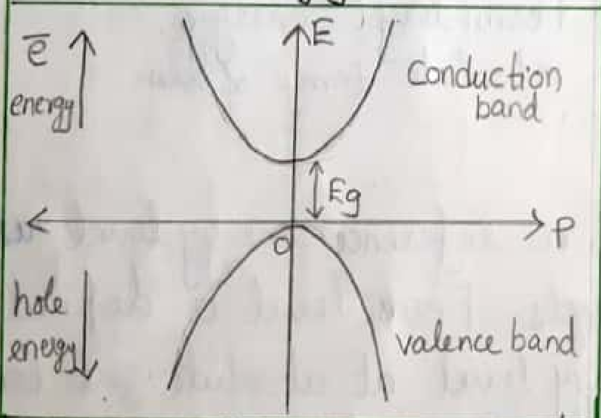
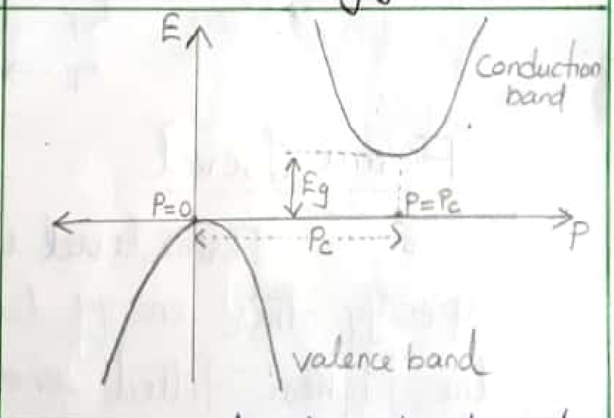
JESSY

MODULE 3
SEMICONDUCTOR PHYSICS

Direct and Indirect Bandgap Semiconductors

Using energy (E) – momentum (P) relationship the energy of a free electron is $E = \frac{P^2}{2m}$.
∴ Energy-momentum relation is parabolic in nature ($E \propto P^2$)
The energy of free electrons in the conduction band is representing by an upper parabola and holes in valence band by lower parabola. The gap between two parabolas at P=0 is the bandgap Eg. According to energy momentum relationship semiconductors are classified into (i) direct and (ii) indirect bandgap type

Direct Bandgap Semiconductor	Indirect Bandgap Semiconductor
	
Maximum of valence band and minimum of conduction band occur at the same momentum	Maximum of valence band and minimum of conduction band occur at two different momentum values
An electron make a transition from valence band to conduction band need not undergo any change in momentum. It requires only energy change ≥ Eg	When an electron make transition from maximum point in valence band to the minimum point in conduction band, it requires both energy change (≥ Eg) and also some momentum change (≥ Pc)
These are compound semiconductors eg. GaAs, GaAsP	These are elemental semiconductors eg. Ge, Si
During ē-hole recombination optical energy is released, which has wide application in LEDs and Laser diodes for efficient generation of photons.	Electron-hole recombination energy is released in the form of heat energy

②

Fermi Dirac Distribution Function

Each energy band in a crystal accomodates large number of electron energy levels. According to Pauli exclusion principle any energy level can be occupied by two electrons only. One spin up and one spin down. However all available energy states are not filled in an energyband

The probability that an electron occupies in an energy level E at thermal equilibrium is

$$f(E) = \frac{1}{1+e^{(E-E_F)/KT}}$$

This equation is known as Fermi Dirac Distribution function, where $K \rightarrow$ Boltzmann's const

$E_F \rightarrow$ Fermi level energy

$T \rightarrow$ absolute temp of sem

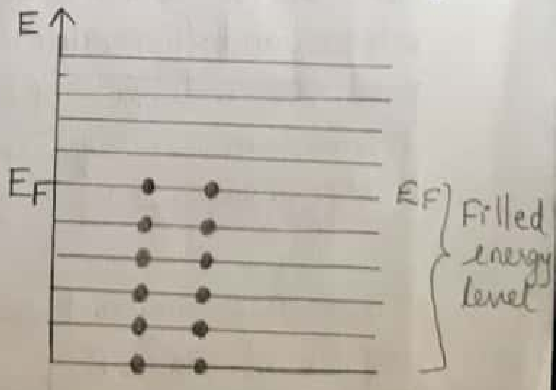
Fermi Level

Fermi level is a reference energy level used to specify other energy levels. Fermi level is defined as the highest filled energy level at absolute zero temp. (0K)

All the energy levels below Fermi level are completely filled at $T = 0°K$. The energy levels above fermi level are empty at absolute zero temp.

The probability occupancy using Fermi Dirac distribution function is

$$f(E) = 0 \quad \text{for } E > E_F$$
$$= 1 \quad \text{for } E < E_F$$



Fermi Level in Conductors

Case 1: at $T = 0K$

Fermi level is the uppermost filled energy level in conductor at 0K.

(i) For energy levels E lying below E_F : $\Rightarrow E < E_F$

$[e^{-\infty} = 0$, $e^{\infty} = \infty]$

$E - E_F$ is a negative quantity

$$f(E) = \frac{1}{1+e^{[(E-E_F)/KT]}} = \frac{1}{1+e^{\frac{-ve}{0}}} = \frac{1}{1+e^{-\infty}} = \frac{1}{1+0} = 1$$

$f(E) = 1$ indicates that all energy levels below E_F are occupied

(ii) For energy levels above E_F : $\Rightarrow E > E_F$

$E - E_F$ is a positive quantity

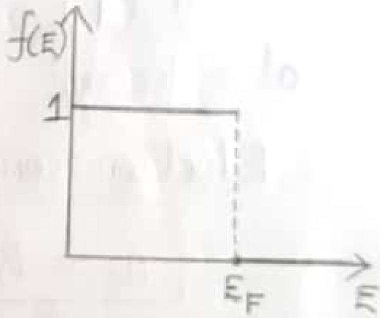
$$f(E) = \frac{1}{1+e^{(E-E_F)/KT}} = \frac{1}{1+e^{\frac{+ve}{0}}} = \frac{1}{1+e^{\infty}} = \frac{1}{1+\infty} = \frac{1}{\infty} = 0$$

$f(E) = 0$ indicates that all energy levels above E_F are vacant at $T = 0k$

(iii) For $E = E_F$

$$f(E) = \frac{1}{1+e^{0/0}} = \text{indeterminate}$$

∴ Occupancy of fermi level at 0k ranges from zero to one.



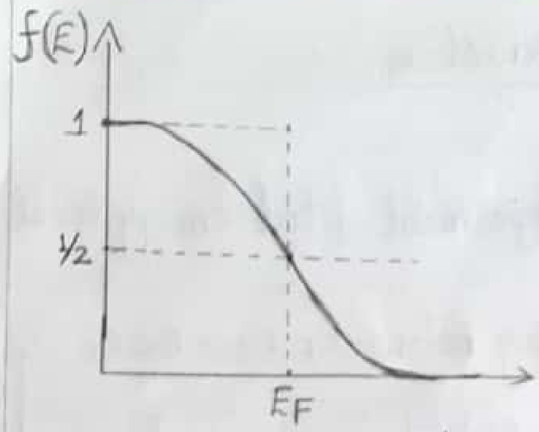
Case 2: $T > 0K$

As temperature increases, thermal excitation of electrons occurs. That is, the electrons having energy a little below E_F, jump into levels above E_F. Therefore probability of finding electrons in the levels below E_F will decrease and that of levels above E_F will increase.

