Physics

UNIT - II - semi-conductor

Crystalline	Amorphous
• The constituents particles are arranged in regular order.	• The constituent particles are irregulary arranged.
• They have sharp melting point.	• They melt over wide range of temperature.
• They show definate heat of fusion.	• They do not have definate heat of fusion
• They show anisotropy i.e. different physical property in different direction.	• They are isotropic i.e. same physical propert in different direction.
• They are true solide • Eg: Diamond, metal.	• They are supercool solid • Eg: Glass, plastic

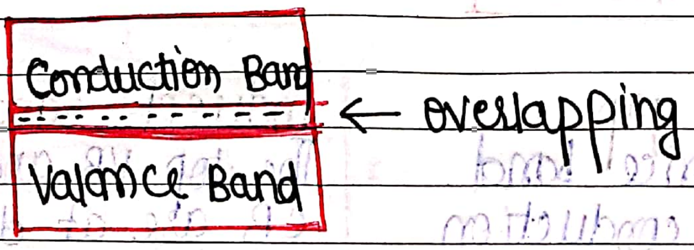
▶ **Band Theory of Solids :**

★ **Metals :**

• In metals like copper, aluminium there is no forbidden gap between valance band and conduction band as the band overlap.

Appointments

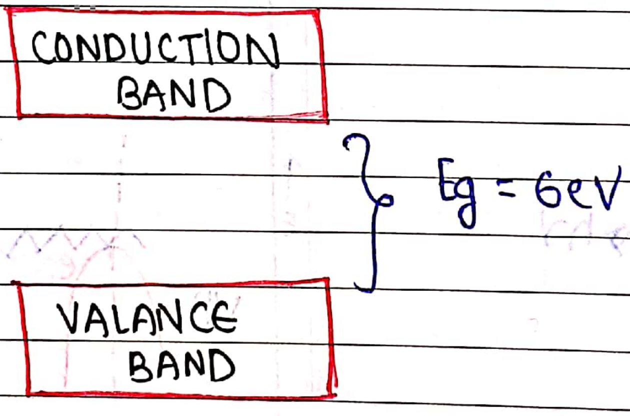
• without any additional energy, such metal contain large amount of ~~energy~~ free electrons in conduction band



★ Insulator :-

• The forbidden gap between valance band and conduction band is large so, band ~~gap is large~~ Eg ≃ 6eV so electron require 6V energy to jump from valance band to conduction band. Electron do not acquire sufficient energy to do so, it continues to be empty.

• Eg : paper, wood.



★ ~~Metalic~~

★ Semi-conductor :

• The forbidden gap is very narrow (Eg ≃ 1eV)

• The energy provided at room temperature is sufficient to ~~f~~ lift the electron from VB to CB.

