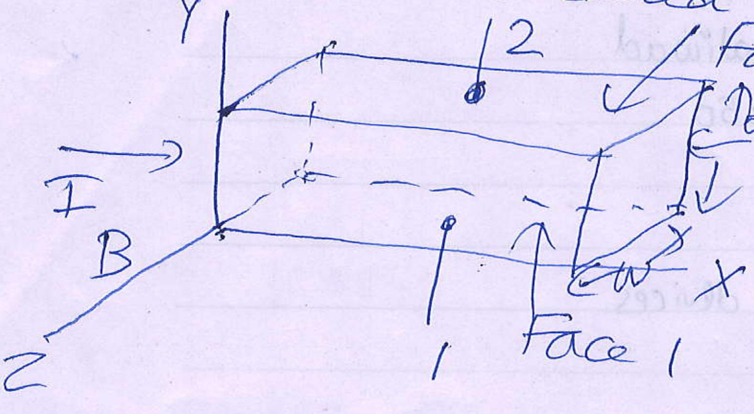
HALL EFFECT : (LECTURE 17/9/2020)

When a specimen metal or semiconductor carrying a current I is placed in a transverse magnetic field B, then an electric field E is induced in the direction perpendicular to both I and B. This phenomenon is called Hall effect.



Consider a semiconductor bar carrying a current I in the positive X direction. Let a magnetic field B is applied in the positive Z direction. Now a force is exerted on the charge carriers (whether electrons or holes) in negative Y direction. Due to this force charge carriers are pressed downwards towards face 1.

e.g. in N type semiconductors the charge carriers are electrons which are accumulated on face 1, so face 1 becomes negatively charged w.r.t face 2.

Therefore a potential difference V_H is developed between surfaces 1 and 2 which is called a Hall voltage.

The polarity of Hall voltage V_H determines whether semiconductor is N type or P type.

Mathematical calculations

In equilibrium state, the electric field intensity $\mathcal{E}$ due to Hall effect must exert a force on the carrier which which just balance the magnetic force

$$e\mathcal{E} = Bev \quad \ldots (1)$$

where e = magnitude of charge on electron or hole and v = drift velocity

$$\mathcal{E} = \frac{V_H}{d} \quad \text{or} \quad V_H = \mathcal{E} d \quad \ldots (2)$$

from equation (1)

$$\mathcal{E} = Bv$$

$$\therefore \quad V_H = Bvd \quad \ldots (2)$$

where 'd' is the distance between 2 surfaces 1 and 2.

$$J = \frac{I}{A} = \frac{I}{w.d} = \rho v$$

Where ρ = charge density and $\cancel{v = \frac{I}{Bwd}}$ $v = \frac{I}{\rho w d}$ ... (3)

From (2) & (3)

$$V_H = B \frac{I}{\rho w d} . d = \frac{BI}{\rho w} \quad \ldots (4)$$

The quantities V_H, B, I and w for semiconductor can be measured and hence the charge density ρ can be determined from equation (4)

<u>Hall coefficient</u> (R_H)

$$R_H = \frac{1}{\rho} = \frac{V_H w}{BI} \quad \ldots (5)$$

<u>Conductivity</u>

$\sigma = p\mu$ .. (6)

<u>Mobility</u> $\mu = \sigma R_H$ .. (7)

Importance of Hall effect-

(1) To determine whether semiconductor is p type or n type

(2) Parameters like electron or hole concentration and mobility can be measured

(3) Used to measure flux density

DETAILED SYLLABUS OF FIRST MODULE

Bohr's atomic model, Bohr's postulates Bonding in semiconductor (covalent), Energy levels, Energy bands, important energy bands in solids; valence band, conduction band and forbidden energy gap, Insulators, Semiconductors and conductors, properties of semiconductors: resistivity, negative temperature coefficient, doping, crystalline structure, crystal lattice, cubic lattice (face centered cubic lattice), Direct and indirect semiconductors, why Silicon is most widely used.

Effect of temperature on conductivity of semiconductor- absolute zero and above absolute zero, hole, EHP electron hole pair), recombination of electron hole, Lifetime, hole current, Intrinsic semiconductor, conduction through intrinsic semiconductor at room temperature, drift current.

Extrinsic semiconductor, doping, N type and p type semiconductor and conduction through them, charge on p type and n type semiconductor , Minority and majority carriers in p type and n type semiconductors mobility of charged particle, expression for mobility, conductivity and resistivity, Mathematical derivation for generation and recombination of charges, recombination centres, Fermi level in an intrinsic semiconductor, p type semiconductor and n type semiconductor, law of mass action, carrier concentration of intrinsic semiconductor p and n type, Law of electrical neutrality, effect of temp. on n, μ, σ and E_G, Diffusion current density, total current density due to drift and diffusion, Einstein's relationship, continuity equation, Hall effect.

EI-27003: Electronics Devices and Circuits
Lecture - 3

Subject Incharge: Mr. Rajesh Khatri
Associate Professor

LECTURE - 3

Year: 2020-21

MASS-ACTION LAW

- In intrinsic semiconductor, e and h are always present in equal quantity.
- When pentavalent impurity is added to intrinsic semiconductor, concentration of free e increases and concentration of h decreases, below intrinsic value.
- When trivalent impurity is added to intrinsic semiconductor, the concentration of h increases and concentration of electrons e decreases, below intrinsic value.

