HALL EFFECT

Experiment No. 2 (Theory)

Title: - Hall Effect

Aim: - To find the Hall coefficient, RH of a given semiconductor and hence estimate the carrier density.

Apparatus: - Hall probe, Sample mounted on holder, Electromagnet with power supply, current source

Theory: - If a current carrying conductor placed in a perpendicular magnetic field, a potential difference will generate in the conductor which is perpendicular to both magnetic field and current. This phenomenon is called Hall Effect. In solid state physics, Hall effect is an important tool to characterize the materials especially semiconductors. It directly determines both the sign and density of charge carriers in each sample.

Consider a rectangular conductor of thickness d kept in XY plane. An electric field is applied in X-direction using Constant Current Generator (CCG), so that current I flow through the sample. If w is the width of the sample and t is the thickness. Therefore, current density is given by

$$J = \frac{I}{wd}$$

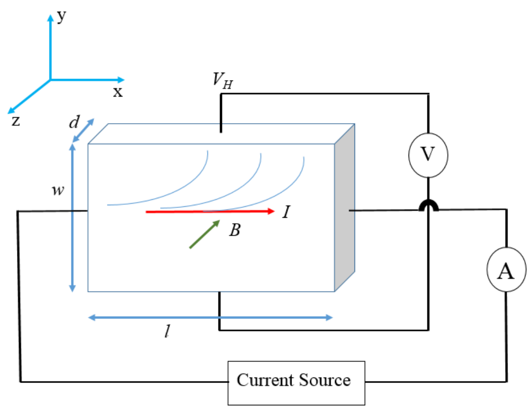

Fig.1 Schematic representation of Hall Effect in a conductor.

If the magnetic field is applied along negative z-axis, the Lorentz force moves the charge carriers (say electrons) toward the y-direction. This results in accumulation of charge carriers at the top edge of the sample. This set up a transverse electric field EH in the sample. This potential difference along y-axis is known as Hall voltage VH and this effect is called Hall Effect.

A current is made to flow through the sample material and the voltage difference between its top and bottom is measured using a volt-meter. When the applied magnetic field B=0, the voltage difference will be ideally zero.

We know that a current flow in response to an applied electric field with its direction as conventional and it is either due to the flow of holes in the direction of current or the movement of electrons backward. In both cases, under the application of magnetic field the magnetic Lorentz force,

$$Fm = q(v \times B) \quad (1)$$

causes the carriers to curve upwards. Since the charges cannot escape from the material, a vertical charge imbalance builds up. This charge imbalance produces an electric field which counteracts with the magnetic force and a steady state is established. The vertical electric field can be measured as a transverse voltage difference using a voltmeter.

In steady state condition, the magnetic force is balanced by the electric force. Mathematically we can express it as,

$$eE = evB \quad (2)$$

where 'e' the electric charge, 'E' the hall electric field developed, 'B' the applied magnetic field and 'v' is the drift velocity of charge carriers.

The total number of charge carriers in the above sample is nAl, where 'n' is the number density (i.e., number of charge carriers per unit volume) of the charge carriers in the conductor of length ‘l’, breadth 'w' and thickness 'd ', the cross-sectional area $A = wd$ and thus Al is the volume. The total charge is thus $neAl$. If this total charge exits the sample in a time T, then the current is

$\frac{neAl}{t}$. It means each charge carrier travels a distance l in a time T and hence has a velocity $= \frac{lI}{T}$.

Therefore, the current 'I ', defined as charge crossing a cross-section of the conductor in a time T, can be expressed as,

$$I = neAv \quad (3)$$

Using (1) and (2) the Hall voltage V_H can be written as,

$$V_H = Ew = vBw = \frac{IB}{ned}$$

By rearranging the equation, we get,

$$V_H = R_H \frac{IB}{d} \qquad (4)$$

$$\therefore R_H = \frac{V_H d}{IB} \qquad (5)$$

Where R_H is the Hall coefficient

$$R_H = \frac{1}{ne}$$

$$\therefore n = \frac{1}{R_H e} \quad (6)$$

The value of RH is calculated from the measured parameters using eq. (5) and that of n from eq. (6).

