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Laboratory Report Cover Page

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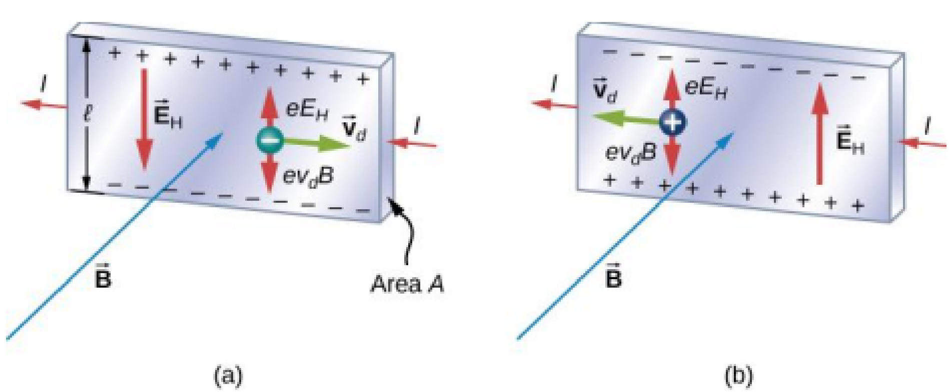
Introduction

The Hall effect is a phenomenon characterized by generating a potential difference across a conductor when an electric current flows through it in the presence of a perpendicular magnetic field. This magnetic field exerts a force on the electrons within the conductor, causing them to accumulate on one side, establishing an electric potential. This electric potential is quantified as the Hall voltage (Vh), and its magnitude and direction are contingent upon the strength and orientation of the magnetic field as well as the magnitude and direction of the current flow. This experiment aims to comprehensively examine the behaviour of electrons within a conductor as they interact with an applied magnetic field during the passage of an electric current.

Theory

Looking at the theory behind the Halls Effect and the traditional method of experiment, it shows that when the Hall voltage is positive, the semiconductor will be a ‘p-type,’ and when the Hall voltage is negative, the semiconductor will be an ‘n-type.’ In the experiment conducted in the lab, if you reverse the magnetic field's direction, the field's polarity will also reverse. In this case, it exhibits a positive Hall voltage for the ‘n-type’ and a negative Hall voltage for the ‘P-type.’ In 1879, Edwin Hall proposed a method for determining the sign of the dominating charge carriers in a conducting material. Charges are what carry current. If a current-carrying material is in a magnetic field, its charges will experience a magnetic force $F = qv \times B$,. Using an example of a metal strip, the electrons travel from left to right, and the magnetic field they encounter pulls them to the strip's bottom edge. This charge separation produces an electric field E_H and a concomitant electric potential ΔV_H, which may be measured using a voltmeter. This field is due to an excess positive charge at the top border of the strip. Charge concentration builds up at both edges until the electric force on the electrons in one direction is balanced by the magnetic pull on them in the opposing direction. So, Equilibrium occurs when $eE = ev_d B$. Where “e” is the magnitude of the electoral charge, v_d is the electrons' drift speed, and E is the magnitude of the electric field formed by the separated charge. Rearranging the equation above will yield the drift speed of an electron: $v_d = \frac{E}{B}$



A crossed-field situation occurs when the electric and magnetic fields are perpendicular. These particles can travel through an apparatus if these fields provide equal and opposing forces on a charged particle with a velocity that equals the forces. Returning to the Hall effect, if the current in the strip is I, then we know the following equation:

$$I = nev_d A$$

Where “A” denotes the strip's cross-sectional area and “n” denotes the number of charge carriers per volume. Incorporating the drift velocity and the current equation results in:

$$I = ne(\frac{E}{B})A$$

The field “E” is proportional to the potential difference “V” between the strip's edges. The value of “V” is known as Hall's potential which can be measured using a voltmeter.

$$E = \frac{V}{l}$$

Combining the “I” and “E” equations yields the final equation of:

$$V = \frac{Ibl}{neA}$$

In addition, we can combine $eE = ev_d B$ and $E = \frac{V}{l}$ to yield an expression for Hall’s voltage in terms of the magnetic field:

$$V = Blv_d$$

According to Hall potentials, the majority of charge carriers are positive in a few metals such as tungsten, beryllium, and many semiconductors. Positive charge conduction is induced by the movement of missing electron sites called holes. The mobility μ of charge carriers is defined as the ratio of the speed of the change carriers to the applied electric field magnitude

$$|V| = \mu|E|.$$

Given the circumstances of this lab, the Hall Electric field points along the width of the wafer (W). So the associated potential difference is $|\Delta V_H| = |E_H|W.$ Combining this with $|E_H| = |V_d||B|$, we yield the equation: $|\Delta V_H| = W|v_d||B|$.

