

UNIT-2 (SEMICONDUCTOR PHYSICS)

FERMI LEVEL IN INTRINSIC S.C. :-

At absolute zero temp., intrinsic s.c. acts as an insulator, so there are no charge carriers hence the probability of finding a hole in V.B. is zero at 0K. As temp. increases, equal no. of electrons and holes get generated and hence probability of finding an electron in C.B. and probability of finding a hole in V.B. is equal. Therefore, fermi level is exactly at midway between forbidden gap. The fermi level in the centre of forbidden gap indicates, equal concentration of free electrons and holes.

Expression for the position of fermi level in an Intrinsic S.C. :-

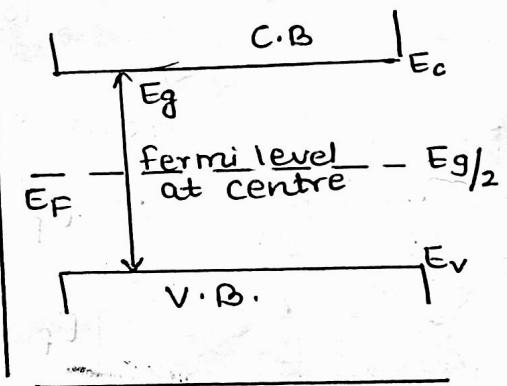
The e⁻ concentration in the C.B.

is given by

$$n = N_c e^{-(E_c - E_f)/kT} \quad (1)$$

The hole concentration in the V.B. is given by

$$p = N_v e^{-(E_f - E_v)/kT} \quad (2)$$



At thermal equilibrium, the density of electrons in the C.B. equals to the density of holes in the V.B. in an intrinsic s.c.

$$\text{i.e. } n = p \quad (3)$$

∴ from equ: (1) and (2)

$$N_c e^{-(E_c - E_f)/kT} = N_v e^{-(E_f - E_v)/kT}$$

Taking log on both sides

$$\log N_c - \left(\frac{E_c - E_f}{kT} \right) = \log N_v - \left(\frac{E_f - E_v}{kT} \right)$$

$$\log N_c - \log N_v = \frac{1}{kT} [E_c - E_f - E_f + E_v]$$

$$KT \log \frac{N_C}{N_V} = E_C + E_V - 2E_F$$

$$2E_F = (E_C + E_V) - KT \log \frac{N_C}{N_V}$$

$$\text{or } 2E_F = (E_C + E_V) + KT \log \frac{N_V}{N_C}$$

$$E_F = \frac{E_C + E_V}{2} + \frac{KT}{2} \log \frac{N_V}{N_C} \quad (4)$$

$$\text{Here, } N_C = 2 \left[\frac{2\pi m_e^* KT}{h^2} \right]^{3/2}$$

$$\text{and } N_V = 2 \left[\frac{2\pi m_h^* KT}{h^2} \right]^{3/2}$$

$$\frac{N_V}{N_C} = \left(\frac{m_h^*}{m_e^*} \right)^{3/2}$$

$$\log \frac{N_V}{N_C} = \frac{3}{2} \log \frac{m_h^*}{m_e^*} \quad (5)$$

from eqn (5), eqn (4) =

$$E_F = \left(\frac{E_C + E_V}{2} \right) + \frac{KT}{2} \cdot \frac{3}{2} \log \left(\frac{m_h^*}{m_e^*} \right)$$

$$E_F = \left(\frac{E_C + E_V}{2} \right) + \frac{3}{4} KT \log \left(\frac{m_h^*}{m_e^*} \right) \quad (6)$$

$$\text{If } m_e^* = m_h^*$$

$$\text{then } \log \frac{m_h^*}{m_e^*} = 0$$

$$\therefore \text{eqn (6)} \Rightarrow E_F = \boxed{\frac{E_C + E_V}{2}}$$

$$\text{or } E_F = \frac{E_C - E_V}{2} + E_V$$

$$E_F = \frac{E_g}{2} + E_V$$

If we denote the top of the V.B E_V as zero level

$$\text{then } E_V = 0$$

$$\therefore E_F = \boxed{\frac{E_g}{2}}$$

FERMI LEVEL
In n-type
is added

FERMI LEVEL POSITION IN EXTRINSIC SEMICONDUCTOR :-

In n-type Semiconductor :-

In n-type S.C., a donor impurity E_c is added. Each donor atom donates one free electron and there are large no. of free e⁻s available in the C.B.

Due to abundant free electrons, the E_v

Probability of occupying the energy level by the electrons, towards the

conduction band is more. This probability is indicated by fermi level E_f . So, in n-type material, the fermi level E_f gets shifted towards the C.B. S.L; it is below the conduction band but above the donor energy level.

