HALL EFFECT

AIM : To study the Hall effect in semiconductor and to determine its allied coefficients.

APPARATUS : Hall effect digital box, hall probe (germanium P type), gauss probe (made of InAs), electromagnet, constant current supply, digital gauss meter with hall probe and a wooden hall probe stand.

INTRODUCTION : Dr. Edwin Hall discovered the Hall effect in 1879. When a current carrying conductor is placed in a perpendicular magnetic field, a potential difference is generated in the conductor which is perpendicular to both magnetic field and current. This phenomenon is called Hall Effect.

THEORY :
Hall effect is an important tool to characterize the materials especially semiconductors. It directly determines both the sign and density of charge carriers in a given sample.Consider a rectangular conductor of thickness 't' kept in XY plane. An electric field is applied in Xdirection using Constant Current Generator (CCG), so that the current I flows through the sample. If 'w' is the width of the sample and 't' is the thickness, the current density is given by

$$J_x = I/w \quad \textbf{(1)}$$

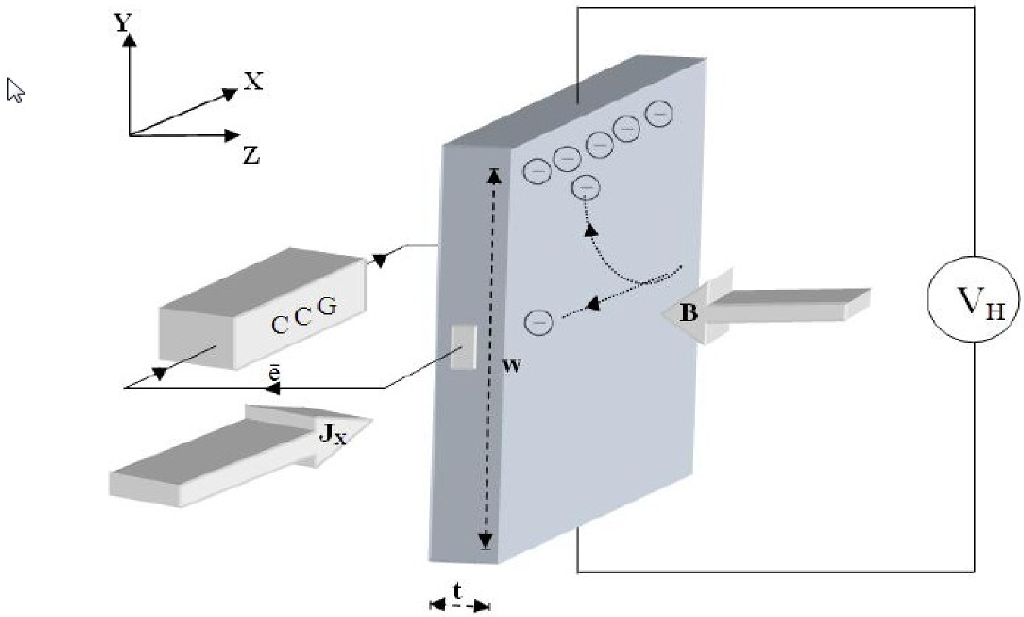

Figure-1 CCG – Constant Current Generator, J_X – current density
e^- – electron, B – applied magnetic field
t – thickness, w – width V_H – Hall voltage

If the magnetic field is applied along negative z axis, the Lorentz force moves the charge carriers (say electrons) towards y direction. This results in the accumulation of charge carriers at the top edge of the sample. This sets up a transverse electric field Ey in the sample,and hence a potential difference is developed along y axis which is known as Hall voltage V_H. 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 voltmeter. When the applied magnetic field B=0,the voltage difference should be zero.

We know that a current flows in response to an applied electric field. The application of magnetic field results in the magnetic Lorentz force, $F_m = q(vxB)$ which causes the carriers to curve. 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

$$eE= evB \qquad \textbf{(2)}$$

Where 'e' is the electric charge, 'E' the hall electric field developed, 'B' is the applied magnetic field and 'v' is the drift velocity of charge carriers. And the current 'I' can be expressed as,

$$I= neAv \qquad \textbf{(3)}$$

Where 'n' is the number density of electrons in the conductor of length 'l' ,breadth 'w' and thickness 't'. Using (1) and (2) the Hall voltage V_H can be written as

$$V_H = EW= vBW= \frac{IB}{net}$$

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

by rearranging eq(4) we get

$$R_H = \frac{V_H t}{IB}$$

Where R_H is called the Hall coefficient

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

The Hall coefficient is dependant on the charge and the concentration of the carriers involved. If R_H is positve it means the crystal is P Type and if R_H is negative , the crystal is n type.