At $T > 0K$, for $E = E_F$

$$f(E) = \frac{1}{1+e^{\frac{E-E_F}{KT}}} = \frac{1}{1+e^{0}} = \frac{1}{1+1} = \frac{1}{2} = 0.5 = 50\%$$

④



This implies that the probability of occupancy of fermi level at any temperature above 0K is 0.5 or 50%. Therefore at temperatures above 0K, is Fermi energy is defined as the average energy possessed by electrons participating in conduction process in a conductor.

Carrier Concentration in Semiconductor

Career concentration is the number of electrons in the conduction band per unit volume (n) and the number of holes in the valence band per unit volume (P) of the material. Carrer concentration is also known as density of charge carriers

Electron concentration in conduction band (n)

$$\boxed{n = N_c\, e^{-(E_c - E_F)/KT}}$$

where N_c is a constant known as effective density of states in conduction band

$$\boxed{N_c = 2\left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2}}$$ where $m_e^* \rightarrow$ effective mass of $\bar{e}$

Hole Concentration in valence band (P)

$$\boxed{P = N_v\, e^{-(E_F - E_v)/KT}}$$

where N_v is called effective density of states in valence band

$$\boxed{N_v = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2}}$$

where $m_h^* \rightarrow$ effective mass of holes.

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Fermi Level in Intrinsic semiconductor

In an intrinsic semiconductor electron and hole concentrations are equal. i.e $\boxed{n = p = n_i}$

The electron concentration in conduction band is

$$n = N_c\, e^{-(E_c - E_F)/KT}$$

The hole concentration in valence band is

$$p = N_v\, e^{-(E_F - E_v)/KT}$$

$$n = p$$

$$N_c\, e^{-(E_c - E_F)/KT} = N_v\, e^{-(E_F - E_v)/KT}$$

Taking logarithm on both sides

$$\ln N_c - \left(\frac{E_c - E_F}{KT}\right) = \ln N_v - \left(\frac{E_F - E_v}{KT}\right)$$

$$\frac{E_F - E_v - E_c + E_F}{KT} = \ln \frac{N_v}{N_c}$$

$$2E_F - E_c - E_v = KT \ln \frac{N_v}{N_c}$$

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

$$N_v = 2\left(\frac{2\pi m_h^* KT}{h^2}\right)^{3/2}$$

$$N_c = 2\left(\frac{2\pi m_e^* KT}{h^2}\right)^{3/2}$$

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

$$2E_F = E_c + E_v + \frac{3}{2} KT \ln \frac{m_h^*}{m_e^*}$$

$$E_F = \frac{E_c + E_v}{2} + \frac{3}{4} KT \ln \frac{m_h^*}{m_e^*}$$

If the effective mass of electron is assumed to be equal to effective mass of hole, i.e $m_e^* = m_h^*$ $\therefore \ln \frac{m_h^*}{m_e^*} = \ln 1 = 0$

$$E_F = \frac{E_c + E_v}{2}$$

$$E_F = \frac{E_c - E_v}{2} + E_v$$

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

If we denote top of valence band E_v as zero level, i.e $E_v = 0$

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

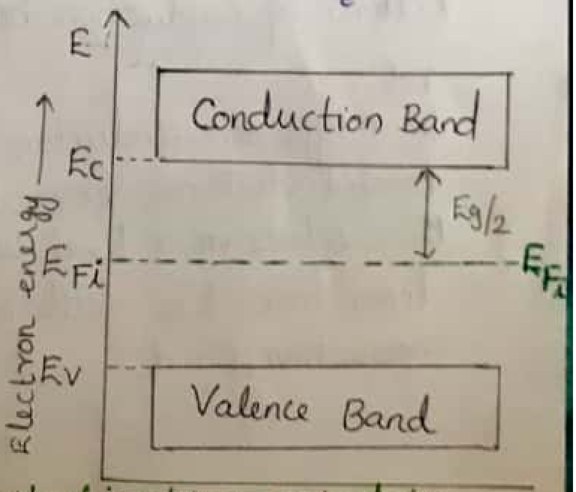

Fig: Fermi level in intrinsic semiconductor

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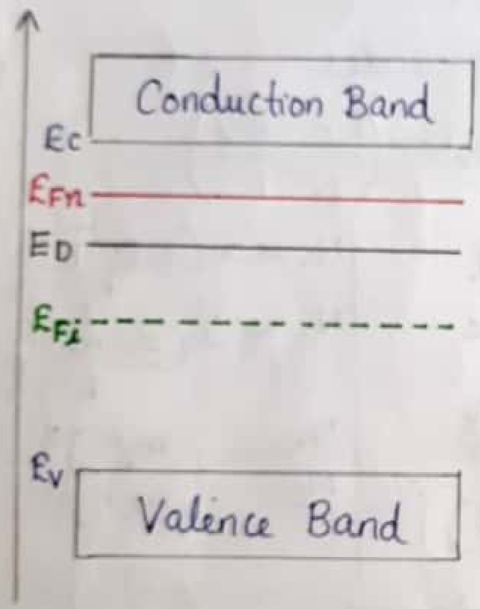
∴ In an intrinsic semiconductor the fermi level lies in the middle of the forbidden gap i.e, Fermi level lies half-way between valence band and conduction band in intrinsic semiconductor.

[Note: In a semiconductor, the fermi level represents the average energy of charge carriers participating in conduction]

Fermi Level in Extrinsic Semiconductor (At T=0K)

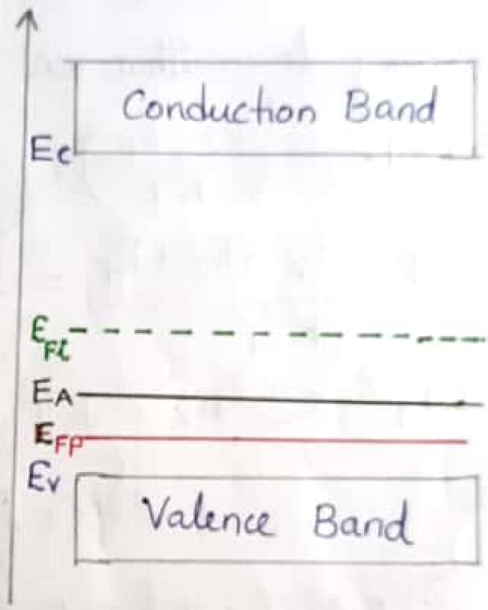
n type Semiconductor



* In n type semiconductor fermi level shift from E_{Fi} to E_{Fn} towards conduction band
* Fermi level must lie near the middle of donor level and bottom of conduction band

note:
In n type semiconductor, the donated electrons accomodate them selves in a level called donor level E_D, little below conduction band

P type Semiconductor



* In P type semiconductor fermi level shift from E_{Fi} to E_{FP} towards valence bands
* Fermi level lie near the middle of acceptor level and top of the valence band.

note:
In P type semiconductor, the extra holes occupy an energy level called acceptor energy level E_A, which is above the valence band.