Expression for the position of fermi level in n-type extrinsic S.C. :-

In n-type S.C., the majority of e⁻s is almost due to extrinsically supplied electrons from the donor atoms and hence,

$$N_D \approx N_C e^{-\frac{(E_c - E_f)}{kT}} \quad (1)$$

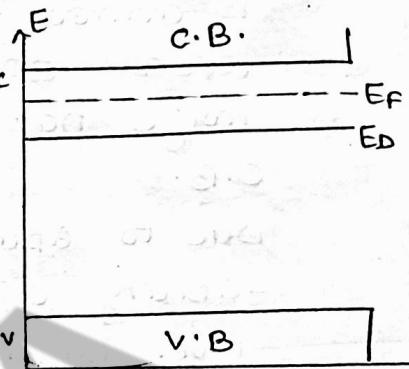
Taking log on both side,

$$\log N_D = \log N_C - \frac{E_c - E_f}{kT}$$

$$\frac{E_c - E_f}{kT} = \log \frac{N_C}{N_D}$$

$$E_c - E_f = kT \log \frac{N_C}{N_D}$$

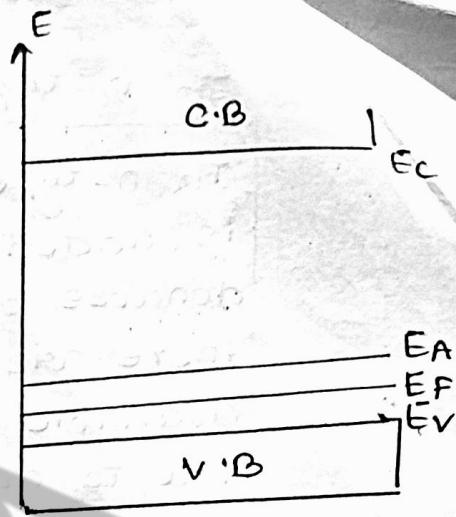
$$E_f = E_c - kT \log \frac{N_C}{N_D}$$



In P-type S.C. :-

In P-type S.C., an acceptor impurity is added. Each acceptor atom creates one hole and there are large no. of holes available in C.B.

Due to abundant holes, the probability of occupying the energy level by the hole, towards the valence band is more. This shifts the fermi level E_F towards the V.B. Hence, it is above the valence band but below the acceptor energy level.



Expression for the position of fermi level in P-type S.C. :-

$$\text{In this case, } p \approx N_A \quad -(E_F - E_V)/kT$$

$$\text{so } N_A = N_V e^{-\frac{(E_F - E_V)}{kT}}$$

Taking log on both side

$$\log N_A = \log N_V - \frac{E_F - E_V}{kT}$$

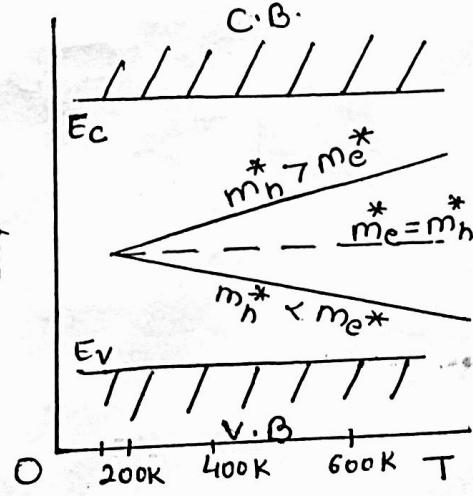
$$\frac{E_F - E_V}{kT} = \log N_V - \log N_A$$

$$E_F = E_V + kT \log \frac{N_V}{N_A}$$

(*) VARIATION OF FERMI LEVEL WITH TEMPERATURE :-

In an Intrinsic S.C. :-

At $T=0K$, the fermi level lies at the middle of the forbidden gap. At low temp, E_F is practically independant of temperature. But there is slight variation in E_F in the high temperature region.



With the increase in temperature the fermi level moves up towards the bottom edge of the C.B or downward to the top edge of the V.B as indication in figure.

The reason, is in actual case $m_h^* = m_e^*$. Thus, the term $\log\left(\frac{m_h^*}{m_e^*}\right)$ begins to contribute slightly. When $m_h^* > m_e^*$, the fermi level moves upward to the C.B and if $m_e^* > m_h^*$, the fermi level will move downward to the top edge of the valence band.

Variation of fermi level with temperature in an n-type S.C.

