Materials Characterization Lab.-II

Laboratory report on

Determining Resistivity, and Band Gap using 4 probe Method

Gurudev Singh

Name of Student

Roll No. 17MM02006

Semester VII

_

School of Minerals, Metallurgical and Materials Engineering

Indian Institute of Technology, Bhubaneswar, India

Date of Submission: 1/9/2020

Determining Resistivity and Band Gap of a semiconductor using 4 probe Method

Objectives

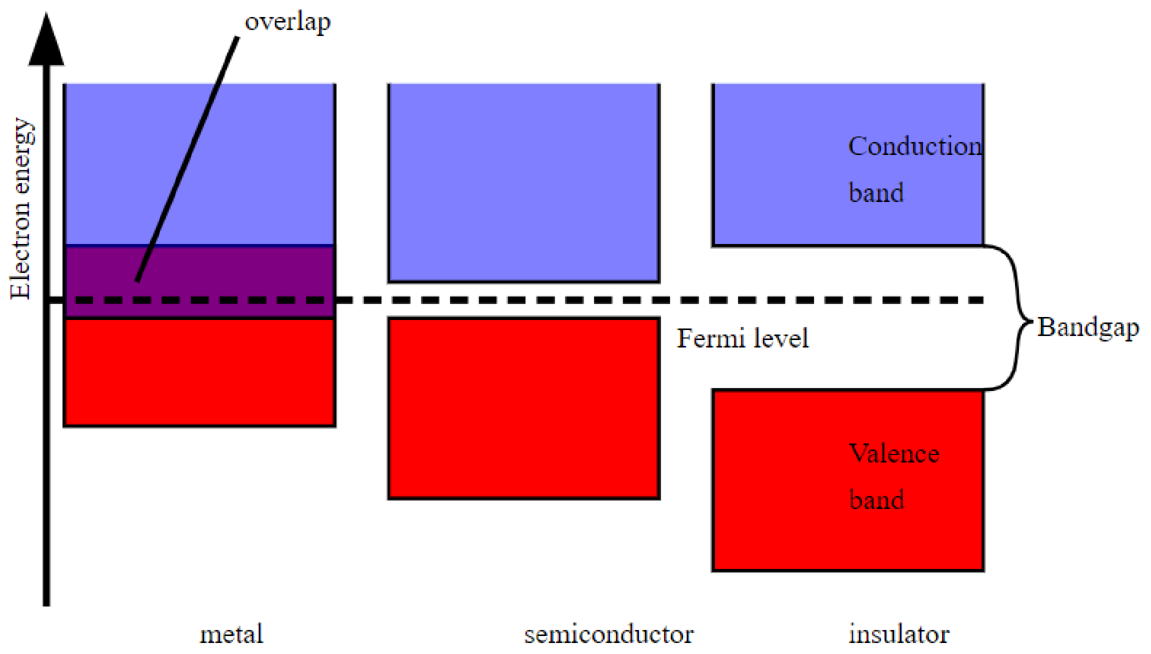
To study and determine following parameters in Germanium

- **Temperature variation of Resistivity and Conductivity**
- **Electronic Band Gap**

Introduction

Semiconductors are defined to have conductivity in between an insulator and a conductor. Due to this property, semiconductors are very common in every day electronics since they likely will not short circuit like a conductor. They get their characteristic conductivity from their small band gap. Having a band gap prevents short circuits since the electrons aren't continuously in the conduction band. A small band gap allows for the solid to have a strong enough flow of electrons from the valence to conduction bands in order to have some conductivity.

Electrons in the conduction band become free from the nuclear charge of the atom and thus can move freely around the band. Thus, this free-moving electron is known as a negative charge carrier since having the electron in this band causes electrical conductivity of the solid. When the electron leaves the valence band, the state then becomes a positive charge carrier, or a hole.



The concentration of intrinsic carriers i.e. the number of electrons and holes in conduction and valence bands per unit volume, respectively, is given by the expression:

$$n = 2\left(\frac{m_e\, kT}{2p\, h^2}\right)^{\frac{3}{2}} \exp\,(\mu - E_g) / kT$$

$$p = 2\left(\frac{m_h\, kT}{2p\, h^2}\right)^{\frac{3}{2}} \exp\,(-\mu / kT)$$

$$np = 4\left(\frac{kT}{2p\, \hbar^2}\right)^{3} (m_e\, m_h)^{3/2} \exp(-E_g / kT)$$