FORMULAE USED:

$$E = \frac{V_H}{t}$$

$$V_H = \frac{IB}{net} \text{ (volt)}$$

$$R_H = \frac{V_H t}{IB} X 10 \text{ } (m^3/C)$$, Where t is in mm, V_H in mV, I in mA and B in gauss.

$$n = \frac{1}{R_H e} \text{ } (cm^{-3})$$

where,

E = The Hall field

n = The density of the charge carriers

B = Applied magnetic field in gauss (1 Tesla=10^4 gauss)

V_H = Hall voltage

R_H = Hall's coefficient

t = Thickness of crystal

PROCEDURE:

PART(A)- Calibration of magnetic field w.r.t. current in solenoid :

1. Connect the constant current power supply with the electromagnet.
2. Place the gauss probe in the magnetic field.
3. Put the probe perpendicular to the magnetic field and at the centre of the electromagnets. Vary the solenoid current in steps of 0.5 A to note the corresponding magnetic field
4. The zero current in the solenoid ideally should result in zero magnetic field. Subtract the value of magnetic field corresponding to zero solenoid current from all the readings if any.

PART(B)-Measurment of Hall voltage:

1. Connect the red colour contacts of the hall probe to the voltage terminals and green colour contacts of the hall probe to the current terminals of the hall effect board.
2. Switch ON the hall effect board.
3. Place the hall probe in the magnetic field.
4. Adjust current to a desired value.
5. Rotate the probe till it becomes perpendicular to the magnetic field.(Hall voltage will be maximum here).
6. Measure the hall voltage for both the directions of current by interchanging the current leads.
7. Measure hall voltage as a function of current keeping the magnetic field constant. Plot a graph and determine V_H / I from its slope.
8. Now change the magnetic field by varying the current to the electromagnet and repeat the above steps.
9. Calculate the value of R_H for each B.

OBSERVATIONS:

TABLE 1: Calibration of magnetic w.r.t. current in the solenoid

Sr. No.	Current (A)	Magnetic Field (Gauss)
1	0.00	
2	0.50	
3	1.00	
4	1.50	
5	2	
6	2.5	
7	3.0	

TABLE 2: Measurement of hall voltage

Sr.No.	Magnetic Field (Gauss)	Current(mA)	Hall voltage V_{H1} (mV)	Hall voltage V_{H2} (mV)	Hall voltage V_H (mV)	V_H/I	Hall coefficient $R_H cm^3 coulomb^{-1}$
1		1.0					
		2.0					
		3.0					
2		1.0					
		2.0					
		3.0					
3		1.0					
		2.0					
		3.0					

GRAPH:

Plot V_H/I

Plot the variations of R_H vs. B.

CALCULATIONS:

Thickness of the hall effect chip = 0.5 mm

Find the value of Hall voltage and hall coefficient.

Slope from the Plot V_H/I =

$$R_H = \frac{V_H t}{IB}.$$

Plot for the variations of R_H vs. B

Find the value of number of charge carriers per unit volume.

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

$$n = \frac{1}{R_H e}$$

RESULT: The Value of Hall coefficient (R_H) is = cm^3 coloumb^{-1}
value of number of charge carriers per unit volume(n) = cm^{-3}.

MAXIMUM PROBABLE ERROR:

$$\frac{\Delta R_H}{R_H} = \frac{\Delta V_H}{V_H} + \frac{\Delta I}{I} + \frac{\Delta B}{B}$$

PRECAUTIONS:

1. High value of current should not be applied to the electromagnet.
2. Hall probe should be placed properly in the field.
3. Hall probes should be connected to the proper terminal (as per colour code).
4. Reading should be taken carefully.
5. Do not touch exposed magnet coil contacts
6. Never suddenly interrupt or apply power to a large magnet. Large inductive voltage surges may damage the insulation. Start with controls set for zero current and gradually increase the current. When turning off, smoothly decrease current to zero and then turn off.
7. Do not leave the magnet current at a high setting for any length of time beyond the minimum needed for data acquisition.

SOURCES OF ERROR:

1. Hall probe may not be positioned properly between the magnetic pole pieces
2. The circuit may not be properly connected.

REFERENCES:

1. http://scienceworld.wolfram.com/physics/HallCoefficient.html
2. http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/hall.html
3. http://www.eeel.nist.gov/812/hall.

VIVA RELATED QUESTIONS:

Q1. Define Hall Effect?

Q2. What causes Hall effect?

Q3. Why the Hall voltage should be measured for both the directions of current?

Q4. What are the uses of Hall effect?

Q5. What is the effect of temperature on Hall coefficient of a lightly doped semiconductor?

Q6. Which type of magnets is used in the experiment,temporary or permanent.

Q7. Significance of Hall coefficient .What information do we get?

Q8. If Hall coefficient is negative,What does it indicate.

Q9 What is the mobility of carriers?

Q10. What is Charge carrier concentration and its unit?

Q11. What is the material of Hall probe used in your experiment?

REFERENCES FOR SUPPLEMENTARY READING:

1. Introduction to Solid State Physics, C. Kittel; John Wiley and Sons Inc., N.Y. (1971), 4th edition.
2. M. A. Omar, Elementary Solid State Physics (Revised Printing, Addison-Wesley, 1993).
3. Solid state physics by S O Pillai.
4. Introduction to semiconductor materials and devices by M. S. Tyagi