Appointments

CONDUCTION BAND

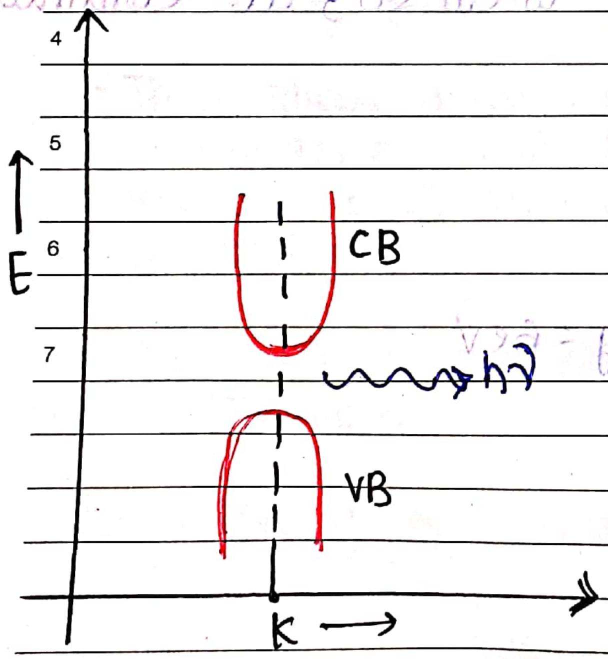
} Eg ~ 1eV

VALANCE BAND

9
10

★ Direct band gap

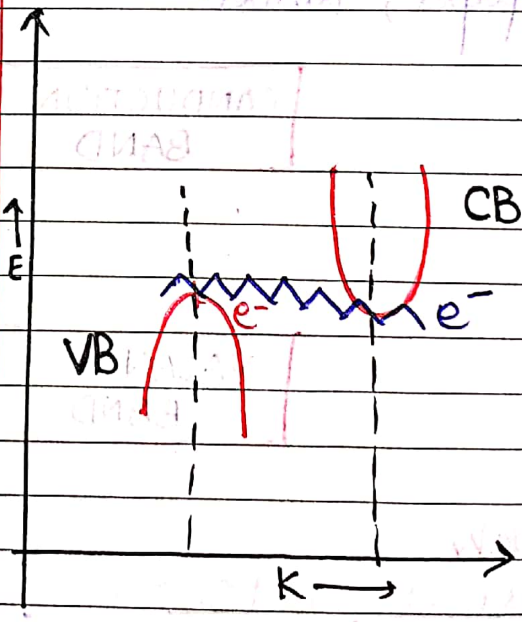
The top of the valance band and bottom of conduction band are at same k value (momentum vector) so, electron from conduction band can directly recombine with hole in valance band & there will be emission of light.



• Eg: GaAs, InP

Indirect band gap

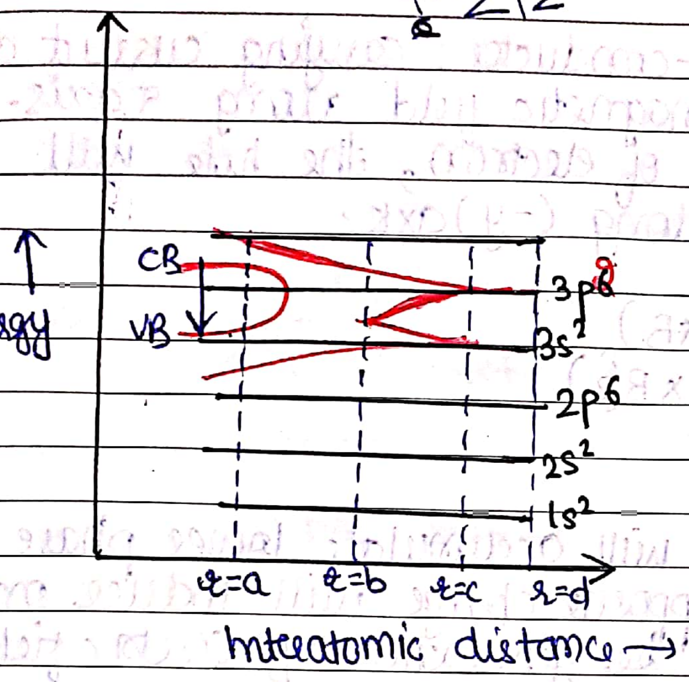
The top VB and bottom of CB are at different k value so, electron can't ~~jump from~~ directly recombine with hole, there will be an intermediate stage through phonon interaction, there will be recombination of electron & hole in the form heat.