I. Effect of temperature on Fermi Level

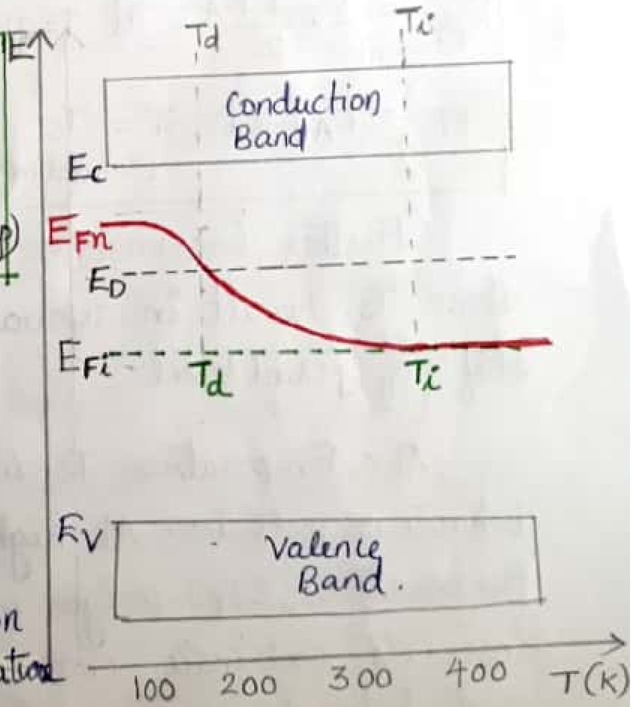
(1) In n type semiconductor

In n type semiconductor at low temperatures, some donor atoms are ionized and provide electrons to the conduction band; while other remains neutral. As electrons in the conduction band are only due to transition from donor levels, the Fermi level must lie between the donor energy level and bottom of conduction band.

When T = 0K, E_{Fn} lies midway between the donor levels and bottom of the conduction band. As the temperature increases the donor levels gradually get depleted and the Fermi level moves downward. At the temperature of complete depletion of donor levels T_d, the fermi level coincide with donor level E_D

$$E_{Fn} = \frac{E_C + E_D}{2} \text{ at } T = 0K$$

$$E_{Fn} = E_D \text{ at } T = T_d \text{ (depletion temp)}$$



Further increase in temperature above T_d, lead to downward shift of fermi level in a linear fashion. At a temp T_i, the intrinsic behaviour contributes to electron concentration. At higher temperature the n type semiconductor loses its extrinsic character and behaves as an intrinsic semiconductor. In the intrinsic region fermilevel approaches the intrinsic value

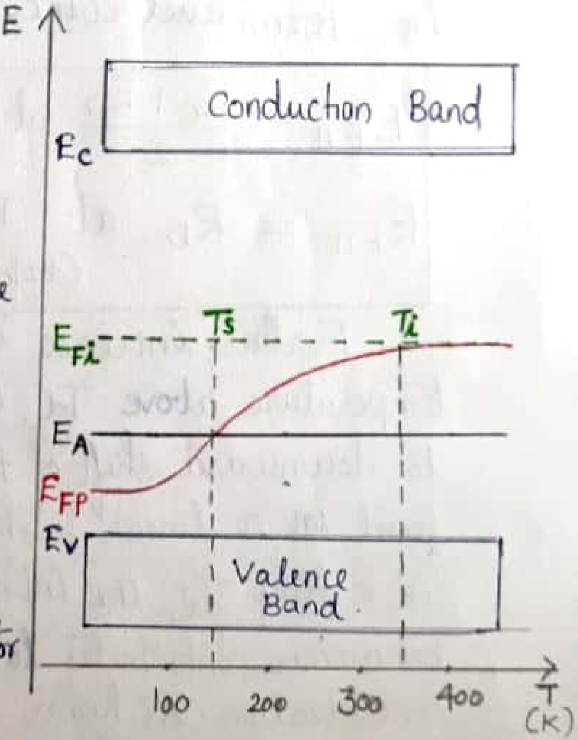
$$\boxed{E_{Fn} = E_{Fi} = \frac{E_g}{2} \text{ at } T \geq T_i}$$ where T_i is intrinsic temp.

⑧ ## (2) In P type semiconductor

In P type semiconductor, at low temperature holes in the valence band are only due to transition of electrons from valence band to the acceptor level. As valence band is the source of electrons and the acceptor levels are the recipients for them, the fermi level must lie between the top of valence band and acceptor energy level

When T = 0K, fermi level E_{FP} lies midway between acceptor level and top of valence band. As the temperature increases, the acceptor levels gradually get filled and the fermi level moves upward. At the temperature of saturation of acceptor levels, T_s, the fermi level coincide with the acceptor level E_A

$$\boxed{\begin{aligned} E_{FP} &= \frac{E_V + E_A}{2} \text{ at } T = 0k \\ E_{FP} &= E_A \text{ at } T = T_s \text{ (saturation temp.)} \end{aligned}}$$



Further increase in temperature above T_s, result in upward shift of fermi level.

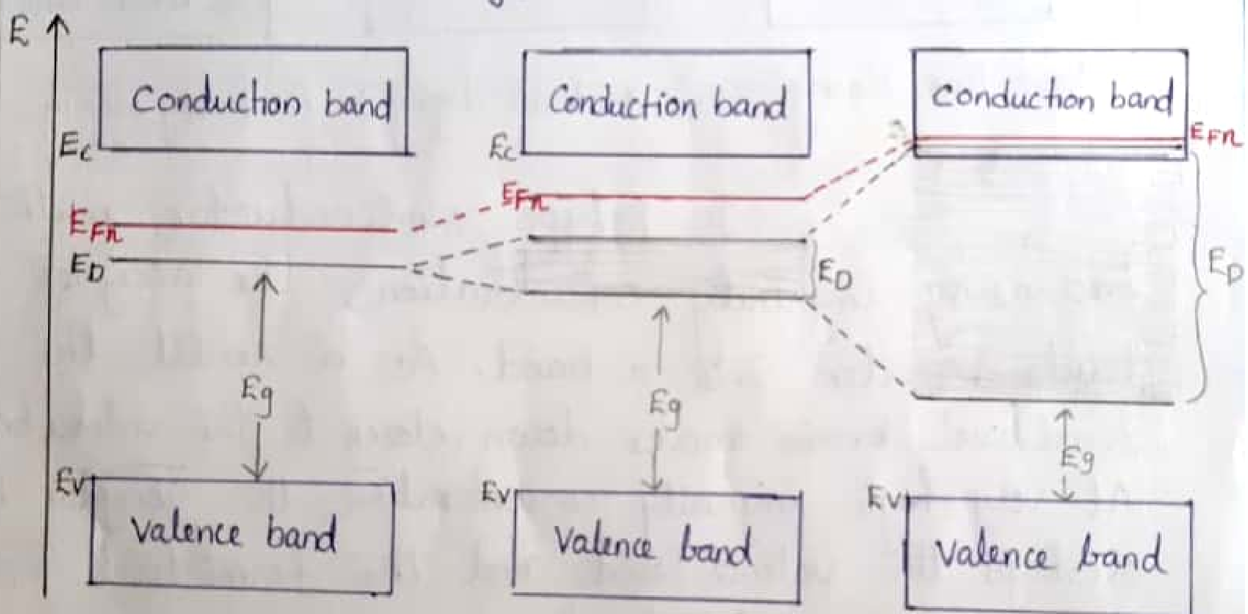
At a temperature T_i, intrinsic behaviour sets in. At higher temperature, the P type semiconductor loses its extrinsic character and behaves as an intrinsic semiconductor. In the intrinsic region fermi level approaches the intrinsic value.

