# Lecture-3

### 1.4.2.3 Extrinsic semiconductor Material

**Extrinsic semiconductor**: A semiconductor material doped with impurity atoms is called impure or extrinsic semiconductor material. On the basis of doping it can of two types i) P-type ii) n-type

**P-type:** When an acceptor impurity is doped in semiconductor material the movable charge particle available is hole which is carrying positive charge. So it is called **'p for positive'** p-type semiconductor material.

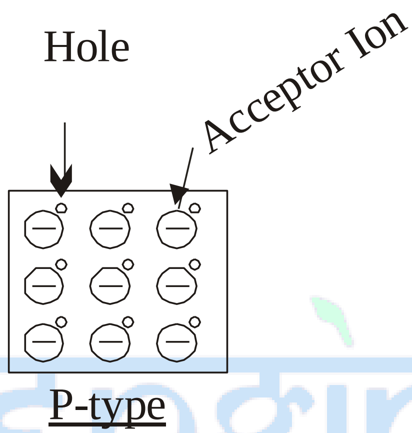



**Fig1.6**

**N-type**: When a donor impurity is doped in a semiconductor material, the movable charge particle available is free electron which carries negative charge. So it is called '**N for negative'** N-type semiconductor material.

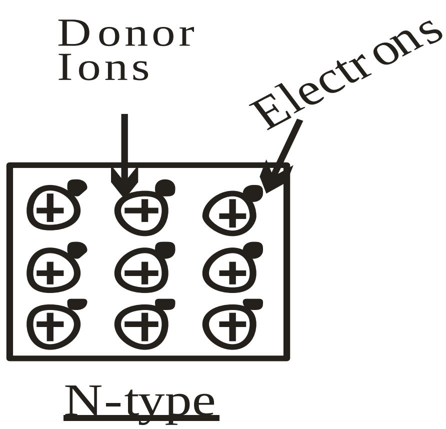
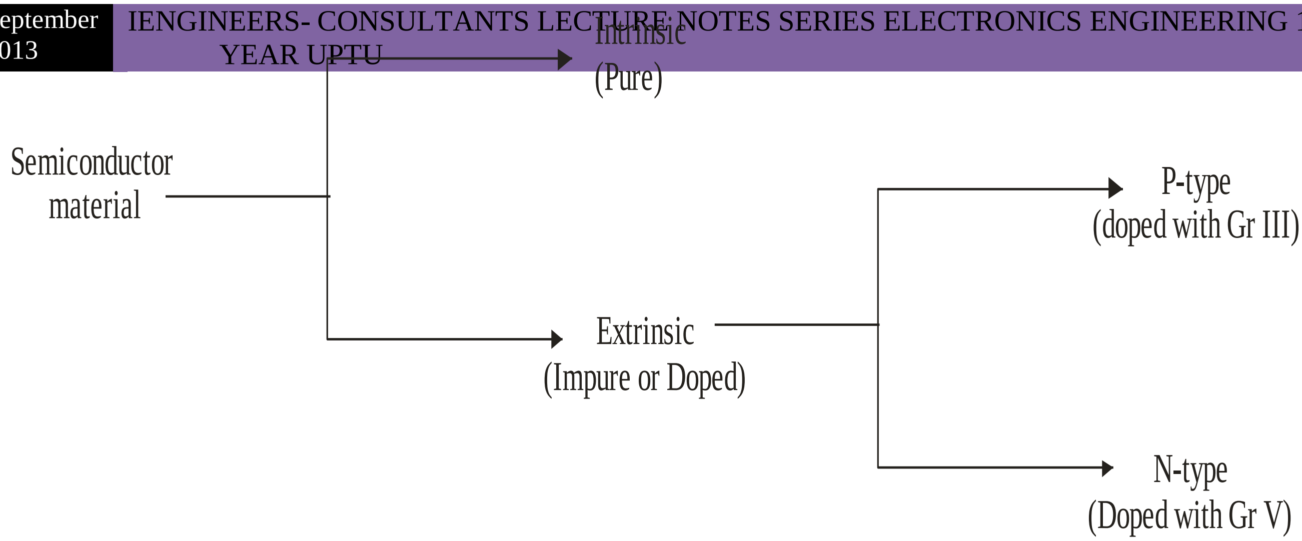



**Fig1.7**

So finally a semiconductor material can be classified as follows.




## Charge particles in extrinsic semiconductor.

**P-type**: In p-type charge particle are as follows

**<u>At $0^0$K or low Temperature</u>**

. **Positive charge particles**.

