Hall Effect

1 Aim

To study the Hall effect, to calculate the Hall coefficient, and to determine the type, the density and the mobility of charge carriers present in the probe.

2 Introduction

When a magnetic field is applied perpendicular to a current carrying specimen (metal or semiconductor), a voltage difference is developed in the specimen in a direction perpendicular to both the current and the magnetic field. This phenomenon was first observed in 1879 by E. H. Hall, and is know as the Hall effect.

A charged particle in motion experiences a magnetic force by a static magnetic field. When the applied magnetic field is perpendicular to the direction of motion of the charge, the force is perpendicular to both, the magnetic field, and the direction of velocity of the particle. Suppose in a semiconductor specimen, a steady current is flowing in the x-direction and magnetic field is applied along the z-direction. The magnetic force will then be in the y-direction. Since the holes and electrons move in opposite directions, they will experience the force in the same direction (in this case the y-direction). Net charge deposition occurs at the edge of the specimen. This produces an electric field $\vec{E}_H$ along the y-direction. The electric field depends on the magnetic field intensity $\vec{H}$ via

$$\vec{E}_H = R_H(\vec{J} \times \vec{H}) \tag{1}$$

where $\vec{J}$ is the current density and R_H is Hall coefficient.

If l, w and t are the dimensions (length, width and thickness) of the specimen, with current in the x direction and the magnetic field is in z-direction, then $\vec{E}_H$ is along the y-direction and we can write

$$R_H = \frac{V_H/w}{JH} = \frac{V_H t}{IH} \tag{2}$$

where V_H is the Hall voltage and $\vec{I} = \vec{J}wt$ is the current.

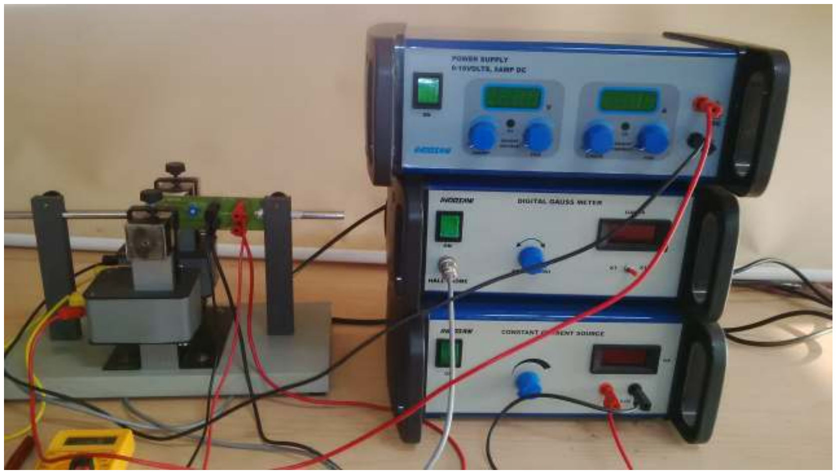

Figure 1: Apparatus for study of Hall effect.

There can be two different cases; if only one type of charge carriers are present (either positive or negative) or charge carriers of both type are there in the specimen. Here we will be concerned with only the 1st case.

2.1 Charge carrier of one type

In metals and doped semiconductors one type of charge carriers (electrons or holes) dominate. The magnetic force on the carriers is

$$e(\vec{v} \times \vec{H}) = \vec{E}_m \tag{3}$$

and is compensated by the Hall field $\vec{F}_H = e\vec{E}_H$, where v is the drift velocity of the carriers. Assuming the directions of various vectors as before

$$\vec{v} \times \vec{H} = \vec{E}_H. \tag{4}$$

The current density $\vec{J}$ is the charge e multiplied by the number of charge carriers traversing a unit area in unit time, which is equivalent to the matter density multiplied by the drift velocity, i.e. $\vec{J} = en\vec{v}$.

Substituting in Eq. (2) we have

$$R_H = \frac{E_H}{JH} = \frac{vH}{envH} = \frac{1}{ne}. \tag{5}$$

This implies that the sign of the Hall coefficient depends on the sign of the charge e. For a fixed magnetic field and input current, the Hall voltage is proportional to $1/n$ or its resistivity, because if one charge carrier dominates, the conductivity of the material is given by

$$\sigma = ne\mu, \tag{6}$$

where μ is the mobility of the charge carriers.

3 Apparatus in the lab and Procedure

1. Switch on the Gauss Meter and place the Hall probe away from the electromagnet. Using the adjustment knob of the Gauss Meter, adjust the reading as zero.
2. Switch on the constant current source and set the current, say at 5mA. Keep the magnetic field at zero.
3. Set the voltage range of the multimeter at $0 - 200$mV. Ensure that the reading of voltage is zero, *i.e.*, when a current of 5mA is passing without any magnetic field, the voltage is zero.
4. Bring the current reading of the constant current source to zero by adjusting the knob of the constant current source.
5. Switch on the electromagnet, at about 17V, 3.5A.
6. Select the range of the Gauss meter as $\times 10$ and measure the magnetic field at the center between the pole pieces. The tip of the Hall probe and the crystal should be placed between the center of the pole pieces.
7. Keep the magnetic field constant during the experiment, and the field strength should be more than 1500 Gauss.
8. Vary the current through the constant current source in small increments. Note the readings for the current (mA) and the Hall voltage (mV).
9. Reverse the direction of magnetic field by interchanging the $+$ and $-$ connections of the coils. Again note down the Hall voltage.
10. In order to measure the conductivity of the specimen, take another set of readings for current vs. voltage (not the Hall voltage) in the absence of magnetic field.

3.1 Sample Details

- Width of the specimen: $w = 6$ mm
- Length of the specimen: $l = 7$ mm
- Thickness of the specimen: $t = 0.5$mm

4 Calculations

1. Find Hall coefficient from Hall voltage Vs Magnetic field graph.
2. Determine the concentration of majority charge carriers in the probe.
3. Find the mobility of the charge carriers $\mu_n(or \mu_h) = R_H \sigma$ where σ is the conductivity.

5 References

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