$$\boxed{E_{FP} = E_i = \frac{E_g}{2} \text{ at } T = T_i}$$

II. Effect of impurity concentration on Fermi Level

I) n type semiconductor

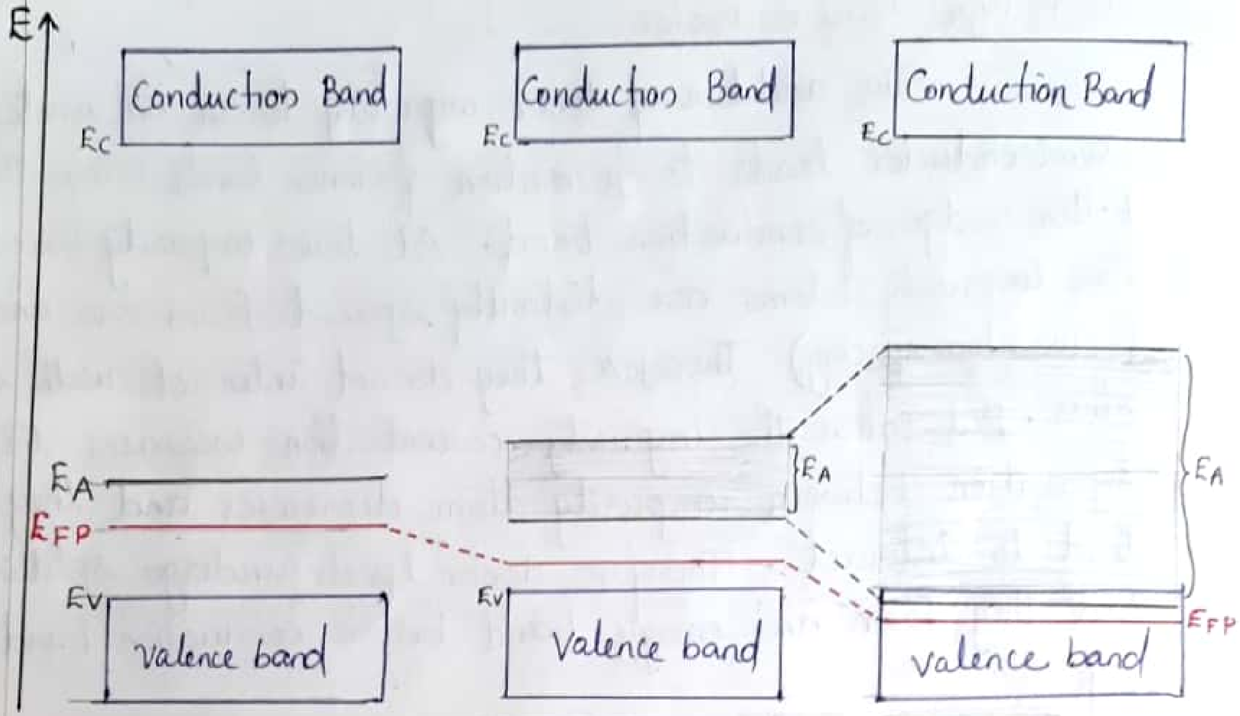
The addition of donor impurity to an intrinsic semiconductor leads to formation of donor levels below the bottom edge of conduction band. At low impurity concentration, the impurity atoms are distantly spaced from one another (≈100 atom spacing). Therefore, they do not interact with each other. But when the impurity concentration increases, the separation between impurity atom decreases and they tend to interact. Therefore donor levels undergo splitting and they form an energy band below conduction band.



(a) Low level doping (b) medium doping (c) Heavy doping

The larger the doping concentration, the broader is the impurity band. The broadening of donor levels into a band ~~is~~ leads to upward displacement of fermi level. With increasing impurity concentration, the fermi level shifts closer and closer to conduction band. At one stage, the impurity donor band overlaps on the conduction band and then fermi level moves in to the conduction band.

2) P type Semiconductor



(a) Low level doping (b) medium doping (c) heavy doping

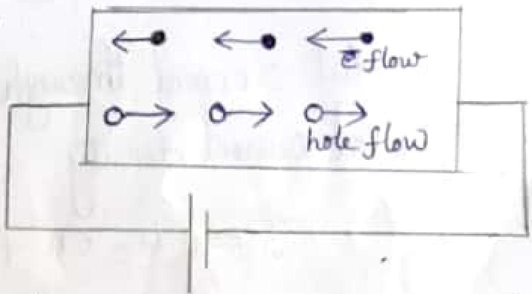
In p type semiconductor, with increasing impurity concentration, the acceptor levels broaden into a band. As a result, the fermi level ~~broad~~ moves down closer to the valence band. At very high impurity concentration, the acceptor band overlaps the valence band and the fermi level E_{FP} shift into the valence band.

Mobility, Conductivity and Current Density

The process of bond breaking in a semiconductor leads to generation of electron-hole pair. At any temp. T, the number of electrons generated will be equal to number of holes generated per unit volume ($n = p = n_i \Rightarrow$ intrinsic concⁿ)
Under thermal equilibrium condition, the electrons in conduction band and holes in valence band possess an average kinetic energy $\frac{1}{2} m v_{th}^2 = \frac{3}{2} kT$

① DRIFT CURRENT

When a potential difference is applied across the solid, equilibrium condition is disturbed. The electric field accelerates the electrons and holes.



But their motion is hindered due to interactions with lattice vibrations. In the steady state condition, there arises a net movement of electrons in a direction opposite to that of electric field and holes in the direction of electric field.

The net movement of electrons and holes under the application of an electric field is called drift, and their corresponding mean velocity is known as drift velocity v_d. The drift motion is directional and causes drift current flow

The drift velocity is directly proportional to applied electric field $v_d \propto E$

$$v_d = \mu E$$ where $\mu \rightarrow$ mobility of charge carrier (Proportionality Constant)

Mobility: $\boxed{\mu = \frac{v_d}{E}}$

∴ Electron mobility is defined as the drift velocity of electrons per unit electric field. (SI unit of $\mu \rightarrow m^2/Vs$) metals $\mu \rightarrow 10^{-3}\, m^2/Vs$, semiconductor $\rightarrow 10^{-1}\, m^2/Vs$
Mobility indicates the ease with which ēs move in a solid

12.