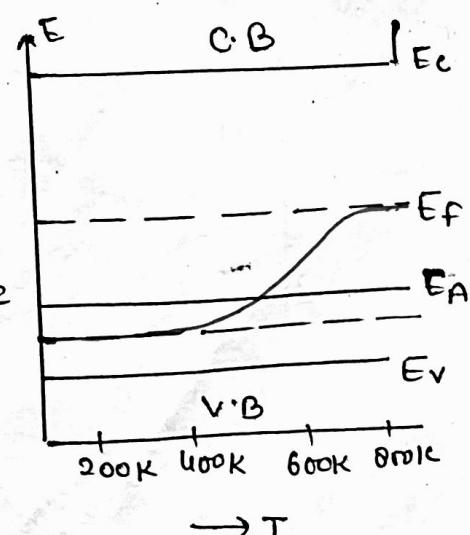
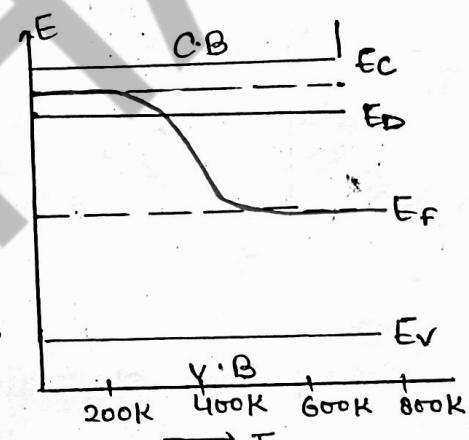
In n-type S.C., the fermi level lies in the middle of the bottom level of the C.B. And donor level.

When the temperature increases, the no. of electrons in the C.B also increases at very high

temperature. The donor concentration exceeds and behaves like an intrinsic S.C. The fermi level moves downwards as the temp. increases and at a particular temperature the fermi level lies in the middle of the energy band gap which mimics an intrinsic S.C.

Variation of fermi level with temperature in an p-type S.C.

In p-type S.C., the fermi level lies in the middle of the top most level of the V.B. and the acceptor level. As the temperature increases, more and more



acceptor atoms are ionized and hence the fermi level moves upwards. At a particular temperature, when all acceptor atoms are ionised, the fermi level lies in the middle of the energy gap and mimic intrinsic s.c.

Carrier generation and Recombination (when S.C. is in equilibrium):

Consider a direct-band gap semiconductor in thermal equilibrium. The continuous thermal vibration of lattice atoms causes some bonds between neighbouring atoms to be broken. When a bond is broken, an e^- -hole pair (EHP) is generated. In terms of the band diagram, the thermal energy enables a valence e^- to make an upward transition to the C.B., leaving a hole in the V.B. This process is called carrier generation and is represented by the generation rate G_{th} (no. of EHPs generates per cm^3 per second). When an e^- makes a transition downward from the C.B. to the V.B., an e^- -hole pair is annihilated. This reverse process is called recombination, it is represented by the recombination rate R_{th} .

Under thermal equilibrium conditions, the generation rate G_{th} must equal the recombination rate R_{th} , so that the carrier concentration remains constant and the condition $n_p = n_i^2$ is maintained.

$$\therefore G_{th} = R_{th}$$

Excess carrier generation and Recombination:

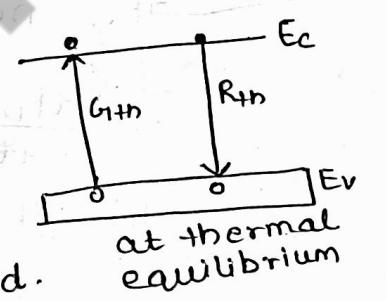
When excess carriers are introduced to a direct band gap S.C., the probability is high that e^- and holes will recombine directly. So the rate of recombination R is expected to be proportional to the no. of electrons available in the conduction band and the no. of holes available in the V.B. i.e

$$R = \beta n_p \quad \text{--- (1)}$$

where $\beta \rightarrow$ Proportionality constant.

So, therefore, in thermal equilibrium, for N types,

$$G_{th} = R_{th} = \beta n_{n0} p_{n0} \quad \text{--- (2)}$$



where, n_{no} and p_{no} represents e^- and hole densities, in an n-type s.c. at thermal equilibrium. When we shine a light ($h\nu \geq Eg$) on the s.c., to produce e⁻ hole pair at a rate G_L , the carrier concentration are above their equilibrium values. The recombination and generation rate become

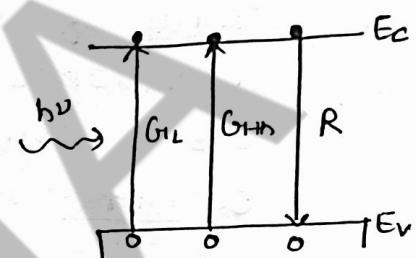
$$R = \beta n_n p_n = \beta (n_{no} + \Delta n) (p_{no} + \Delta p) \quad (3)$$

$$G_I = G_L + G_{th} \quad (4)$$

where, Δn and $\Delta p \rightarrow$ excess carrier concentration

$$\text{and } \Delta n = n_n - n_{no} \quad (5)$$

$$\Delta p = p_n - p_{no} \quad (6)$$



under illumination

$$\text{and } \Delta n = \Delta p$$

The net change of hole concentration,
rate of

$$\frac{dp_n}{dt} = G_I - R = G_L + G_{th} - R \quad (7)$$

In steady state, $\frac{dp_n}{dt} = 0$

$$\text{so equ (7)} =$$

$$G_L = R - G_{th} \equiv V \quad (8)$$

$V \rightarrow$ recombination rate due to illumination of light

from equ (2) and (3), equ (8) \Rightarrow

$$V = \beta (n_{no} + \Delta n) (p_{no} + \Delta p) - \beta n_{no} p_{no}$$

$$= \beta (n_{no} \cdot \Delta p + \Delta n p_{no} + \Delta n \Delta p) \quad (\because \Delta n = \Delta p)$$