• Eg: Ge & Si

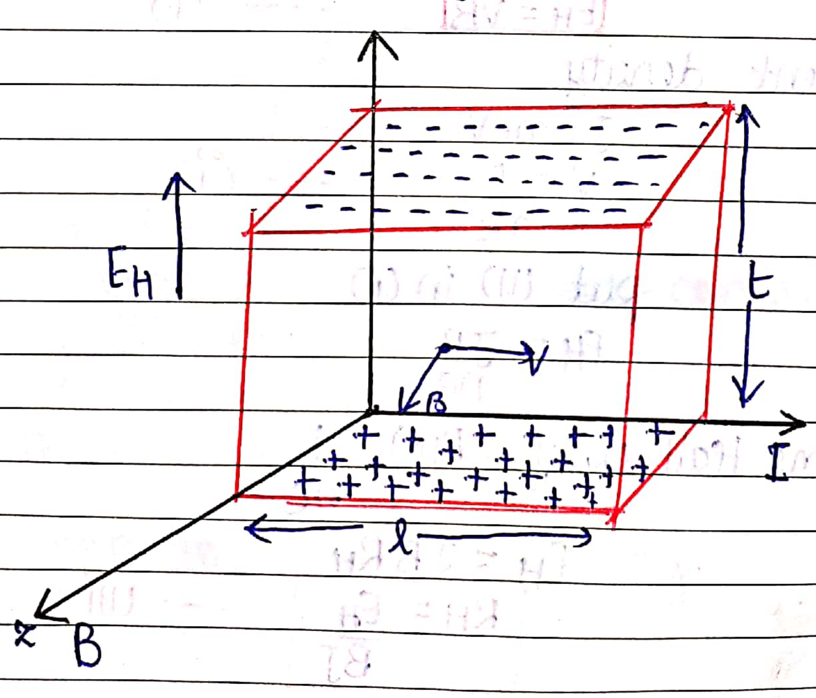
Appointments

$Si = 14 = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$



★ Hall Effect :

When a current carrying conductor is placed perpendicular (⊥) to magnetic field there will be production of voltage ⊥r to both magnetic field & current.



Appointments

Consider a p type semi-conductor, carrying current along x axis and placed in magnetic field along z axis.
v is the drift velocity of electron, the hole will experience Lorentz force along (−y) axis.

Acc. Lorentz force:

$$\vec{F} = q(V \times B)$$

$$\vec{F} = e(V\hat{i} \times B\hat{k})$$

$$\vec{F} = eVB\hat{j}$$

Due to Lorentz force, holes will accumulate lower phase of the specimen and equivalent opposite charge will induce on upper phase & there will be generation of Electric field along positive y axis.

$$F_e = eE_H\hat{j}$$

At eq^m

$$F_e = F_m$$

$$eE_H = eVB$$

$$\boxed{E_H = VB} \quad \text{---- (i)}$$

current density

$$J = neV$$

$$V = \frac{J}{ne} \quad \text{--- (ii)}$$

put (ii) in (i)

$$E_H = \frac{JB}{ne}$$

Define Hall coeff. $(R_H) = \frac{1}{ne}$

$$E_H = JBR_H$$

$$\boxed{R_H = \frac{E_H}{BJ}} \quad \text{--- (iii)}$$

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

$$J = \frac{I}{A} \quad \text{---- (IV)}$$

$$A = b \times t$$

$$J = \frac{I}{b \times t} \quad \text{-- (V)}$$

Put (IV) & (V) in (III)

$$R_H = \frac{V_H \times b \times t}{B \times I \times t}$$

$$\boxed{R_H = \frac{V_H \times b}{B \times I}}$$

SI unit $\frac{Vm}{T}$ or $\frac{m^3}{C}$

$$\sigma = e\mu$$

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

$$\sigma = \frac{1}{R_H}\mu$$

$$\boxed{\mu = \sigma R_H}$$

Importance of R_H:

i) D/W n type & p-type semi-conductor
ii) Mobility can be calculated.
iii) Number density or charge density is calculated.
iv) flux density is calculated.

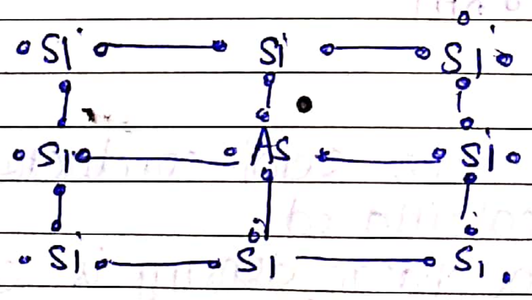
- R_H will remain constant always.

Appointments

* Intrinsic semiconductor	Extrinsic semiconductor
• It is pure semiconductor as it does not have any impurities.	• It contains suitable impurities added to it.
• Electrical conductivity is low.	• Electrical conductivity is high.
• The no. of electrons in CB is always equal to no of holes in VB	• n type. n(e) in CB is larger than n(h) in VB. p type reverse.
• Eg: pure Si & Ge	• 5 doped Si (or Ge).
• Rarely used	• ~~too~~ widely used

* N-type semiconductor :

• They are doped with pentavalent impurities which means 5 electron in valence shell. Eg P, As etc.