- Holes due to doping => $p_d$

**Negative charge particles**.

- Acceptor ion due to doping =>$N_A$

**It is a neutral material so**

$p_d = N_A$

[$p_d$, is movable charge particles]

[$N_A$ is not movable charge particle]

**ii) <u>At room temperature or higher temperature</u>** .

**Positive charge particles are**

a) Holes due to doping, $p_d$

b) Holes due to temperature, $p_t$

So total positive charge particles = $p_d + p_t$

**Negative charge particles**

a) Accepter ions due to doping, $N_A$

b) Electrons due to temperature, $n_t$

Total negative charge particles = $N_A + n_t$

**It is a neutral material so**

$p_d + p_t = N_A + n_t$

[$p_d$, $p_t$, $n_t$ are movable charge particles]

[NA is not movable charge particle]

**N-type**: In n-type charge particle are as follows

**i) <u>At $0^0$K or low Temperature</u>**

. **Positive charge particles**

a) Donor ions due to doping, $N_D$

**Negative charge particles**

a) Electrons Due to doping, $n_d$

**It is a neutral material so**

$N_D = n_d$

[$n_d$ is movable charge particles]

[$N_D$ is not movable charge particle]

**ii) <u>At room temperature or higher temperature</u>**

**Positive charge particles are**

a) Donor ions due to doping, $N_D$

b) Holes due to temperature, $p_t$

So total positive charge particles = $N_D + p_t$

**Negative charge particles**

a) Electrons due to doping, $n_d$

b) Electrons due to temperature, $n_t$

Total negative charge particles =$n_d + n_t$

**It is a neutral material so**

$N_D + p_t = n_d + n_t$

[$n_d$, $p_t$, $n_t$ are movable charge particles]

[$N_A$ is not movable charge particle]

**Note:** Movement of free electron means movement of electron in conduction band.

Movement of hole means movement of bonded electron in valence band by breaking and making of bonds

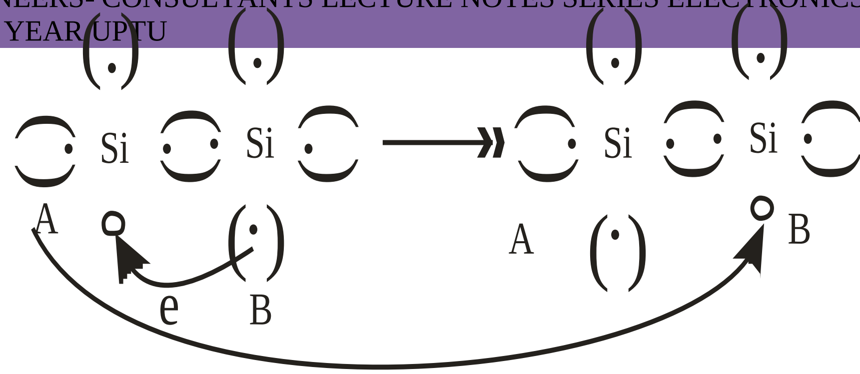



**Fig1.8**

Here in above figure hole moves from ‘A’ to ‘B’ due to movement of bonded electron by breaking its band at ‘B’ and making at ‘A’.

**So we can say movement of hole is more difficult than free electron. It means mobility of electron will be greater than mobility of holes.**

**1.5 Comparison between Intrinsic and extrinsic semiconductor materials**

| Intrinsic | Extrinsic |
| --- | --- |
| 1. It is a pure semiconductor material | 1. It is an impure semiconductor material material. |
| 2. There is no doping | 2. Impurities are doped to increase conductivity |
| 3. Its conducting depends on Temperature | 3. Its conductivity depends on temperature as well as doped impurity |

**1.6 Current elements in semiconductor**:

Current in any material is rate of flow of charge particle. It means for a current through any material the movable charge particle should be present. So current in any material can be dependent on following points.

i) Availability of movable charge particle

ii) Type of movable charge particle i.e. positive or negative

iii) Cause of movement of charge particle i.e. voltage or concentration difference

So on the basis of above three points, we can discuss about currents in a semiconductor material.

**1.6.1 Availability of movable charge particles**:

In Intrinsic semiconductor material at $0^0$K or lowertemperature movable charge particles are not present so current is not possible. But at room or higher temperature holes and electrons are possible so at higher temperature current is possible.

In case of extrinsic semiconductor material movable charge particles are available due to doping. So current is possible at lower as well as at higher temperature.

**1.6.2 Type of charge particle**: In semiconductor material tow types of charge particle are possible i) holes ii) electrons.

It means in semiconductor material current is possible due to holes as well as electrons.

In intrinsic semiconductor electron and holes are available in equal amount so current in intrinsic semiconductor current available will be due to electrons and holes both.

- In extrinsic semiconductor material both type of charge particle are available but majority depends on type of doping.
- In p-type doping impurity is Gr III element so the majority current in p-type will be due to holes.
- Similarly in n-type majority current will be due to electrons.

**1.6.3Cause of Movement of charge particle:**

Charge particle in a semiconductor material can move in two situations

i) Due to voltage difference or electric field.

ii) Due to concentration gradient.

**1.6.3.1Due to voltage difference**:

If a voltage difference is applied across a material. The free charge particles present in the material will start movement due to attractive or repulsive force. This type of movement will be called drift movement and current due to this movement will be called Drift current.

Suppose is a material there are N free charge particles having charge q.

length and area of the material is L & A respectively.