$$= \beta (n_{no} + p_{no} + \Delta p) \cdot \Delta p \quad (9)$$

for low-level injection Δp , $p_{no} \ll n_{no}$, eq (9) \Rightarrow

$$V \approx \beta n_{no} \Delta p = \frac{p_n - p_{no}}{\beta n_{no}} \quad (10)$$

Therefore, the net recombination rate is proportional to excess minority carrier concentration. Obviously $V=0$ in thermal equilibrium.

The proportionality constant $1/\beta n_{no}$ is called the lifetime τ_p of the excess minority carriers, or

$$V \equiv \frac{P_n - P_{no}}{\tau_p} \quad \text{--- (11)}$$

where,

$$\tau_p = \frac{1}{\beta n_{no}} \quad \text{--- (12)}$$

In steady state, from equ. (8) and (11)

$$G_{IL} = V = \frac{P_n - P_{no}}{\tau_p} \quad \text{--- (13)}$$

$$\text{or } P_n = P_{no} + \tau_p G_{IL} \quad \text{--- (14)}$$

If at an arbitrary time, say $t=0$, the light is suddenly turned off, the boundary conditions are $P_n(t=0) = P_{no} + \tau_p G_{IL}$ as given by equ. (14) and

$$P_n(t \rightarrow \infty) = P_{no}$$

so, time dependent expression for equ. (7) becomes

$$\frac{dP_n}{dt} = G_{IL} - R = -V = -\frac{(P_n - P_{no})}{\tau_p} \quad \text{--- (15)}$$

and the solution is

$$P_n(t) = P_{no} + \tau_p G_{IL} \exp(-t/\tau_p) \quad \text{--- (16)}$$

Ex:- A Si sample with $n_{no} = 10^{14} \text{ cm}^{-3}$ is illuminated with light and 10^{13} e^- -hole pairs/ cm^3 are created every microsecond. If $\tau_n = \tau_p = 2 \mu\text{s}$. find the change in the minority carrier concentration.

Sol:- Before illumination,

$$P_{no} = n_i^2 / n_{no} = (9.65 \times 10^9)^2 / 10^{14} = 9.31 \times 10^5 \text{ cm}^{-3}$$

after illumination,

$$\begin{aligned} P_n &= P_{no} + \tau_p G_{IL} = 9.31 \times 10^5 + \frac{2 \times 10^{-6} \times 10^{13}}{1 \times 10^{-6}} \\ &= 2 \times 10^{13} \text{ cm}^{-3} \end{aligned}$$

CARRIER TRANSPORT : DIFFUSION AND DRIFT CURRENT :-

Under the condition of thermal equilibrium, the electrons and holes are uniformly distributed in the crystal and in the absence of an external stimulus, their average velocity is zero and no current flows through the crystal. This is equally true for an intrinsic or an extrinsic semiconductor.

Drift current: When an electric field E is applied across a S.C., the charge carriers acquire a directional motion over and above their thermal motion and produce drift velocity. This drift causes current to flow in S.C. under the influence of external electric field. This current produced due to net drift of charge is called drift current.

When we apply an electric field \rightarrow across the conductor or S.C., the randomly moving e^- experience an electrical force in the direction of E .

$$\text{so } F = qE$$

$$\text{acceleration } a = \frac{qE}{m}$$

and the drift velocity will be $v_d = a \times \text{time}$

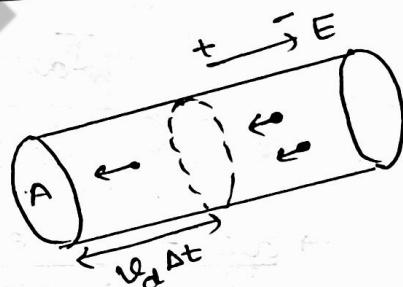
$$v_d = \left(\frac{qE}{m}\right)\tau$$

where $\tau \rightarrow$ average time

In the time interval Δt , each e^- will cover the distance $= v_d \cdot \Delta t$

and the volume of the portion is $= v_d \cdot \Delta t \cdot A$

\rightarrow no. of free e^- s in this portion will be $= n v_d \cdot \Delta t \cdot A$



Hence the charge crossing the area in time Δt

$$\Rightarrow \Delta Q = neA v_d \Delta t$$

$$\text{So the drift current } I = \frac{\Delta Q}{\Delta t} = neAv_d$$

Hence, the drift current density due to free electrons is given by

$$J_n(\text{drift}) = \frac{I}{A} = nev_d = n_e e u_n E \quad (\because v_d = u_n E)$$