If no. of holes is equal to no. of electrons we get-

$$n_i = p_i = 2\left(\frac{kT}{2p\, \hbar^2}\right)^{\frac{3}{2}} (m_e\, m_h)^{3/4} \exp(-E_g / 2kT)$$

And we know conductivity of a semiconductor can be written by the expression below-

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

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

$$= (K)\, T^{3/2}\, (\mu_n + \mu_p).\ \exp \frac{-E_g}{2kT}$$

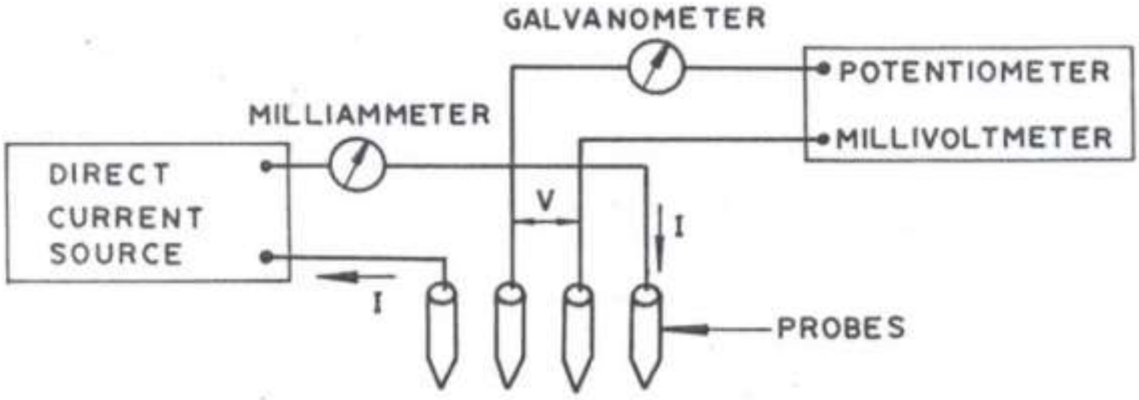
Substitution the concentration of charge carriers in the expression, we get the equation! Now if we take Ln on both the side, (since the exponential term is the only term that changes significantly with conductivity, hence all others can be clubbed together in K.

Thus we have,

$$\mathrm{Log}_e\, \rho = \frac{E_g}{2kT} - \log_e K$$

Thus we can see that log of Resistivity and 1/T are linearly dependent on each other.

Four Probe Experiment



In this setup, 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.

Floating voltage Vf at a distance r from the electrode carrying current I is-

$$V_f = \frac{\rho_0 I}{2\pi r}$$

Thus the voltage between the central probes-

$$V = V_{f2} - V_{f3} = \frac{\rho_0 I}{2\pi}\left(\frac{1}{S_1} + \frac{1}{S_3} - \frac{1}{S_2 + S_3} - \frac{1}{S_1 + S_2}\right)$$

If spacing between probes are equal, then

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

But again, if the width of the sample is small enough, it influences the resistivity,

$$\rho = \frac{\rho_0}{G_7(W/S)}$$

Where, G7(W/S)= 2S/W ln(2)

Experiment details

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. The resistance between the Red and Black probes and Yellow and Green probe may be approximately few K-Ohms (~1-4 K-Ohms).

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.

6. 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'.

Results

Sample: Ge Crystal **Constant Current: 08 mA**

Sl. No.	Temperature T (K)	Voltage V (V)	Resistivity ρ Ohm-cm
1.	310	0.524	19.781
2.	320	0.415	15.666

3.	330	0.355	13.401
4.	340	0.316	11.929
5.	350	0.217	8.191
6.	360	0.146	5.511
7.	370	0.110	4.152
8.	380	0.085	3.208
9.	390	0.065	2.453
10.	400	0.050	1.887
11.	410	0.039	1.472
12.	420	0.031	1.170
13.	430	0.026	0.981
14.	440	0.021	0.792

Distance between the Probes (s) = 2.00 mm.