Let us consider a semiconductor across which a pd V applied $\rightarrow$ gives electric field E

$V_{de} \rightarrow$ drift velocity of $\bar{e}$, $\mu_e \rightarrow$ mobility of $\bar{e}$

$V_{dh} \rightarrow$ drift velocity of hole, $\mu_h \rightarrow$ mobility of hole

$J_e \rightarrow$ Current density due to $\bar{e}$, $n \rightarrow$ electron concentration

$J_h \rightarrow$ Current density due to hole, $p \rightarrow$ hole concentration

$\sigma_e \rightarrow$ conductivity due to $\bar{e}$, $I_e \rightarrow$ Current due to electron drift

$\sigma_h \rightarrow$ conductivity due to hole, $I_h \rightarrow$ Current due to hole drift

$$J_e = V_{de}\, en = \mu_e E\, en$$

$$J_h = V_{dh}\, ep = \mu_h E\, ep$$

Comparing with $J = \sigma E$; $\sigma_e = \mu_e en$

$\sigma_h = \mu_h ep$

$$I = A V_d en$$

$$J = \frac{I}{A} = V_d en$$

$$J = \sigma E$$

$$V_d = \mu E$$

Total current through semiconductor $I = I_e + I_h$

Total current density $J = J_e + J_h$

$$J = \underbrace{(\mu_e en + \mu_h ep)}_{\sigma} E$$

$$\therefore \quad \sigma = (\mu_e en + \mu_h ep) = (\mu_e n + \mu_h p)e$$

For intrinsic semiconductor $n = p = n_i$

$$\boxed{\sigma = n_i e(\mu_e + \mu_h)}$$

(2) Diffusion Current

In semiconductors, current can also flow without applying electric field. If there are more charge carriers on its one side, other than on the other side, there is a concentration gradient. This concentration gradient causes a directional movement of charge carriers, which continues until all the carriers are evenly distributed throughout the material.

Any movement of charge carriers constitute an electric current and this type of movement produces a current known as diffusion current.

The difference in the concentration of charge carriers initiates the carriers to diffuse from the region of higher concentration to the region of low concⁿ. in order to restore equilibrium condition. As the carriers are charged particles the migration produces a current flow, which is the diffusion current.

Diffusion Current strength $\propto$ Concentration gradient $\Downarrow$ (rate of change of carrier concⁿ per unit length)

The current component due to electron & hole diffusion are

$$J_e(\text{diff}) = e D_e \frac{dn}{dx}$$ where $D_e \rightarrow$ Diffusion coefficient due to $\bar{e}$

$$J_h(\text{diff}) = -e D_h \frac{dP}{dx}$$ $D_h \rightarrow$ Diffusion coefficient due to hole

Drift and diffusion current coexist in semiconductors.

Total current density = drift current density + Diffusion current density

for $\bar{e}$s $\Rightarrow$ $$J_e = J_e(\text{drift}) + J_e(\text{diff})$$
$$= \mu_e e n E + e D_e \frac{dn}{dx}$$

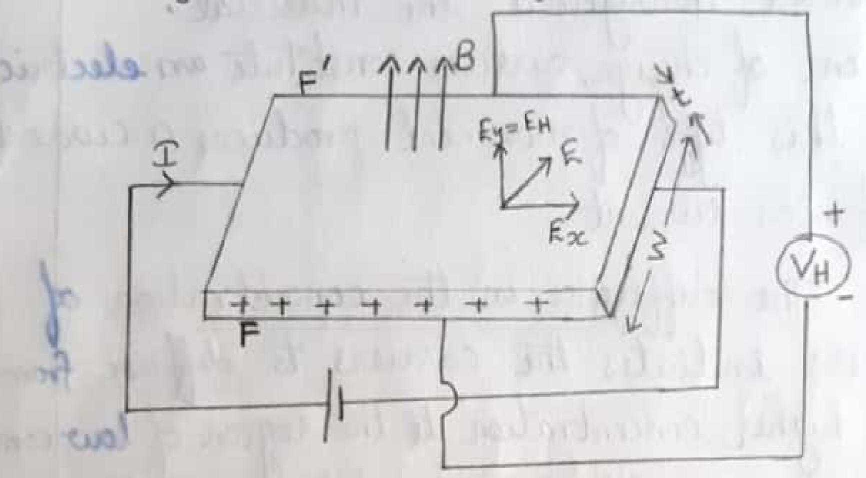
for $\bar{e}$ $\Rightarrow$ $$J_e = e\left[n\mu_e E + D_e \frac{dn}{dx}\right]$$

for hole $\Rightarrow$ $$J_h = e\left[P\mu_h E - D_h \frac{dP}{dx}\right]$$

HALL EFFECT (by E. H. Hall in 1879)

"If a current carrying conductor or semiconductor is placed in a transverse magnetic field, a potential difference V_H is produced in a direction normal to both magnetic field and current direction. This is known as Hall effect."

Experimental arrangement



p type semiconductor

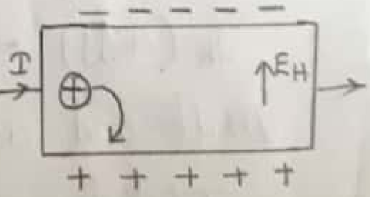
Area $= wt$

Major charge carrier $\Rightarrow$ holes

$p \Rightarrow$ hole concentration

Consider a thin rectangular p type semiconductor of thickness 't' and width 'w', which is mounted on an insulating strip. A voltmeter and a constant current source is connected across it. This arrangement is placed between two poles of an electromagnet such that the magnetic field act is perpendicular to the lateral faces of semiconductor.

Hall voltage



Before the application of magnetic field B, holes moves parallel to face F and F'. After applying magnetic field, the holes experience sideways deflection due to magnetic Lorentz force F_L.

Magnetic Lorentz force $F_L = e V_d B$

Holes are deflected towards the front face F and pile up there.