So $J_n(\text{drift}) = n_e u_n E$

Now the drift current density due to holes is

given by $J_p(\text{drift}) = p_e u_p E$

Therefore, the total drift current density is

$$J_{\text{drift}} = J_n(\text{drift}) + J_p(\text{drift})$$

$$J_{\text{drift}} = n_e u_n E + p_e u_p E$$

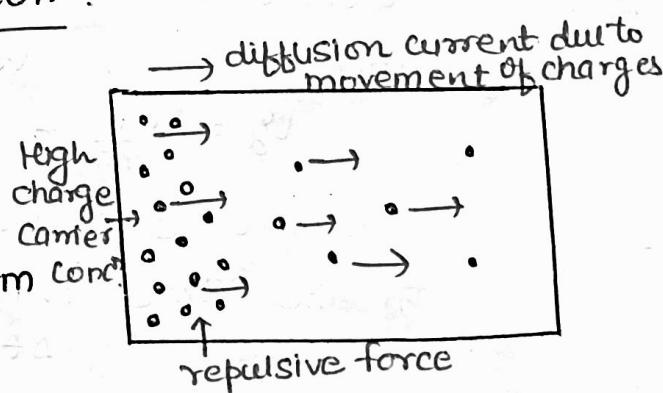
$$J_{\text{drift}} = e(n_u u_n + p_u u_p) E$$

→ drift current occurs only when external electric field is present across the solid. Although electrons and holes move in opposite directions, the direction of conventional current flow due to both the carriers is in same direction.

Diffusion current :-

Diffusion current occurs due to the transport of charges occurring becoz of non-uniform concentration of charged particles in a S.C.

Consider a piece of a S.C. which is non uniformly doped. Due to such non-uniform doping, one type of charge carriers occur



Process of diffusion

at one end of a piece of S.C. The charge carriers are either electrons or holes, of one type depending upon the impurity used. They have the same polarity and hence experience a repulsion between them. The result is that there is a tendency of the charge carriers to move gradually, i.e. to diffuse from the region of the high carrier density to the low carrier density. This process is called diffusion.

This movement of charge carriers under the process of diffusion constitutes a current called diffusion current.

Fig. shows the variation of electron concentration with distance. Due to this concentration gradient diffusion current flows.

Electron diffusion current density \propto charge density

$$J_n(\text{diffusion}) \propto e \cdot \frac{dn}{dx}$$

$$J_n(\text{diffusion}) = e D_n \frac{dn}{dx}$$

where $D_n \rightarrow$ electron diffusion coefficient. electron concentration versus distance

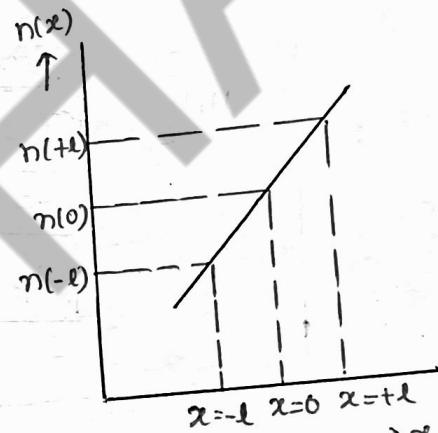
$$(D_n = \mu_n \frac{KT}{q})$$

Similarly, the hole diffusion current density is proportional to the hole density gradient and to the electronic charge, so

$$J_p(\text{diffusion}) \propto e \cdot \frac{dp}{dx}$$

$$J_p(\text{diffusion}) = -D_p e \frac{dp}{dx}$$

(- sign represents that the conventional diffusion current density due to hole is in negative dire.)
Here, $D_p \rightarrow$ hole diffusion coefficient ($D_p = \mu_p \frac{KT}{q}$)



The diffusion current continues till the carriers are evenly distributed throughout the material. A diffusion current is possible only in case of non-uniformly doped S.C.

Total current density:

Drift and diffusion currents coexist in S.C.s; the total current density due to drift and diffusion of electrons may be written as

$$J_n = J_{n\text{drift}} + J_{n\text{(diff.)}}$$

$$J_n = e \left(n \mu_n E + D_n \frac{dn}{dx} \right)$$

Similarly for holes,

$$J_p = J_{p\text{drift}} + J_{p\text{(diff.)}}$$

$$J_p = e \left(p \mu_p E - D_p \frac{dp}{dx} \right)$$

Continuity Equation:-

The fundamental law governing the flow of charge is called the continuity equation.

The continuity equation as applied to semiconductors describes how the carrier concentration in a given elemental volume of the crystal varies with time and distance. The variation in density is attributable to two basic causes, viz. (i) the rate of generation and loss by recombination of carriers within the element and (ii) drift of carriers into or out of the element. The continuity equation enables us to calculate the excess density of electrons or holes in time and space.