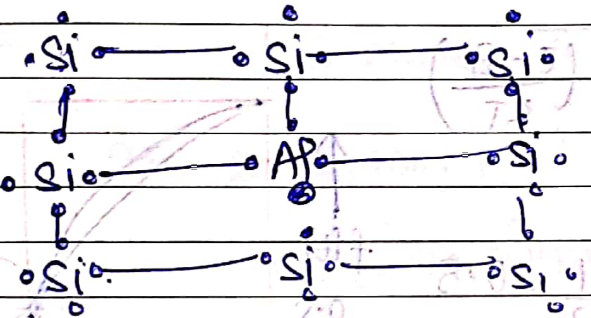
• Out of five valence electrons of arsenic atom, four is bonded while fifth electron is not being part of any bond, it is free.

• The each pentavalent atom added releases one free electrons in the crystal so it is called as donor atom.

- no of free electron is much higher than no. of holes so, electrons are majority carriers and holes are minority carriers.

★ p type semi-conductor:

- They are doped with the trivalent impurities which means 3 electron in valence shell. Eg: Al, B.



- Being dopant atom only has three electron, there is one bond which is incomplete with neighbouring Si atom due to deficiency of atom.

- The bond is completed by taking an electron from one neighbouring Si - Si atom. It acquires a negative charge and holes is created.

- As trivalent atom accepts electron from the silicon so it is acceptor atom.

- Holes are majority carriers & electrons are minority carriers.

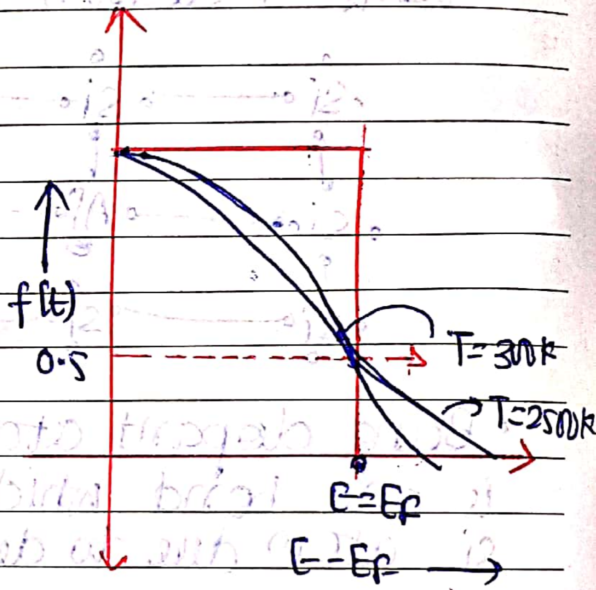
• Fermi - Dirac function :

F(E) represents the probability that a state of given energy is E is occupied by electron under condition of thermal equilibrium

Or

Fractional occupancy of possible state.

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{KT}\right)}$$



CASES :

i) $E = E_F$

$$f(E) = \frac{1}{1 + \exp(0)} = \frac{1}{1+1} = \frac{1}{2} = 0.5$$

ii) $E > E_F$

$$f(E) = \frac{1}{1 + \exp\left(\frac{+}{0}\right)} = \frac{1}{1 + \infty} = 0$$

iii) $E < E_F$

$$f(E) = \frac{1}{1 + \exp\left(\frac{-}{\infty}\right)} = \frac{1}{1} = 1$$

The rectangular distribution implies that at 0K every available energy upto E_F is filled with electrons and all the above states are empty.

• Fermi Energy :

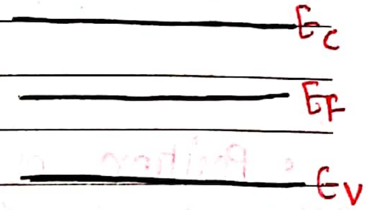
It is the energy corresponding to fermi-layer.

* Position of Fermi-level in intrinsic semi-conductor :

The concentration of electron (e^-) in conduction band :

$$n_e = 2\left(\frac{2\pi m_e KT}{h^2}\right)^{3/2} e^{-(E_c - E_F)/KT}$$

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



The concentration of electron (e^-) in valance band :