Procedure

In this experiment, we utilized several materials, including banana cables, a current supply (with a maximum current of 50 mA), a strong magnet, a Germanium hall effect wafer with specific dimensions (L = 10.00 mm, W = 5.00 mm, T = 1.00 mm), two multimeters, and a zero gauss chamber. We used a probe to measure the magnetic field inside the zero gauss chamber, a crucial parameter for our subsequent calculations. Then, by setting up the banana cables according to the provided diagram, we applied a current across the wafer's width, generating a magnetic field within the zero-gauss chamber. We simultaneously measured the potential difference (Vh) and current using multimeters. Lastly, we adjusted the DC power supply to increase the current and recorded the potential difference values. We repeated these steps to measure potential differences along the length of the wafer by rearranging the banana cables. This experiment enables us to investigate the Hall effect in Germanium under different conditions, helping us understand its electrical properties in the presence of magnetic fields.

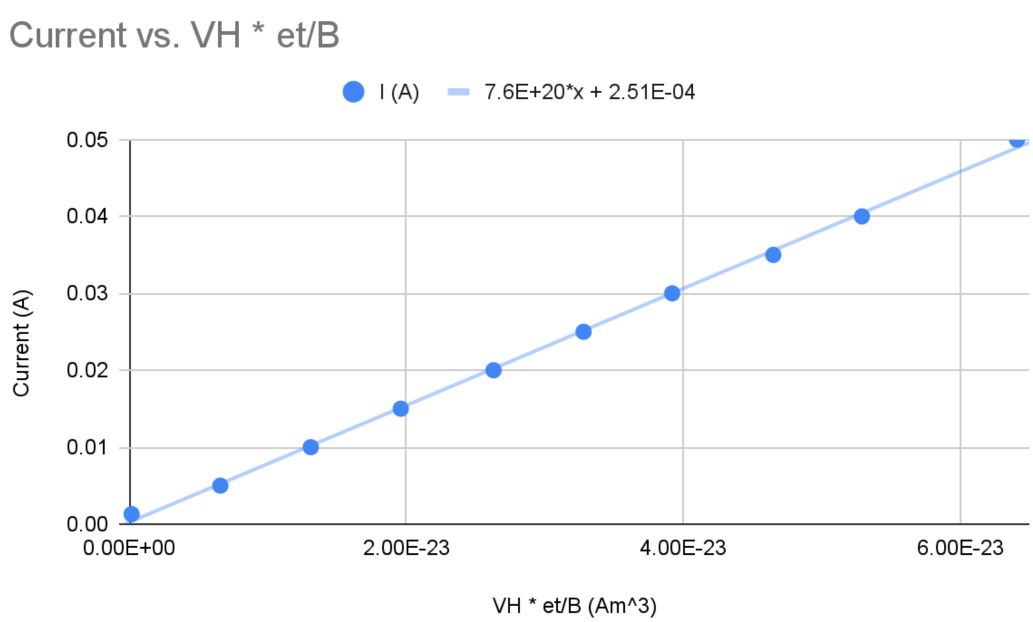
Results and Calculations

Magnetic Field (T) = (0.2 ± 0.0005) T (Down)

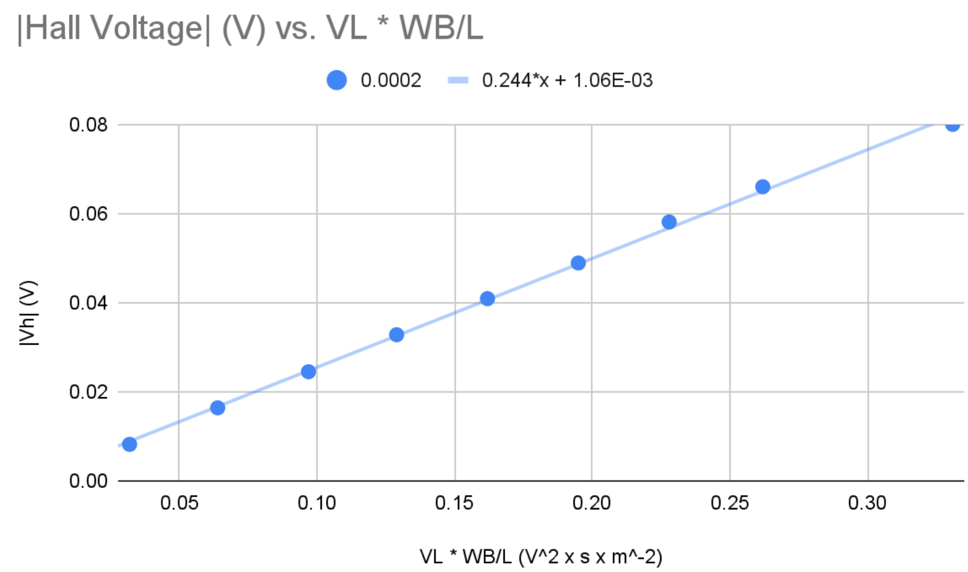
Current (mA) left	V_H (out)	V_L
1.3 ± 0.05 mA	-0.2 ± 0.05 mV	0.0839 ± 0.005 V
5 ± 0.05 mA	-8.2 ± 0.05 mV	0.32 ± 0.005 V
10 ± 0.05 mA	-16.4 ± 0.05 mV	0.64 ± 0.005 V
15 ± 0.05 mA	-24.5 ± 0.05 mV	0.97 ± 0.005 V
20 ± 0.05 mA	-32.8 ± 0.05 mV	1.29 ± 0.005 V
25 ± 0.05 mA	-40.9 ± 0.05 mV	1.62 ± 0.005 V
30 ± 0.05 mA	-48.9 ± 0.05 mV	1.95 ± 0.005 V
35 ± 0.05 mA	-58.1 ± 0.05 mV	2.28 ± 0.005 V
40 ± 0.05 mA	-66.0 ± 0.05 mV	2.62 ± 0.005 V
50 ± 0.05 mA	-80.0 ± 0.05 mV	3.31 ± 0.005 V

