Lab 4: Hall Effect

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EE 145L
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1 Abstract

The purpose of this lab is to experimentally determine, using the Hall effect, the semiconductor type, carrier concentration and mobility of an extrinsic semiconductor, indium gallium arsenide doped with erbium arsenide nanoparticles. The extrinsic semiconducting chip was found to be p-type, and the experimental values were found as $p = 2.99 * 10^{20} cm^{-3}$, $\mu_p = 8.12 * 10^{-2} \frac{cm^2}{Vs}$ and $R_H = 2.09 * 10^{-2} \frac{cm^3}{C}$.

2 Introduction

The purpose of this lab is to measure the semiconductor type (n or p), carrier density p or n, mobility μ_p or μ_n, and Hall Coefficient R_H of an indium gallium arsenide chip embedded with erbium arsenide nanoparticles using the Hall Effect. A sketch of the experimental setup is shown in Figure 1.

The Hall effect is a phenomenon that happens when a magnetic field is applied to a current carrying conductor. A voltage, called the Hall Voltage V_H is produced transverse to the direction of current flow when a magnetic field B_z is applied perpendicular to the direction of current flow. This Voltage can be found as a function of the current and applied magnetic field by Equation 1 for n-type semiconductors and Equation 2 for p-type semiconductors, where q is the elementary charge and t is the thickness of the semiconductor material. Using one of these two equations, and data for I_x and B_z, the carrier density can be determined if q and t are known.

$$V_H = \frac{-I_x B_z}{|q| n t} \tag{1}$$

$$V_H = \frac{I_x B_z}{|q| p t} \tag{2}$$

Once the carrier density is known, the mobility can be found by using Equation 4, derived from the mutual relation to a material's conductivity σ shown in Equation 3. R is the material's resistance (in this lab determined experimentally via Ohm's law) and A is the cross-sectional area of the current path, or the thickness t times the width of the material w.

$$\sigma = \frac{L}{AR} = |q| \mu_p p \tag{3}$$

$$\mu_p = \frac{L}{AR|q|p} \tag{4}$$

Additionally, a material's Hall Coefficient R_H determines how strong of an electric field the material produces when a current through it is subjected to a perpendicular magnetic field. For the purposes of this lab, R_H can be found by Equation 5 or Equation 6 for p-type and n-type respectively.