Consider an infinitesimal N-type semiconductor bar of length dx and area A . The hole current density leaving the volume, $J_p(x+dx)$, can be larger or smaller than the current density entering $J_p(x)$ depending on the generation or recombination of carriers taking place within the volume. The net increase in hole concentration per unit time dP_n/dt , is the difference between the hole flux per unit volume entering and leaving, minus the recombination rate. We can convert hole current density to hole particle flux density by dividing J_p by e . The current densities are already expressed per unit area; thus dividing $J_p(x)/e$ by dx gives the no. of carriers per unit volume entering $Ax \cdot A$ per unit time, and $(\frac{1}{e})(J_p(x+dx)/dx)$ is the no. leaving per unit volume and time.

$$\frac{dP_n}{dt} \Big|_{x \rightarrow x+\Delta x} = \frac{1}{e} \frac{J_p(x) - J_p(x+\Delta x)}{\Delta x} - \frac{\Delta P}{\tau_p} \quad (1)$$

↓
Rate of holes build up Increase of hole concn. in $\Delta x \cdot A$ per unit time - recombination rate

As Δx approaches zero, we can write the current change in derivative form

$$\frac{dP_n}{dt} = \frac{d\Delta P}{dt} = -\frac{1}{e} \frac{dJ_p}{dx} - \frac{\Delta P}{\tau_p} \quad (2)$$

Equation (2) is called the continuity equation for hole.

Similarly for e^- , we can write

$$\frac{d\Delta n}{dt} = \frac{1}{e} \frac{dJ_n}{dx} - \frac{\Delta n}{\tau_n} \quad (3)$$

(since the e^- -charge is negative.)

Note using diffusion currents as

$$J_n(\text{diff.}) = e D_n \frac{dn}{dx}$$

$$\text{and } J_p(\text{diff.}) = -e D_p \frac{dp}{dx}$$

so eqn (2) and (3) =

$$\frac{d\Delta P}{dt} = -D_p \frac{d^2 p}{dx^2} - \frac{\Delta P}{\tau_p} \quad (4)$$

$$\text{and } \frac{d\Delta n}{dt} = D_n \frac{d^2 n}{dx^2} - \frac{\Delta n}{\tau_n} \quad (5)$$

In steady state, $\frac{d\Delta P}{dt} = \frac{d\Delta n}{dt} = 0$

so eqn (4) and (5) becomes

$$(ca^n 4) \Rightarrow 0 = D_p \frac{d^2 p}{dx^2} - \frac{\Delta P}{\tau_p} \quad (6)$$

$$\text{and } \frac{d^2 p}{dx^2} = \frac{\Delta P}{D_p \tau_p} = \frac{\Delta P}{L_p^2}$$

$$(ca^n 5) \Rightarrow 0 = D_n \frac{d^2 n}{dx^2} - \frac{\Delta n}{\tau_n} \quad (7)$$

$$\text{or } \frac{d^2 n}{dx^2} = \frac{\Delta n}{D_n \tau_n} = \frac{\Delta n}{L_n^2}$$

where L_n and L_p are defined as $\sqrt{\tau_n D_n}$ and $\sqrt{\tau_p D_p}$
are called diffusion lengths.

P-N JUNCTION :-

Semiconductors that are doped with impurities form the basis of the practical devices. A semiconductor that has been doped with acceptor impurities and into the surface of which donor atoms are diffused forms a p-n junction diode. A p-n junction diode is also known as a semiconductor diode.

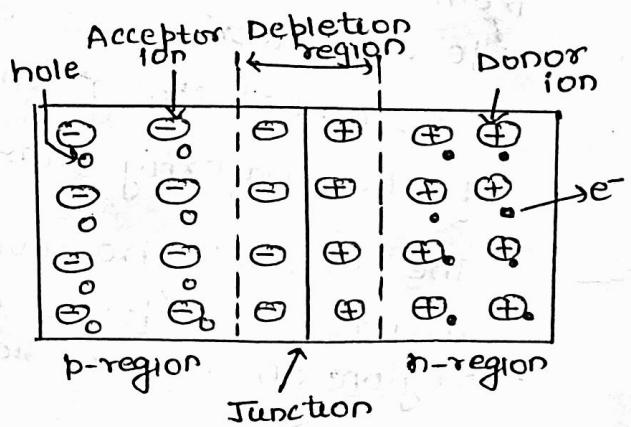
p-type and n-type semiconductors conduct with equal facility in both the directions just like a resistor and exhibit linear conduction characteristic. Such behaviour is known as ohmic behaviour. It is indeed.

possible to grow a s.c. crystal with part of the crystal n-type and the other part p-type. P-n junction is the boundary between one region of a s.c. with p-type impurities and another region containing n-type impurities.

The most remarkable property of the p-n junction is that it has a non-linear conduction characteristic and allows current in one direction and opposes it in the opposite direction. This is known as rectifying property.