Due to this equivalent negative charge is left on the rear face F'. These separation of opposite charges produce a transverse electric field, E_H. The direction of E_H is from front (F) to rear face (F')

$$E_H = \frac{V_H}{W}$$

Due to E_H, holes experience an electric force F_E in addition to Lorentz force. When electric force F_E balances magnetic force F_L, equilibrium condition is reaches and holes flow along x direction parallel to face F and F'

At equilibrium $F_E = F_L$

$$e E_H = e v_d B$$

$$\cancel{e} \frac{V_H}{W} = \cancel{e} V_d B \Rightarrow \boxed{v_d = \frac{V_H}{BW}}$$

$$V_H = V_d BW$$

$$= \frac{I}{Aep} BW$$

$$= \frac{IB\cancel{W}}{(\cancel{W}t)ep}$$

$$V_H = \frac{BI}{pet}$$

$$I = AV_d ep$$

$$V_d = \frac{I}{Aep}$$

$J_x = \frac{I}{A}$, Area $A = Wt$

$$V_H = \frac{J_x BW}{eP} ; \Rightarrow \left(R_H = \frac{1}{eP} = \frac{V_H}{J_x BW} \quad R_H = \frac{1}{eP} = \frac{E_H}{J_x B} \right)$$

$$\therefore \boxed{V_H = \frac{BI}{Pet}} \rightarrow (\text{P type}) \qquad \boxed{V_H = \frac{BI}{net}} \rightarrow (\text{n type})$$

P → hole concⁿ n → electron concⁿ

Hall Coefficient R_H

Hall coefficient is defined as Hall field per unit current density per unit magnetic induction

$$\boxed{R_H = \frac{E_H}{J_x B}}$$

Also

$$\boxed{R_H = \frac{1}{pe}}$$

i.e; Hall coefficient is the reciprocal of charge density

(16) For p type semiconductor $R_H = \frac{1}{pe}$

For n type semiconductor $R_H = -\frac{1}{ne}$

Therefore carrier concentration (n or p) can be determined from the value of R_H

$$V_H = \frac{BI}{pet} \Rightarrow V_H = \frac{R_H BI}{t}$$

$$\therefore R_H = \frac{V_H t}{BI}$$

SI unit of $R_H \rightarrow m^3/C$

Hall Mobility

Mobility is the drift velocity acquired in unit electricfield

$$J = \sigma E$$

$$V_d e p = \sigma E$$

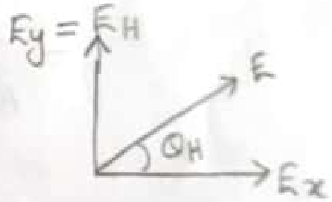
$$\frac{V_d}{E} = \frac{\sigma}{pe}$$

for holes $\boxed{\mu_h = \sigma R_H}$

$V_d = \mu E$

$\mu = \frac{V_d}{E}$

$J = V_d e p$ ← hole conc^n



Hall Angle

θ_H is the angle between net electricfield E in semiconductor and E_x (External field applied)

$$\tan\theta_H = \frac{E_H}{E_x}$$

$$= \frac{V_H}{W}\frac{\sigma}{J_x}$$

$$= \frac{BI}{petW}\frac{\sigma}{J_x}$$

$$= \frac{B\sigma}{pe}$$

$E_H = \frac{V_H}{W}$, $J_x = \sigma E_x$

$E_x = \frac{J_x}{\sigma}$

$\frac{I}{tW} = J_x$

$\frac{1}{pe} = R_H$, $\mu_h = \sigma R_H$

$$\boxed{\begin{aligned} \tan\theta_H &= \sigma R_H B \\ \tan\theta_H &= \mu_h B \end{aligned}}$$

Factors affecting Hall Voltage

$$V_H = \frac{BI}{Pet}$$

→ Hall voltage is directly proportional to mag. field strength B and current I passing through the material

→ Hall voltage is inversely proportional to the charge carrier concentration and thickness of material.

∴ Hall voltage will be larger, the larger the magnetic field or current. Further Hall voltage is larger, the smaller the carrier concentration and thinner the material.

(note: For semiconductors the number of charge carriers per unit volume is about $10^{23}/m^3$, while that of metal is about $10^{28}/m^3$. Therefore, the Hall voltage is about 10^5 greater in semiconductor than in metals)

Applications of Hall Effect (Importance of Hall effect)

Hall effect helps to determine

① the type of semiconductor ($R_H = -ve$ for n type, $R_H = +ve$ for p type)

② the charge carrier concentration $\left(n = \left|\frac{1}{R_H e}\right|,\ P = \frac{1}{R_H e}\right)$

③ the charge carrier mobility $(\mu = \sigma R_H)$

④ the mean drift velocity of charge carrier $\left(V_d = \frac{V_H}{BW}\right)$

⑤ Measurement of magnetic fields.

(18)

Fermi Level Diagram for PN Junction

(1) UNBIASED

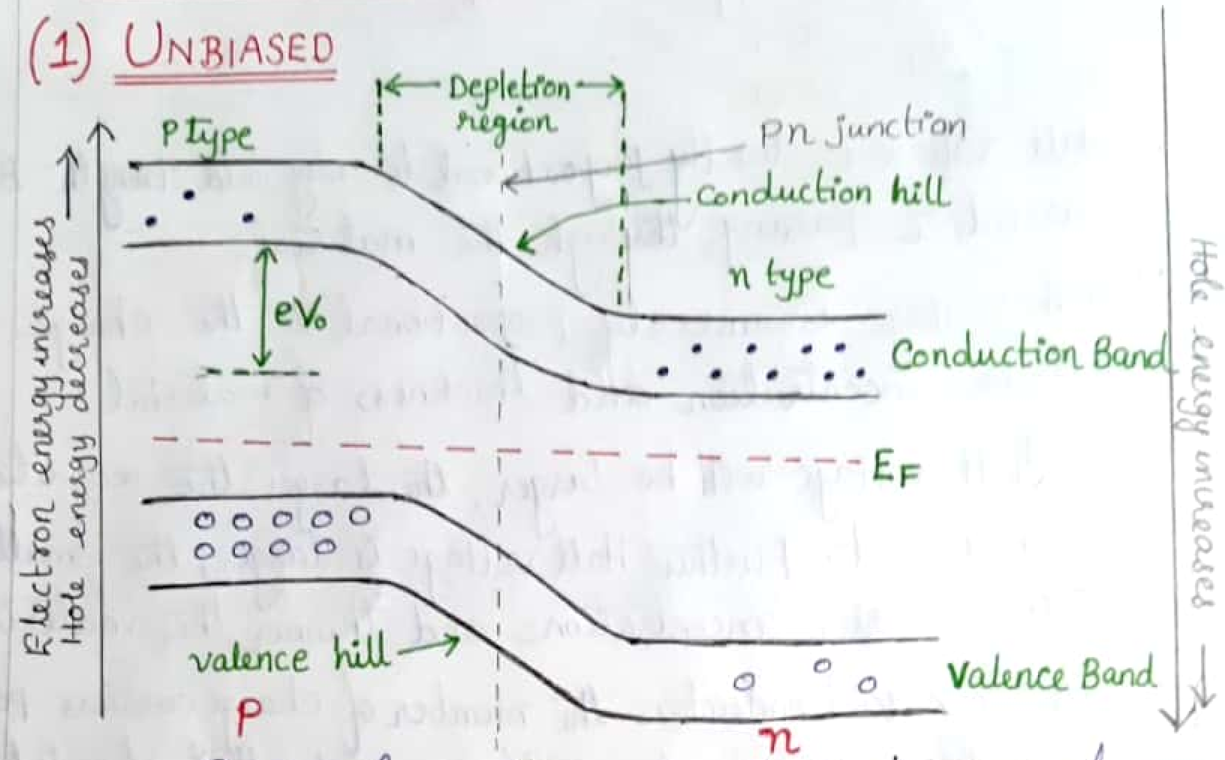


Figure shows the energy level diagram of an unbiased diode. Initially at the instant of formation of PN junction, the fermi level on p side and n side are at different positions. In order to establish equilibrium the fermi level in both regions must come to same level. Hence the energy bands get displaced in opposite direction.