➢ Under thermal equilibrium the product of concentration n of free electrons and concentration p of holes is constant and independent of amount of doping by donor and acceptor impurities. This is known as Mass-Action Law.

$$n.p = n_i^2$$

Charge Densities in Semiconductors

- In intrinsic semiconductor

$$n.p=n_i^2$$

Let N_D be concentration of donor atoms. As donor atom are ionized at room temperature, there will be N_D immobile positive charges per cubic meter contributed by donor ions.

hence total positive charge density = $N_D + p$

Similarly N_A be concentration of acceptor atoms. In this case there will be N_A immobile negative charge per cubic meter.

hence total negative charge density = $N_A + n$

Since semiconductor is electrically neutral

$$\mathbf{N_D + p = N_A + n}$$

Charge densities in n-type Semiconductor

- In n-type semiconductor there in NO acceptor doping

i.e. $N_A=0$.

- Moreover no. of electrons is much greater than no. of holes (n>p) , hence $n \sim N_A$
- Thus in n-type semiconductor, free electron concentration is approximately equal to density of donor atoms.

$$n_n = N_D$$

- Now the concentration of holes p_n in n-type semiconductor

$$n_n . p_n = n_i^2$$

$$p_n = \frac{n_i^2}{n_n} \quad \text{or} \quad \frac{n_i^2}{N_D}$$

Charge densities in p-type Semiconductor

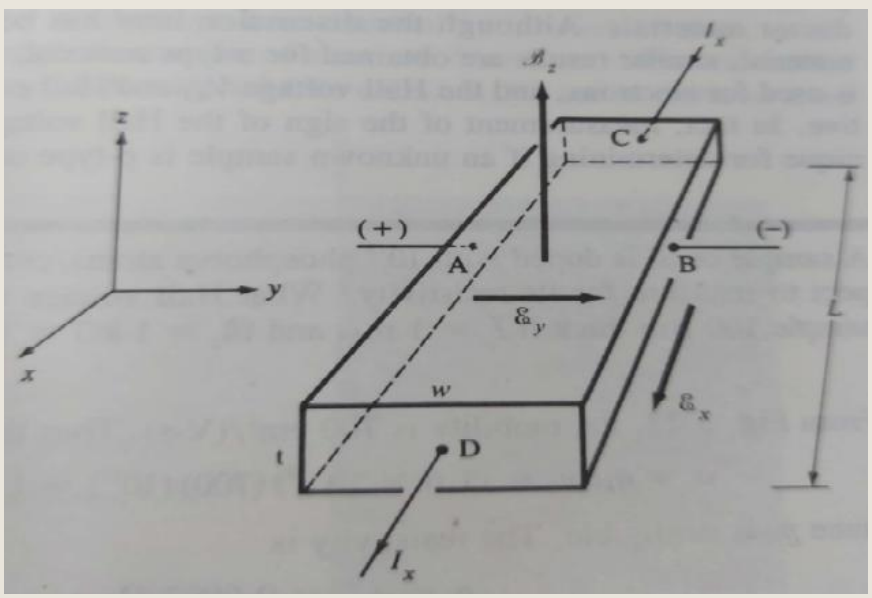
- Similarly for p-type semiconductor

$$n_p.p_p = n_i^2$$

But since, $p_p = N_A$

$$n_p = \frac{n_i^2}{p_p} \text{ or } \frac{n_i^2}{N_A}$$

Hall Effect

- If a current carrying conductor is placed in a magnetic field, such that the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor.
- A built-up of charge at sides of conductor will balance this magnetic influence producing a measurable voltage between the two sides of conductor called as Hall Voltage
- 

Hall Voltage - Derivation

- Total force on a single hole due to electric and magnetic field

F=q(E+V.B)

In y-direction the force is

$$F_y = q(E_y - V_x B_z)$$

Electric field E_y is established along the width of bar. Each hole will experience a net force in –ve y direction due to : qV_xB_z product.

Therefore to maintain a steady state flow of holes down the length of the bar, the electric field E_y must just balance product V_xB_z

$E_y = V_xB_z$ so that net force is F_y=0

Derivation ....

- Physically, this electric field is set-up when the magnetic field shifts the hole distribution slightly in –ve y direction.
- Once the electric field E_y becomes as large as $V_x B_z$, no net force is experienced by holes as they drift along the bar.
- The establishment of electric field E_y is known as Hall Effect and resulting voltage $V_{AB} = E_y W$ is called as Hall Voltage.
- The electric field E_y using drift velocity, q and P_0 for holes is

$$E_y = \frac{J_x B_z}{q P_0} = R_H J_x B_z \quad \text{where } R_H = \frac{1}{q P_0} \text{ is hall coefficient}$$

Thus Hall field is proportional to product of current density and magnetic flux density.

Derivation…. Rough work

- We know

$J = qp\mu E$

Where J=current density

q= charge

p=concentration of holes

E=electric field

$V = \mu E$

Hence $J = qpv$

Or

$V = \frac{J}{qp}$

Application of Hall Effect

- We have: $R_H = \frac{1}{qP_0}$ or $P_0 = \frac{1}{R_H q}$

$$P_0 = \frac{J_x}{q}\frac{B_z}{E_y} = \frac{I_x/_{wt}}{V_{AB}/_{w}}\frac{B_z}{q} = \frac{I_x}{q}\frac{B_z}{t}\frac{1}{V_{AB}}$$

Since all quantities on right hand side of equation can be measurable, hence Hall effect can be used to give accurate values of carrier concentration.

1. To find accurate concentration of charge carriers.
2. To determine if an unknown sample is p-type or n-type.

Time for Quiz-3

- Link for Quiz:

https://forms.gle/pvyfYBDW5Ys74fg37

Any Queries

???

Thanks…. See You Tomorrow