1. P-N Junction with no external voltage :-

A p-n junction is shown in figure. The p-type region has holes as majority charge carriers, and an equal no. of fixed negatively charged acceptor



ions. Similarly, the n-type region has electrons as majority charge carriers, and an equal number of fixed positively charged donor ions.

In addition to these majority charge carriers, there are a few minority charge carriers in each region (few thermally-generated electrons and holes within both the p- and n-regions). The p-region contains a few electrons while the n-region contains a few holes.

As soon as p-n junction is formed, there is an immediate diffusion of the majority charge carriers across the junction due to thermal agitation. Some of the electrons in the n-region diffuse into the p-region, while some of the holes in the p-region diffuse into the n-region. The diffused charge carriers combine with their counterparts in the vicinity of the junction and neutralise each other. Thus, in the vicinity of the junction, positive charge is built on the n-side, and negative charge on the p-side. This sets up a potential difference across the junction, and hence an internal electric field E_i directed from the (positive) n-side to the (negative) p-side. Equilibrium is established when the field E_i becomes strong enough to stop further diffusion of the majority charge carriers.

The field E_i , however, helps the minority carriers to diffuse across the junction. The region on either side of the junction which

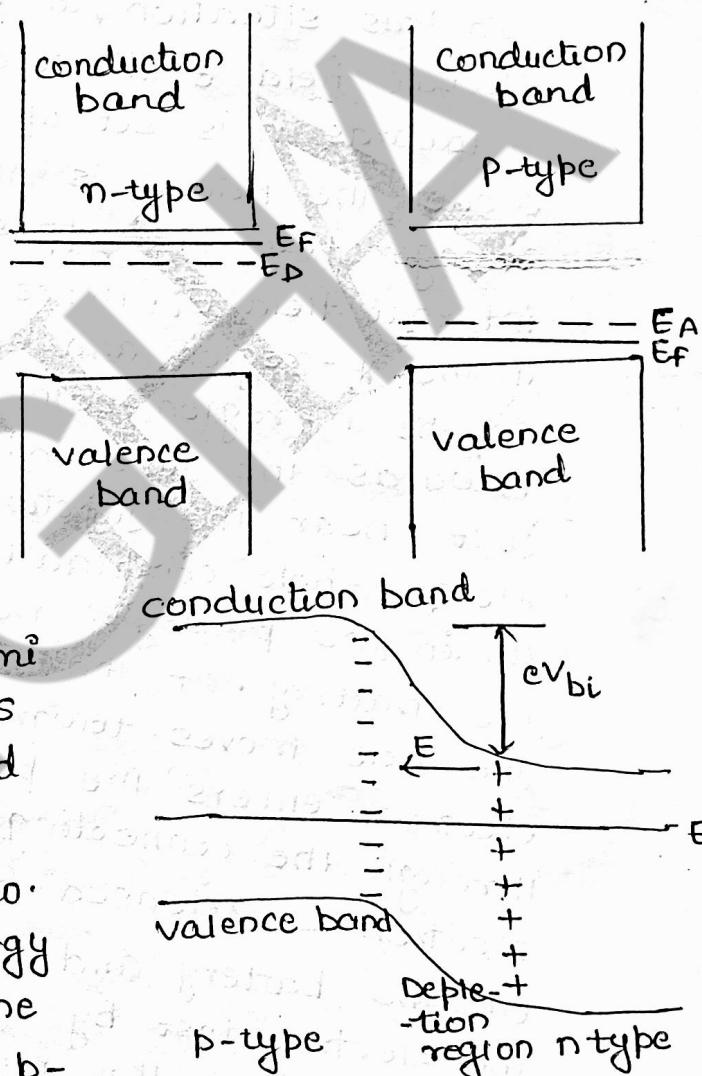
becomes depleted (free) of the mobile charge-carriers is called the depletion region. The width of the depletion region is of the order of 10^{-6} m. The potential difference developed across the depletion region is called the potential barrier. It is about 0.3 V for Ge p-n junction and about 0.7 V for Si p-n junction.

Fig. shows the energy levels in the p and n types before they were brought into contact.

The Fermi level is near the donor level in the n-type material and near the acceptor level in the p-type.

In the tail of the Fermi distribution of electrons in the conduction band of the n-region there will be a smaller no. of electrons with energy above the bottom of the conduction band in the p-

region. These electrons have sufficient energy to overcome the barrier and cross into p-region. There they recombine with the holes. This results in the recombination electron current. It is balanced by the p to n thermal electron current.