Current (mA)	V_H * et/B	V_L * WB/L
1.3 ± 0.05 mA	1.60 x 10^{-25} Am^3	0.0084 $V^2s^1m^{-2}$
5 ± 0.05 mA	6.57 x 10^{-24} Am^3	0.032 $V^2s^1m^{-2}$
10 ± 0.05 mA	1.31 x 10^{-23} Am^3	0.064 $V^2s^1m^{-2}$
15 ± 0.05 mA	1.96 x 10^{-23} Am^3	0.097 $V^2s^1m^{-2}$
20 ± 0.05 mA	2.63 x 10^{-23} Am^3	0.129 $V^2s^1m^{-2}$
25 ± 0.05 mA	3.28 x 10^{-23} Am^3	0.162 $V^2s^1m^{-2}$
30 ± 0.05 mA	3.92 x 10^{-23} Am^3	0.195 $V^2s^1m^{-2}$
35 ± 0.05 mA	4.65 x 10^{-23} Am^3	0.228 $V^2s^1m^{-2}$
40 ± 0.05 mA	5.29 x 10^{-23} Am^3	0.262 $V^2s^1m^{-2}$
50 ± 0.05 mA	6.41 x 10^{-23} Am^3	0.331 $V^2s^1m^{-2}$

Since our Hall Voltage is **negative**, our germanium wafer is **n-type**.



MEASURED charge carriers per volume of germanium (n) = slope = 7.6×10^{20} m^{-3} = 7.6×10^{14} cm^{-3}



Mobility = slope = 0.244 $m^2V^{-1}s^{-1}$ = 2440 $cm^2V^{-1}s^{-1}$

$$\%error = \left|\frac{measured-accepted}{accepted}\right| \times 100 = \left|\frac{2440-3900}{3900}\right| \times 100 = 37\%$$

Discussion

Theoretically, the conductivity of intrinsic germanim is about 2.2 $\Omega^{-1}m^{-1}$. Since our germanium was doped, and was therefore extrinsic, our germanium has more charge carriers and should have a higher conductivity. The formula for conductivity is $\sigma = en\mu$, after plugging in the values from our experiment we get, $\sigma = (1.6022 \cdot 10^{-19}C)(7.6 \cdot 10^{20}m^{-3})(0.244\frac{m^2}{Vs}) = 29.7\,\Omega^{-1}m^{-1}$. Therefore, our germanium sample was more conductive.

If the magnitude of the magnetic field was increased, the magnitude of the hall voltage would also increase. This is because the hall voltage is directly proportional to the magnetic field according to the formula $|\Delta V_H| = W|v_d||B|$, which is derived earlier in the theory section. Although, if the magnitude of the magnetic field is increased, the mobility would decrease. We can get a formula for mobility by rearranging the equation $\left|V_H\right| = \mu \cdot \frac{W|B|V_L}{L}$ to $\mu = \frac{|V_H|L}{W|B|V_L}$, this shows that the mobility is inversely proportional to the magnitude of the magnetic field.

Conclusions

In conclusion, our experiments showed us the relationship between a magnetic field and current applied to a semi-conductor, and the hall voltage it creates. Our germanium sample had a negative hall voltage, which means it had an excess of negative charge carriers and was n-type. We also successfully determined a rough approximation for the amount of charge carriers and their mobility, with an acceptable percent error.

References

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