The occupancy of energy level by electrons in conduction band on n side is high and p side is low. Similarly occupancy of energy level by holes in valence band on P side is high and n side is low. Hence in the conduction band electrons on the 'n' side move into 'p' side similarly in the case of valence band holes on the 'P' side move into 'n' side. As high energy electrons leave n region, the fermi level E_{Fn} which represents the average energy of electrons moves downwards. This causes downward shift of band structure in n region. On the p side, holes having high energy leave the valence band in that region. The direction of decrease in hole energy is upward and hence fermi leve E_{FP} moves upward.

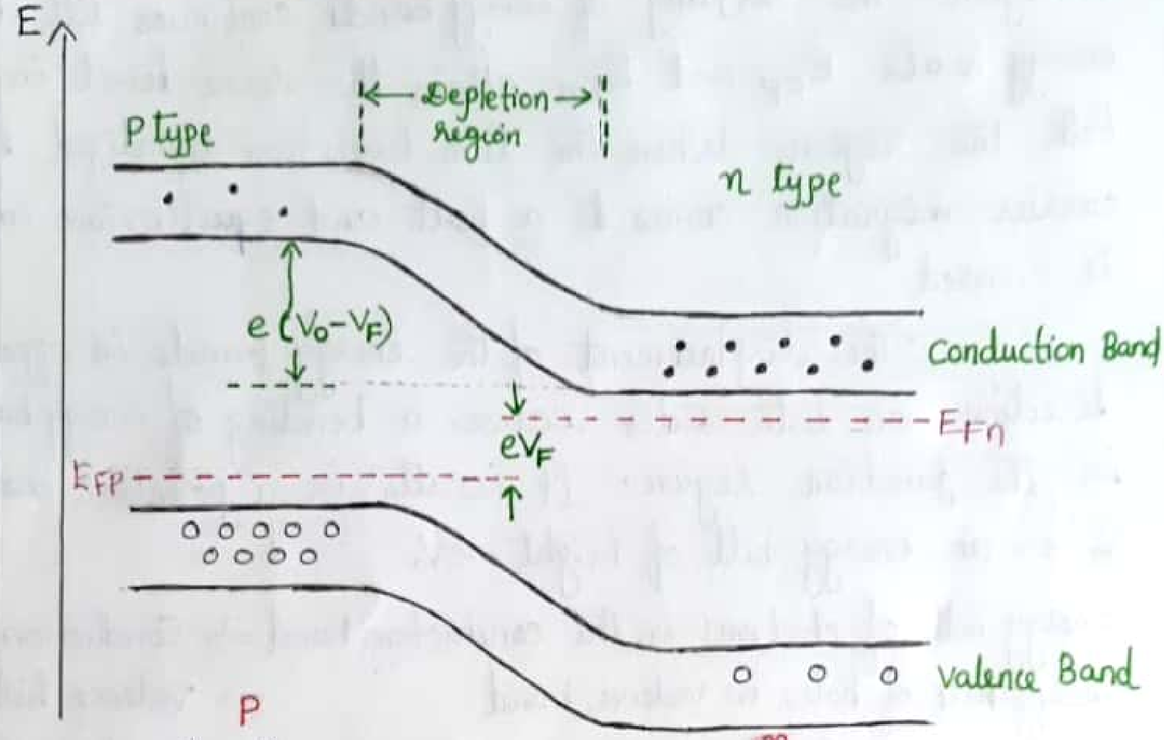
This causes upward shift of bandstructure in p region. The shifting of energy bands continues till the energy levels E_{FP} and E_{Fn} attain the same level in both the regions. When the two levels are equalized, the carrier migration comes to a halt and equilibrium condition is occured.

The displacement of the energy bands in opposite direction on both sides causes a bending of energy bands in the junction region. It results in a potential barrier V_0 or an energy hill of height eV_0.

Energy hill of electrons in the conduction band $\Rightarrow$ Conduction hill
Energy hill of holes in valence band $\Rightarrow$ Valence hill

It means that the electrons on the n side cannot go into the p region unless they have a minimum energy of eV_0. Similarly, the holes on the 'p' side cannot go into 'n' side unless they have a minimum energy of eV_0.

(2) FORWARD BIASED

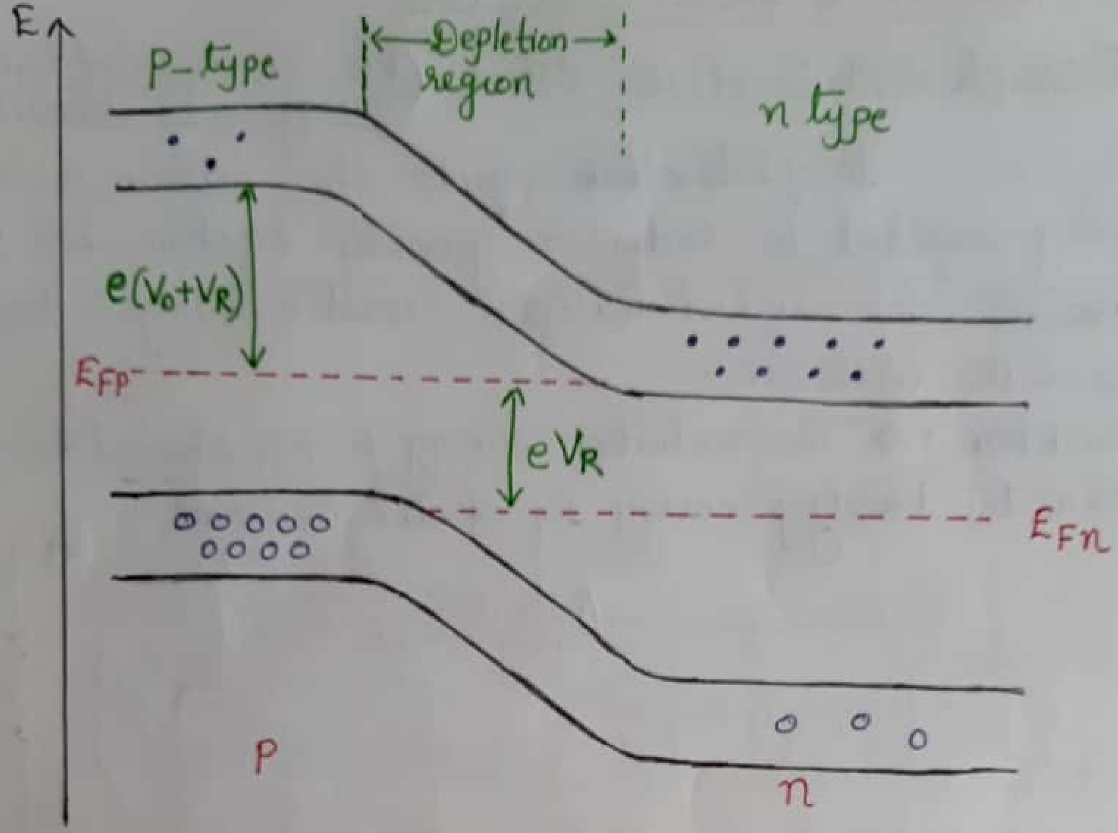


In forward biasing, the negative terminal of external voltage source is connected to n region and positive terminal to n region. The negative terminal of voltage source causes an increase in electron energy and an upward shift of all energy levels on n side. Similarly the positive terminal connected to p side causes an increase in hole energy and a lowering of levels on p side.