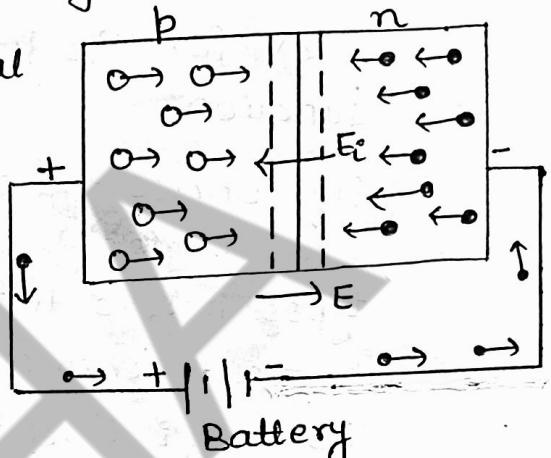
P-N Junction on forward bias:-

A junction diode is said to be forward-bias when the positive terminal of the external battery is connected to the p-region and the negative terminal to the n-region of the diode.

In this situation, an external electric field E directed from p towards n is set up in the diode. The field E is much stronger than the opposing internal field E_i . Hence, holes in the p-region and electrons in the n-region both move

towards the junction. These holes and electrons combine just near the junction and cease to exist. For each electron-hole combination, a covalent bond breaks up in the p-region near the positive terminal of the battery. Of the hole and the electron so produced, the hole moves towards the junction, while the electron enters the positive terminal of the battery through the connecting wire. At the same time, an electron is released from the negative terminal of the battery and enters the n-region to replace the electron lost by combining with a hole at the junction. Thus, the motion of majority-carriers constitutes a current across the junction. This is called forward current. The current in the external circuit is carried by electrons.

In addition to this large current, there is a small reverse current due to the motion of minority-carriers, but it is almost negligible.



In forward-biased junction, the applied field E dominates the small barrier field E_i . As a result, the majority carriers are pulled towards the junction. Hence, the width of the depletion region decreases. It is due to the reason that the junction diode offers a low resistance for the current to flow in forward bias.

The manner in which the p-n junction on forward bias respond in a circuit can be learnt from a graph representing the current against the applied voltage. Such a curve is called a V-I characteristic.

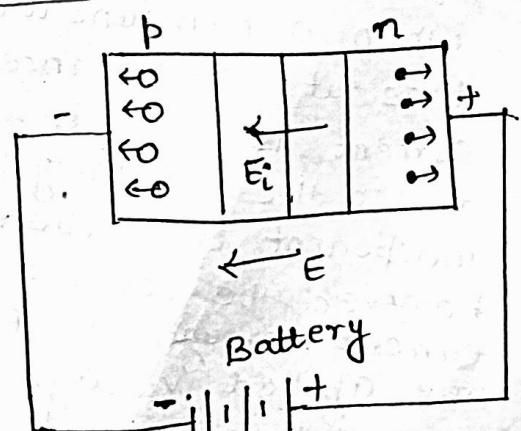
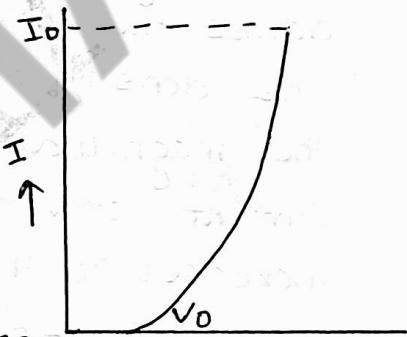
For the first few tenths of a volt of applied pot. diff., the current is found to be small.

In this region, the potential barrier of the junction is not

overcome. Once the external voltage $v \rightarrow$ exceeds the barrier potential, the current rises sharply. The voltage at which the current starts to rise sharply is called the cut-in or knee voltage (V_0). When p-n junction is on forward bias, its resistance is low and the current is large. Hence, the voltmeter used usually has a range of 0-1 volt. A millimeter is used to measure the current.

P-n junction on Reverse bias:-

A junction diode is said to be reverse-biased, when the positive terminal of the external battery is connected to the n-region and the negative terminal to the p-region of diode.



In this situation, the external field E is directed from n towards p and thus aids the internal barrier field E_i . Hence holes in the p -region and electrons in the n -region are both pushed away from the junction i.e. they can not combine at the junction. Thus, there is almost no current due to flow of majority carriers.

However, when the junction is reverse-biased, a very small reverse current ($\sim 1\text{A}$) flows across the junction. This current is carried by the few thermally-generated minority carriers which move across the junction under the applied field E . Since the density of the minority-carriers depends upon the magnitude of thermal agitation. The reverse current is very much temperature-dependent and increases with increasing temperature of the junction.

In reverse-biased junction, the applied field E supports the barrier field E_i . As a result, the majority carriers are pushed away from the junction. Hence, the width of the depletion region increases. It is due to this reason that the junction diode offers a high resistance for the current to flow in reverse bias.

Graph shows the V - I characteristic of a p - n junction on reverse bias. When a p - n junction is on reverse bias its resistance is high and the current is low ($\sim 1\text{A}$). This current is due to the minority carriers and is almost independent of applied reverse bias. If, however, the reverse bias is made too large the current through the p - n junction increases abruptly. The applied voltage at which this occurs is called breakdown voltage.

