~electron~~ charge carriers enter the conduction band from the valence band.

Sengupta
2/9/2022