$$n_h = 2\left(\frac{2\pi m_h KT}{h^2}\right)^{3/2} e^{-(E_F - E_V)/KT}$$

$$n_h = N_V e^{-(E_F - E_V)/KT}$$

In intrinsic semiconductor conc. of electrons = conc. of holes

$$n_e = n_h$$

$$N_c e^{-(E_c - E_F)/KT} = N_V e^{-(E_F - E_V)/KT}$$

$$\frac{N_c}{N_V} = \frac{e^{-[E_c - E_F]/KT}}{e^{-[E_F - E_V]/KT}}$$

$$\frac{N_c}{N_V} = e^{[E_V + E_c - 2E_F]/KT}$$

Taking log both side

$$\log\left(\frac{N_c}{N_V}\right) = \frac{E_V + E_c - 2E_F}{KT}$$

If $m_e = m_h$

$$KT \ln \frac{m_e}{m_h} = E_V + E_c - 2E_F$$

$$E_V + E_c - 2E_F = 0$$

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

Appointments

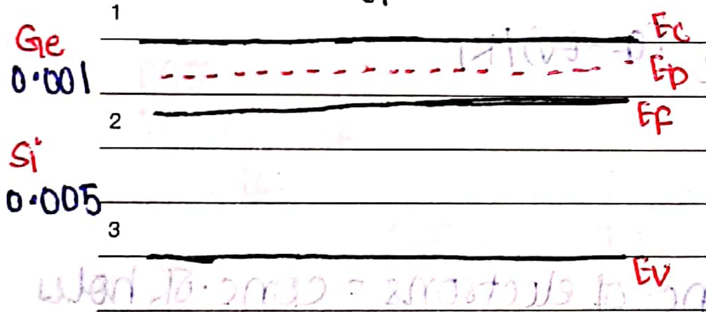
law of conservation of mass action:

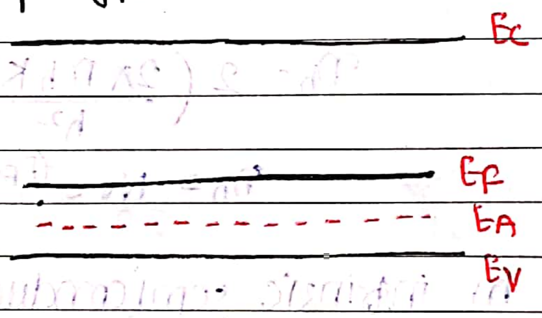
$$n_e n_h = n_i^2$$

$$n_i^2 = 4\left(\frac{2\pi KT}{h^2}\right)^3 (m_e m_h)^{3/2} e^{-E_g/KT}$$

• Position of Fermi-layer in Extrinsic semi-conductor :-

For n type semi-conductor | p type semi-conductor





n type is semi-conductor is formed when donor type impurity is added in intrinsic semi-conductor and fermi-level shifts towards the conduction band.

$n_e = N_c e^{-(E_c - E_F)/KT}$

For n type

$n_e \simeq N_D$

$N_D = N_c e^{-(E_c - E_F)/KT}$

Take log both side

$$\log \frac{N_D}{N_C} = -\frac{[E_C - E_F]}{KT}$$

$$\boxed{E_F = E_C - KT \log \frac{N_C}{N_D}}$$

p type semi-conductor is join when acceptor type impurity is added in intrinsic semi-conductor & fermi-level shift towards valance band & lies above the valance band.

$n_h = N_V e^{-(E_F - E_V)/KT}$

For p type

$n_h \simeq N_A$

$N_A = N_V e^{-[E_F - E_V)/KT}$

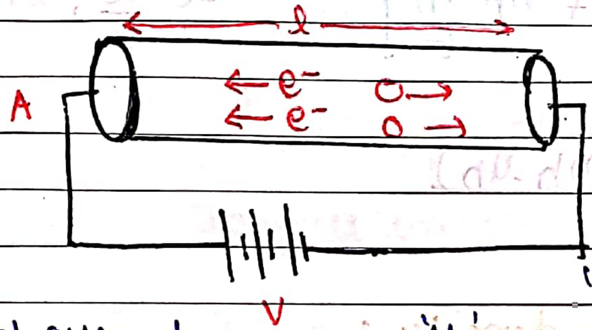
Take log both side

$$\log \frac{N_A}{N_V} = -\frac{[E_F - E_V]}{KT}$$

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

when temperature is increased, the production of more electron and holes combination. and it (behaviour) ~~waves~~ behaves as intrinsic semi-conductor and fermi level be in the middle position..