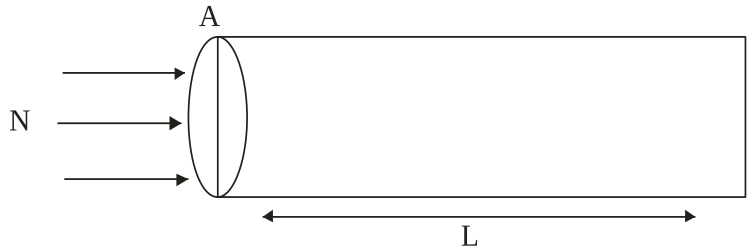



**Fig1.9**

Suppose N charge particles are entering into the material and travel length L in time T, then it means Q = Nq charge particles are moving L distance in time C. So the current through this material will be

$$I_D = \frac{Q}{T} = \frac{NQ}{T}$$

We can also say

$$I_D = \frac{Nq}{L}.V_d$$

Where $V_d$ is drift velocity of charge particles.

We can also say $$I_D = \frac{NqV_d\, x\, A}{LA}$$

Where V= LA $\Rightarrow$ volume of material

$\Rightarrow$ $I_D$ = nqA $V_d$

Here n = N/V $\Rightarrow$ concentration of charge particles

$V_d$ = µE

µ $\Rightarrow$ Mobility of charge particles

E = Applied electric field

E = $V_V$/L $\Rightarrow$ $V_V$ $\Rightarrow$ Applied voltage, L $\Rightarrow$ Length

So we can say Drift current due to applied voltage through a material is

$$I_D = nqA\mu E \quad \Rightarrow I_D = \sigma AE$$

Here $\sigma = nq\mu$ (Conductively of material)

Drift current density

$$I_D = \frac{I_D}{A} = nq\mu E \quad = \quad \sigma E$$

**1.6.3.1 (a) Drift current in Intrinsic Semiconductor**

Now suppose a voltage source V is applied across an intrinsic semiconductor material.

Then total Drift current through intrinsic semiconductor will be

$I_{DT}$ = $I_D$ Due to holes +$I_D$ due to electrons

= $I_{DP}$ +$I_{DN}$

And $I_{DP} = Apq\mu_p E$

p $\Rightarrow$ Concentration of holes

q $\Rightarrow$ Charge on a hole

$\mu_p$ = Mobility of hole

Similarly $I_{Dn} = Anq\,\mu_n E$

n $\Rightarrow$ Concentration of electrons

q $\Rightarrow$ Charge on a electron

$\mu_n$ $\Rightarrow$ Mobility of electron

So Total drift current through intrinsic semiconductor will be

$$I_{DT} = Apq\,\mu_p E + Anq\mu_n E$$

Here p = n = $ni$

$ni \Rightarrow$ Intrinsic Concentration

And n.p = $ni^2$

**1.6.3.1 (b)Drift current in Extrinsic Semiconductor material**

**i) P-type semiconductor**

In P-Type semiconductor majority charge carrier is hole and its concentration p will be equal to concentration Doping of Acceptor impurity $N_A$, i.e. p=$N_A$

So $I_D = Apq\mu_p E$

$= AN_A q\,\mu_p E$

**ii) n-type semiconductor**

In n-type semiconductor material majority charge carrier is electron and its concentration n will be equal to concentration doping of donor impurity $N_D$, i.e. n = $N_D$

So $I_D = Anq\mu_n E \Rightarrow AN_D q\mu_n E$

$\Rightarrow$ At room temperature some minority carries will also be available.

**1.6.3.2Diffusion Current (current due to concentration Gradient):** when in a material the concentration of charge particles are different at different positions, then charge particles starts diffusion from high concentration to low concentration ,the current due to this type of movement is called diffusion current.

Diffusion current, $I_{Diff}$ will always be proportional to concentration gradient, i.e. $I_{Diff}\ \alpha\ \frac{dc}{dx}$

$\frac{dc}{dx}$ $\Rightarrow$ Concentration gradient

So $I_{Diff} = AqD\dfrac{dc}{dx}$

D $\Rightarrow$ Diffusion Constant

For semiconductor martial there are two possible charge particles, i,e, electrons and holes. So total diffusion current in semiconductor,

$I_{Diff}$(total) = $I_{Diff}$ due to holes + $I_{Diff}$ due to electrons

= $I_{DiffP}$ + $I_{DiffN}$

$$I_{DiffT} = Aq\,D_P\frac{dp}{dx} + Aq\,D_n\frac{dn}{dx}$$

### 1.6.4 Total current in a semiconductor material In semiconductor material:

Total current = Drift current +Diffusion Current

= Drift current + Drift current

Due to holes due to electrons

+ Diffusion current + Diffusion current

Due to holes current due to electron

In Intrinsic semiconductor at $0^0$ K or lower temperature total current will be zero.

But at higher temperature current will be due to holes as well as due to electrons

$$I_{Total} = nqA\mu_n E + PqA\mu_P E + ADPq\frac{dP}{dx} + AD_n q\frac{dn}{dx}$$

Similarly in case of extrinsic semiconductor total current will be due to holes and electrons due to Drift and diffusion.