$$R_H = \frac{1}{|q|p} \tag{5}$$

$$R_H = \frac{-1}{|q|n} \tag{6}$$

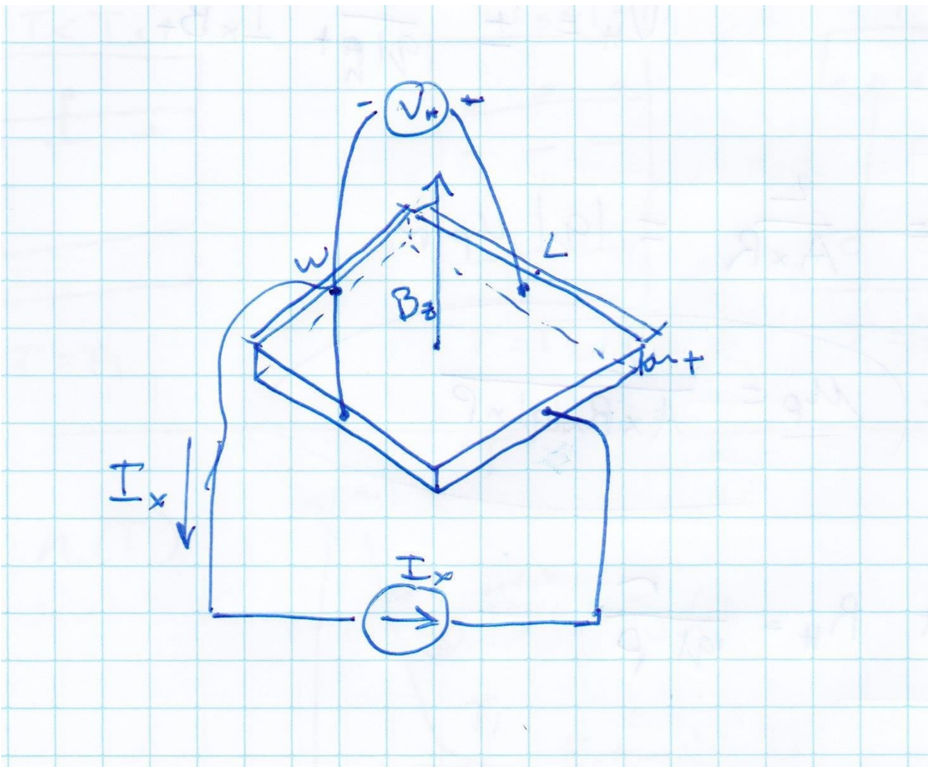

Figure 1: Sketch of experimental setup

3 Materials and Methods

Materials:
-Electromagnet
-3 Digital Multimeters
-1 doped indium gallium arsenide chip
-Current Supply

Methods: Because of equipment malfunction, most likely a short in the semiconductor chip, the data for this lab was provided by the TA. The Hall voltage was measured for different currents I_x and applied magnetic fields B_z. Additionally, voltage and current values were measured for the semiconductor chip to determine its resistance.

		I_x(mA)			
		1	2	3	4
B_z(mT)	200	1.71	3.41	5.12	6.83
	400	4.18	8.35	12.52	16.68
	600	6.54	13	19.56	26.05
	800	9.02	18.01	26.96	35.85

Table 1: Data for Hall Voltage V_H with respect to I_x and B_z

Voltage (V)	Current (mA)
0.5	7.51
1	14.91
1.5	22.36
2	30
2.5	37.99
3	47.08

Table 2: Voltage and Current data to determine resistance of semiconductor chip

4 Results and Analysis

First regarding the constants, L was measured as 1cm, $w = L = 1cm$, $t = 0.001969cm$ and $q = 1.602 * 10^{-19}C$

The magnetic field experiment data provided by the TA is shown in Figure 1. Considering Equation 1, V_x is directly proportional with respect to both I_x and B_Z. To find the proportionality constant $\frac{1}{|q|nt}$, for each value of I_x, a linear regression was performed on V_H vs B_z, and that value of I_x was divided out, resulting in a value for $\frac{1}{|q|nt}$. This operation was performed for each value of I_x, and in a similar way for each value of B_z, holding B_z constant and taking a linear regression of V_H vs I_x. The eight values of $\frac{1}{|q|nt}$ were then averaged, and the resulting value was found to be $\frac{1}{|q|nt} = 10.59\frac{cm^2}{C}$. Because this value is positive, the material corresponds with Equation 2 and the semiconductor is p-type. The carrier density p was then found as $\frac{1}{10.59*|q|t} = 2.99 * 10^{20}cm^{-3}$.

The resistance of the semiconductor was found by taking a linear regression of the data in Figure 2, and was found to be $R = 65.266\Omega$. The mobility of the semiconductor was then found using Equation 4 to be $8.12*10^{-2}\frac{cm^2}{Vs}$. Then, the Hall constant R_H was calculated using Equation 5, and was found to be $R_H = 2.09 * 10^{-2}\frac{cm^3}{C}$.

5 Conclusions

Reading the textbook, chapter 5.2 gives examples of extrinsic conductor carrier densities. Those densities are often on the order of 10^16cm^{-3} or 10^17cm^{-3}. This makes the experimental value of $p = 2.99 * 10^{20}cm^{-3}$ seem a bit large. However, the concentration depends how heavily the semiconductor was doped with the erbium arsenide and since the dopant concentration is unknown, one consideration is that this is just a heavily doped sample.

During this lab, I learned that the hall effect is a method one can use to experimentally determine a material's carrier concentration and by extension, mobility. I also refreshed myself on analyitical techniques regarding linear 3D data sets.