* Electrical conductivity of Extrinsic semi-conductor :-



consider a slab of extrinsic semi-conductor having length 'l', area of cross-section 'A'.
'n_e' no. density of electrons
'n_h' no. density of holes
'I' total current
'μ_e' mobility of electron
'V_e' drift velocity of electrons
'μ_h' mobility of holes.
'V' applied potential
'V_h' - drift velocity

* In semiconductor total current consist of electron current plus hole current.

$$I = I_e + I_h$$
$$I_e = e n_e A V_e$$
$$I_h = e n_h A V_h$$
$$I = Ae(n_e v_e + n_h V_h) \quad \text{--- (i)}$$

we know $R = \rho \frac{l}{A}$ ---(ii)

$$I = \frac{V}{R} \quad \text{--- (iii)}$$

Put (iii) in (i)

$$\frac{V}{R} = Ae(n_e V_e + n_h V_h) \quad \text{-- (iv)}$$

Put (ii) in (iv)

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$$\frac{VA}{\rho l} = Ae(n_e v_e + n_h v_h)$$

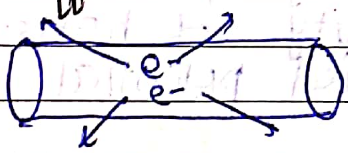
$$\frac{V}{\rho l} = e(n_e v_e + n_h v_h)$$

$$E = \frac{V}{l}$$

$$\frac{E}{\rho} = e\left[n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right] \qquad \mu_e = \frac{v_e}{E},\ \mu_h = \frac{v_h}{E}$$

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

▶ **Drift & Diffusion current density :**



Drift current : In the absence of electric field there is ~~no~~ net motion in crystal ie zero but with applied electric field electrons will move to positive terminal of battery and electrons will move to negative terminal of battery. So, there will be net flow of charge which will lead to production of drift current.

$$J_e(\text{drift}) = n_e\, e\, \mu_e E$$
$$J_h(\text{drift}) = n_h\, e\, \mu_h E$$

$$J_{drift} = J_e + J_h$$

Appointments

▶ Diffusion current :

Due to non-uniform distribution of charge carrier, the ~~ele~~ excess carriers moves from higher concentration to lower concentration region leads to production of diffusion current.

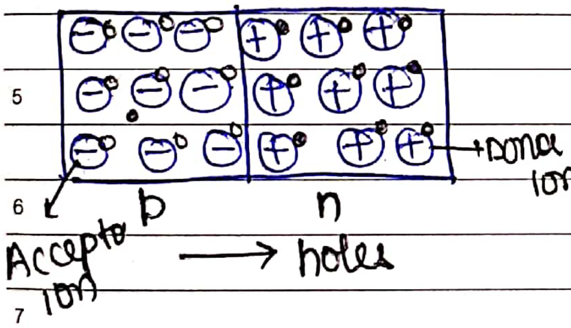
$$J_e(\text{diff}) = e D_n \frac{dn}{dx}.$$

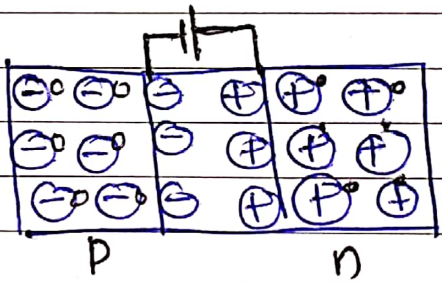
$$J_h(\text{dif}) = -e D_h \frac{dh}{dx}$$

$$J_{\text{diffusion}} = J_{\text{drift}} + J_{\text{diff}}$$

$$J_{\text{total}} = J_{\text{drift}} + J_{\text{diff}}$$

▶ Unbiased p-n junction :





- In p-n ~~region~~ junction diode p region is having higher concentration of holes and n region is having that of electrons, the movement when p-n junction is formed holes from p region starts diffusing across the junction into n region while electron from n region start diffusing across the junction into p region.

When an electron diffuses into p region it falls into vacancy i.e. holes and recombination take place.

Appointments

- This result in production of immobile ionized acceptor
9 near p-region. Similarly holes from p-region
recombine with electrons in n side & result in
10 production immobile ionized donor atom near
n side
11 - This layer of immobile ion creates an electric
field which further opposes the diffusion
12 process due to this field there is potential
at junction known as barrier potential V_B &
1 the region where electron-hole recombination
takes place known as depletion region.

2

3

4