Design of Experiment: -

- An electromagnet which can produce a magnetic field of B=1000 Gauss in a gap of 30mm between the pole pieces is selected. An electromagnet (Fig. 2) consists of two solenoids with solid cylindrical iron cores such that the flat surfaces of the cylinders facing each other are North and South poles thus producing uniform field in the gap between the pole pieces.
- The sample is mounted on an insulating wooden sample holder. The sample holder is placed between the pole pieces such that the magnetic field lines (parallel to axis of the pole pieces shown by the red dashed line in Fig. 2) are perpendicular to the sample.
- A Hall probe is placed in the gap very near the sample such that its sensing element is also perpendicular to the magnetic field. The electrical contacts for current and voltage measurements are made by pressure contacts. The pressure contacts are made of stainless-steel plates as shown in Fig. 3.
- The pressure can be varied by tightening the screws which hold the contacts down. Ideally, it is expected that the tips of the current contacts should be aligned in a straight line; similarly, voltage contacts should also be aligned.

- In practice, there is always a misalignment as shown schematically in Fig.3 for the voltage contacts. This leads to a voltage V0 even in the absence of a magnetic field when a current is passed through the sample. This must be subtracted out from the voltage obtained with field to obtain Hall voltage.

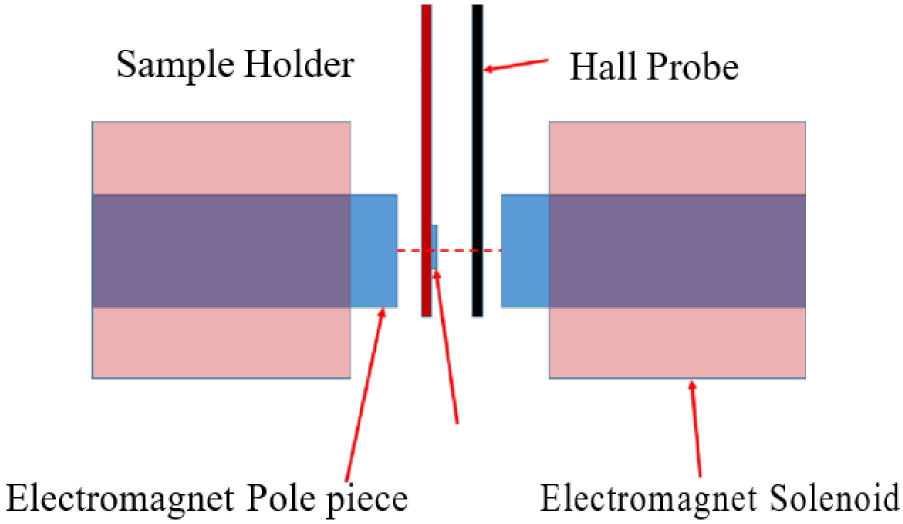

Fig. 2 Sample and Hall probe are aligned such that they are parallel to each other and perpendicular to the axis of the pole pieces and hence the magnetic field.

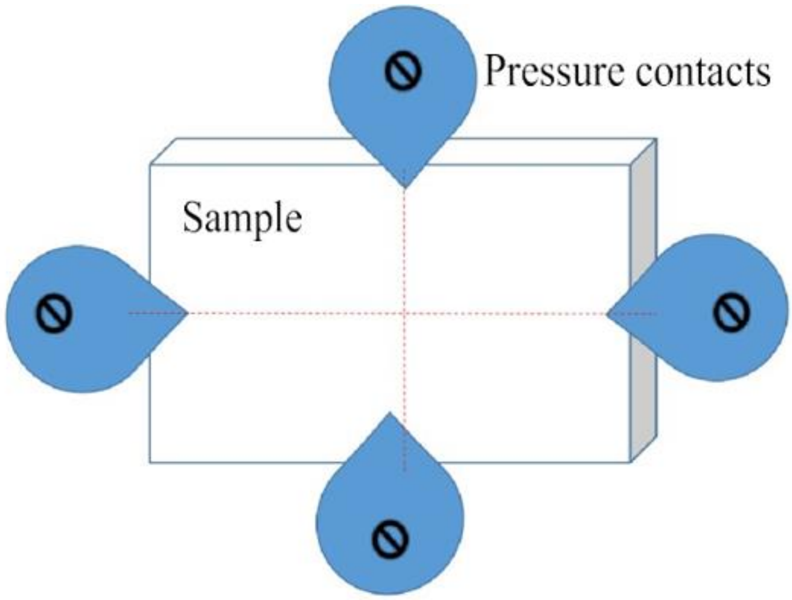

Fig. 3 Stainless steel plates (four blue pieces) are held down on the sample by the respective screws. Misalignment of the voltage probes can be seen.