

SEMICONDUCTOR

Lab 3 :: Monday 10/5/2009 9:30am

TAs: Uttarwar & Yang

LAB REPORT

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INTRODUCTION

The purpose of this experiment is to determine the band gap energy (E_0) in the elemental solid germanium. In a semiconductor like germanium electrons must be promoted from the valence energy band through the band gap to the conduction band in order for the substance to conduct electricity [1]. Therefore, the band gap can be thought of (in a semiconducting element) as the amount of energy required to for the element to conduct electricity.

In this experiment we will be increasing the temperature of the sample to provide the thermal energy necessary to promote valence electrons across E_0 . Resistance, which is inversely proportional to the conductivity (σ), will be measured at different temperatures. This will reveal how many free electrons are present for the conduction of electricity at each temperature. This can then be related to the amount of energy required to promote those electrons from the valence band to the conduction band; namely the band gap energy.

PROCEDURE

The objective of this lab was to determine average values of the resistance (Ω) of the semiconducting material through a temperature range of 35°C, 40°C ... 75°C and then to ultimately determine the band gap of the material. The resistance is measured as the temperature rises and as the temperature falls. When an average value for the resistance is found, it will be used to find the band gap, E_0 .

SETTING UP THE EXPERIMENT:

This lab requires the use of hot plate, a cooling plate, an ohm meter, an electronic thermometer and a piece of semiconducting material. The ohm meter and the electronic thermometer are connected to the semiconducting material through low resistance, highly conductive wires.

TRANSFERRING HEAT FROM THE HOT PLATE TO THE SEMICONDUCTING MATERIAL:

1. The semiconducting material is placed onto the hot plate.
2. The hot plate is turned on and begins to heat up, transferring heat to the semiconducting material.
3. When the temperature reads 35°C the resistance is measured at that point.
4. Step 3 is repeated for every +5°C.
5. When the temperature reaches 75°C, a final resistance is measured for that point.
6. The hot plate is allowed to rise in temperature slightly past 75°C before switching plates.

TRANSFERRING HEAT FROM THE SEMICONDUCTING MATERIAL INTO THE SURROUNDINGS:

1. The semiconducting material is removed from the hot plate and placed on the cooling plate, which is located away from the hot plate.
2. When the temperature falls back down to 75°C the resistance is measured at that point.
3. Step 2 is repeated for every -5°C.
4. When the temperature reaches 35°C, a final resistance is measured for that point.

FINDING THE AVERAGE RESISTANCE:

1. From the experiment there are 2 resistance values, (R_1 and R_2), for the same temperature.
2. $\bar{R} = (R_1 + R_2)/2$

(1)

FINDING THE BAND GAP, E_0 :

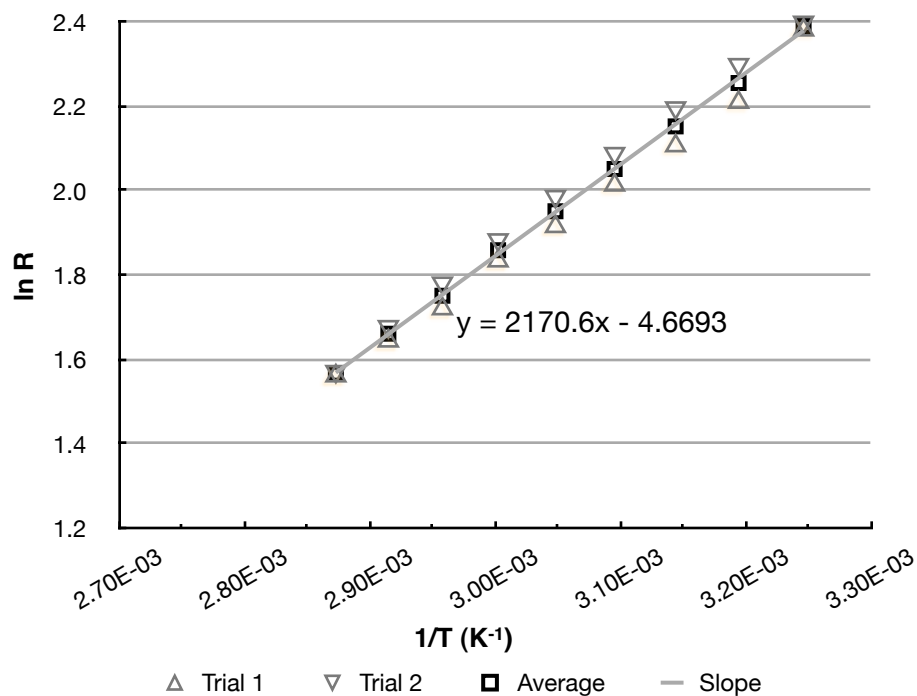
1. The band gap is found using linear regression.
2. $y = mx + b \Rightarrow \ln \bar{R} = \ln \frac{c}{\sigma_0} + \frac{E_0}{2k} \times \frac{1}{T}$ where k is Boltzmann's constant.