As the displacements of the energy levels occur in opposite directions, the fermi levels E_{Fn} and E_{FP} get separated by an amount of energy eV_F. Also the height of potential barrier is reduced by an to $e(V_0-V_F)$ from eV_0. Due to reduction of height of potential barrier, the movements of majority carriers is promoted.

Jessy.

(3) REVERSE BIASED



In reverse biased condition, the positive terminal of the bias voltage connected to the n-side reduces the energy of electrons. Therefore energy bands on n side are displaced downwards. Similarly, the negative terminal connected to P side reduces the energy of holes in p region. Hence the energy bands on p side are displaced upwards. Due to the displacement of these energy bands in opposite direction, the Fermi level E_{Fn} and E_{FP} get separated by an amount of energy eV_R. The barrier height in this case increases to a value of $e(V_0+V_R)$. Hence electrons (majority carrier) in n region cannot climb the conduction hill to go to p region. Similarly holes in p region cannot float up the valence hill to go into n region. The diffusion of majority carriers is totally stopped. However the barrier does not influence the drift motion of minority carriers.

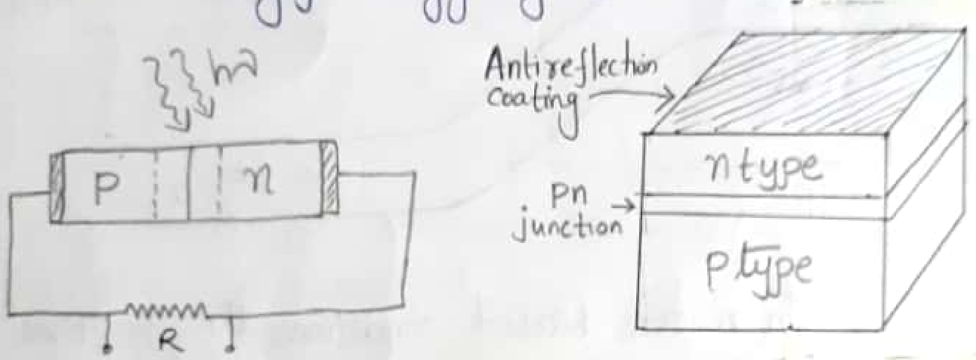
Applications of Semiconductors.

① Photovoltaic Cell - Solar Cell

Principle: Photo voltaic Effect (i.e Conversion of light energy into electrical energy)

In photovoltaic effect when certain materials being exposed to radiation generates electron-hole pairs available for conduction. As a result a voltage is developed across the material.

Condition :⇒ The radiation energy $E=h\nu$ should be greater than the bandgap energy E_g of the material



Solar cell is a p-n junction diode with very high doping level. It consist of a p type material on which thin layer of n type material is grown. The top layer is thin so that incident solar energy can reach the junction area. When the solar radiation is incident on device ($E=h\nu > E_g$) electron-hole pairs are generated in both p and n region. The majority of them cannot recombine in the regions. They reach the depletion region at the junction where an electric field due to space charge separates them. Electrons in the p region are drawn into n region and holes in the n region are drawn into p region. It results in accumulation of charge on the two sides of the junction and produces a potential difference called photoemf. If a load is connected across the cell a current flows through it

(2) Light Emitting Diode (LED)

A light emitting diode is a semiconductor diode that gives off light when it is forward biased. LEDs are generally fabricated using III-IV group element compound semiconductors such as GaAs, GaP, GaAsP etc. which have a direct band gap.

Principle: When a pn junction is forward biased, the electrons and holes diffuse through the junction in opposite direction. In this process they recombine with each other in the depletion region and release some energy called recombination energy. According to energy band structure, during this recombination, the electron comes back to the valence band with release of some energy equal to the band gap energy Eg (i.e optical energy is released)

In this case the recombination energy is emitted as optical energy.

The wavelength of emitted light is given by

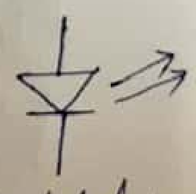
$$\boxed{\lambda = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)} \ \mu m}$$

$E = h\nu = \frac{hc}{\lambda} = E_g$

$\therefore \lambda = \frac{hc}{E_g}$

The colour of emitted light depends on type of material used.

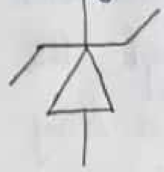
Material used	Colour
1. GaAs (Gallium Arsenide)	Infrared
2. GaAsP (Gallium Arsenide phosphide)	Red or Yellow
3. GaP (Gallium phosphide)	Red or green



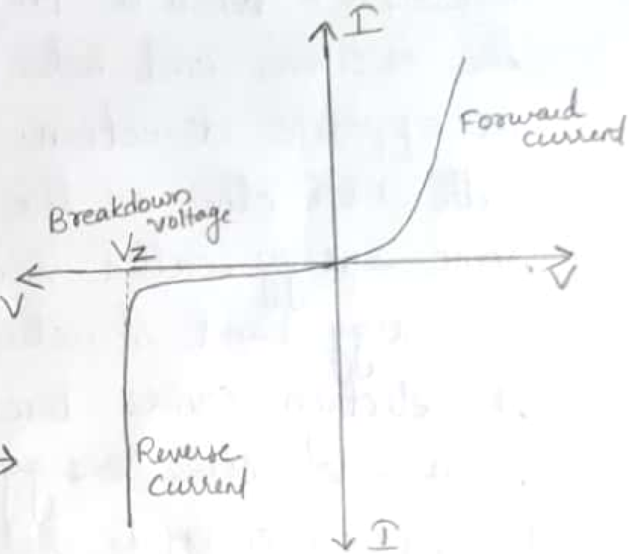
symbol of LED

3 Zener Diode

Zener diode is a semiconductor diode specially designed to operate in the breakdown region of the reverse bias. Zener diodes are always operated in reverse bias condition. By varying the impurity concentration and other parameters, it is possible to design the breakdown voltage to suit specific applications e.g: voltage regulators



Symbol



VI characteristics of Zener diode →

Zener diode acts like ordinary diode under forward biased condition. During reverse biasing, at a particular value of reverse voltage, the reverse current increases abruptly. This voltage is called zener breakdown voltage or zener voltage Vz.
In the zener region, the voltage across zener diode remains constant, but the current changes depending on supply voltage. The voltage drop across the zener diode is equal to the zener voltage of that diode no matter how high the reverse bias voltage is above zener voltage.

for video lectures
Youtube: Physics Jessy

Study Well
Best Wishes
Dr. Jessy P.J