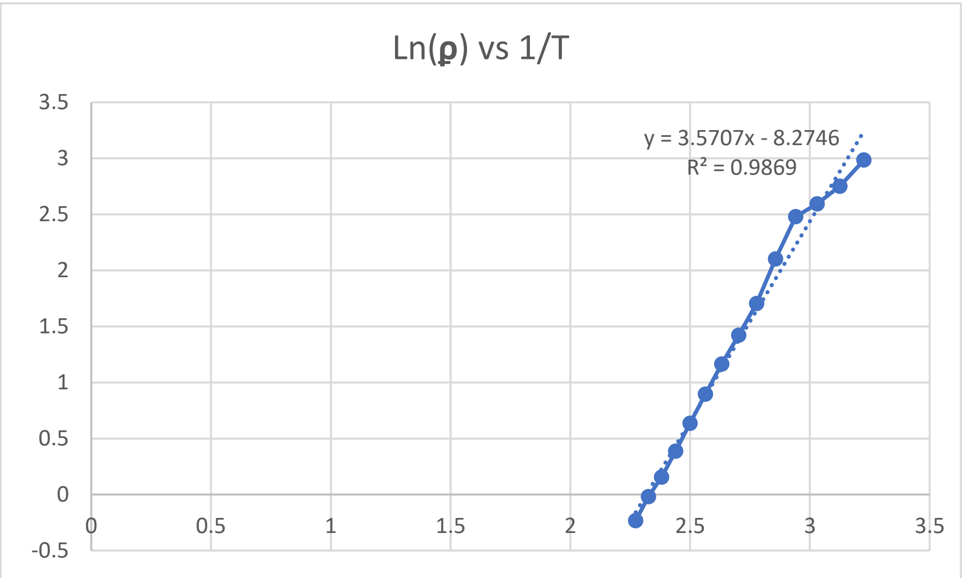
Thickness of the Crystal (w) = 0.66 mm.

Calculation-

1) **G7(W/S) =2S/W ln (2)**
   G7(W/S)= 2*(2/0.66)*0.6931=4.2;

2) **ρ0=V/I * 2piS**
   ρ= ρ0/ G7(W/S);

   2piS/I=157;



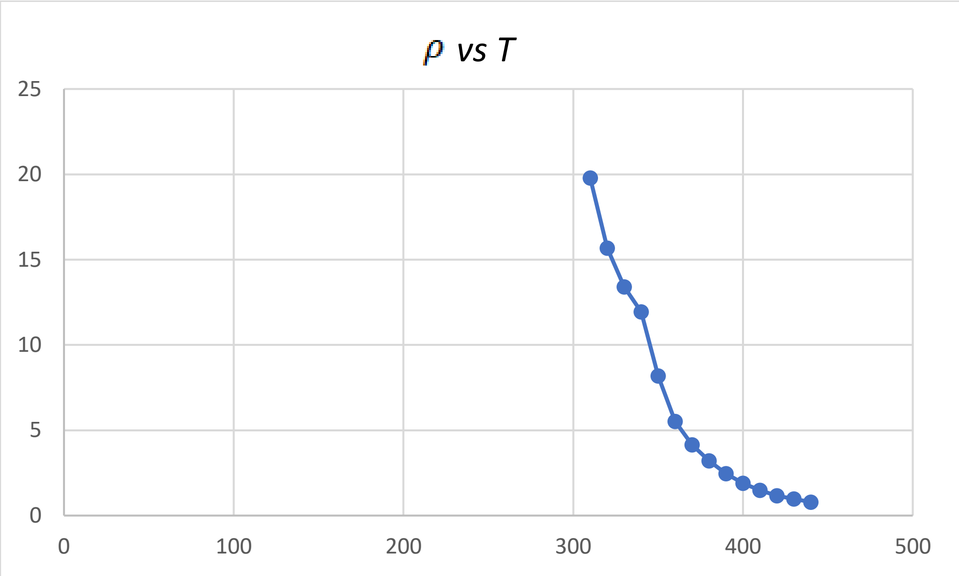
Slope=3.5707=Eg*1000/2K;

Eg=3.5707*2*K/1000;

E0g=9.855*10^-26;

Eg=0.6146 eV;

Note- K= 1.38064852 × 10-23 m2 kg s-2 K-1;



Discussion

- The Semiconductor is very thin and can break pretty easily, precaution has to be taken in that case.
- Current should not be too large to prevent overheating of sample due to input current.
- At lower temperature, the deviation is large from the ideal scenario, this can be due to the fact that material was just started heating up and the temperature distribution must not be homogenous in the beginning.
- It is scene that Resistivity decreases with increase in temperature, or say conductivity increases with increase in temperature, this is because charge carriers are more mobile at higher temperature.

Conclusion

- We performed the four probe method, where voltage was measure with change in temperature.
- G7(W/S) was computed out to be= 4.2.
- The slope was measured from the Ln ρ vs 1/T that came out to be-3.5707
- Eg = 0.6146eV.

References-

1) **https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Semiconductors/Band_Theory_of_Semiconductors#:~:text=According%20to%20the%20band%20theory,band%20and%20unoccupied%20conduction%20band.**

Thank You