(2)

3. When this linear function is plotted on a Cartesian coordinate system the slope can be determined and the band gap can be solved for.

$$E_0 = m2kT$$

(3)

RESULTS**Figure 1 - Resistance versus Temperature**

$$\frac{E_0}{2k} = 2170.6$$

Where $k = 8.62 \times 10^{-5} \text{ eV/K}$

(4)

Therefore:

$$E_0 = 0.374 \text{ eV}$$

DISCUSSION

Semiconductors are materials where the band gap energy is nonzero, but still sufficiently small to make them particularly useful for many purposes where this behavior is required. The typically cited range of band gap energies of materials classified as a semiconductors is 0eV to 2eV, with any substance having a band gap energy higher than 2eV being considered an insulator [1].

*Table 1 - Band Gap Energies of
Common Semiconductors [2]*

Material	Band Gap (eV)
Silicon	1.11
Selenium	1.74
Germanium	0.64
Silicon Carbide	2.86

Our experimental value of $E_0=0.374\text{eV}$ is significantly less than the accepted standard value of 0.64eV for germanium [2]. We speculate that this is due to either or both:

1. Testing equipment slightly out of calibration. The testing equipment used for this lab was temperamental and would give erroneous readings if not handled delicately. We repeated the measurements while the sample was cooling because we were concerned about incorrect readings.
2. Impurities in the germanium sample. While germanium is one of the two intrinsic (natural) elemental semiconductors, and is therefore a semiconductor in its pure natural state, its conductivity is easily affected by even very small amounts of impurity. Silicon, for example, the other intrinsic elemental semiconductor becomes extrinsic (semiconductive due to impurity) with only a 1 atom in 10^{12} impurity [1]. Thus, even a very small impurity could result in the much lower band gap energy that we measured experimentally.

CONCLUSION

Germanium is an intrinsic semiconductor with a band gap energy of:

$$E_0 = 0.374 \text{ eV}$$

APPENDIX

Table 2 - Raw Data

Temp (°C)	Temp (K)	Trial 1 (kΩ)	Trial 2 (kΩ)	Average (kΩ)
35	308	10.8	11	10.9
40	313	9.10	9.95	9.525
45	318	8.21	8.98	8.595
50	323	7.48	8.06	7.77
55	328	6.78	7.28	7.03
60	333	6.25	6.57	6.41
65	338	5.58	5.93	5.755
70	343	5.17	5.35	5.26
75	348	4.76	4.81	4.785

SAMPLE CALCULATION:

1. Temperature Reading (T): $35^\circ\text{C} + 273 = 308\text{K}$
2. Resistance Readings: Trial 1=10.8 kΩ, Trial 2=11 kΩ
3. Average Resistance (\bar{R}): $\frac{10.8 + 11}{2} = 10.9\text{k}\Omega$
4. Use spreadsheet to plot: $\ln \bar{R}$ vs. $1/T$
5. Use linear regression (trend line) to find slope of sample points.

$$6. \text{ Using: } \ln \bar{R} = \ln \frac{c}{\sigma_0} + \frac{E_0}{2k} \times \frac{1}{T} \Rightarrow y = mx + b$$

$$6.1. \text{ Where: } \ln \frac{c}{\sigma_0} \sim b \text{ (constant)}$$

$$6.2. \text{ And: } \frac{E_0}{2k} \times \frac{1}{T} \sim mx \quad \text{Where: } \frac{1}{T} \sim x \quad \therefore \frac{E_0}{2k} \sim m = \text{slope} = 2170.6$$

$$7. \quad E_0 = 2170.6 \times 2(8.62 \times 10^{-5} \text{ eV/K}) = 0.374 \text{ eV}$$

BIBLIOGRAPHY

1. Callister, W.D. and D.G. Rethwisch, *Fundamentals of materials science and engineering: an integrated approach*. 3rd ed. 2008, Hoboken, NJ: John Wiley & Sons. xxv, 882 p.
2. Streetman, B.G. and S. Banerjee, *Solid state electronic devices*. 6th ed. Prentice Hall series in solid state physical electronics. 2006, Upper Saddle River, N.J.: Pearson/Prentice Hall. xviii, 581 p.