Sumedh

- **Topics :-**

i) Intrinsic
ii) Extrinsic
iii) Recombinatn
iv) Drift & Diffusion
v) Continuity
vi) PN, Fwd, Rev
vii) Metal Semi (Skotch, Ohmi)
viii) Photo-diode
ix) LED

- **Intrinsic Semi-cons**

Pure Semi-con contains very small amt. of imp. Forbidden gap is present so conductn not possible when $\bar{E}$ applied

eg Si Ge

The no. of e^- excited from top of VB to bottom of CB can be calc by fermi dirac statistics

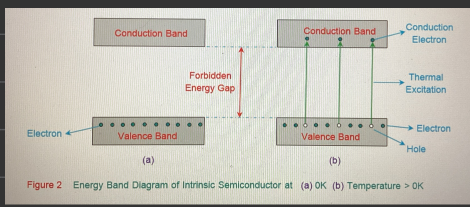


Figure 2 Energy Band Diagram of Intrinsic Semiconductor at (a) 0K (b) Temperature > 0K

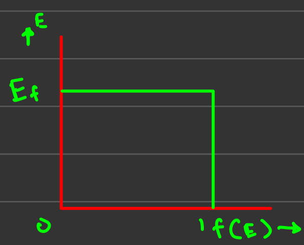
Fermi-level

The no. of free e's per unit Vol. is 'n' in conductn band
The no. of holes per unit Vol. is 'p' in val. band

Carrier density

$$n = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2} e^{(E_F - E_c/kT)/kT}$$

$$p = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{3/2} e^{(E_v - E_F)/kT}$$



$\because$ n = p in intrinsic

$$\cancel{2}\left[\frac{\cancel{2\pi} m_e^* \cancel{kT}}{\cancel{h^2}}\right]^{3/2} e^{(E_F - E_c/kT)/kT} = \cancel{2}\left[\frac{\cancel{2\pi} m_h^* \cancel{kT}}{\cancel{h^2}}\right]^{3/2} e^{(E_v - E_F)/kT}$$

$$\left(\frac{m_e^*}{m_h^*}\right)^{3/2} = e^{(E_v + E_c - 2E_F)}$$

$$\left(e^{2E_F}\right)\left(\frac{m_e^*}{m_h^*}\right)^{3/2} = e^{(E_v + E_c)}$$

Taking log

$$E_F = \frac{3kT}{2}\log\left(\frac{m_h^*}{m_e^*}\right) + \frac{E_v + E_c}{2}$$

also $m_e^* = m_h^*$

$$E_F = 0 + \frac{E_v + E_c}{2}$$

- Extrinsic Semicon

These type of semicons have tri & penta imp doped in a tetravalent semicon to inc conductivity i.e inc free e^-s

① Fermi - level in N- type

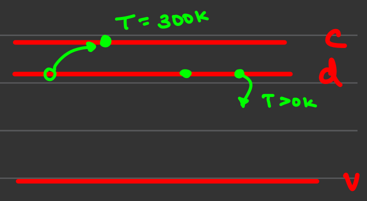
i) Penta-valent impurity
ii) eg P in Si semicon

Suppose P is added to Si atom, 4/5 e^- in outermost orbital, this 5th e^- is loosely bound to parent atom, its called donar e^- and is close to lower lvl of CB.

Most of donar lvl e^- are excited into CB at room T & become majority charge carriers.

$$E_F = \frac{(E_c + E_d)}{2} + \frac{3kT}{2} \ln\left(\frac{N_d}{2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}} \right)$$

at $T = 0$



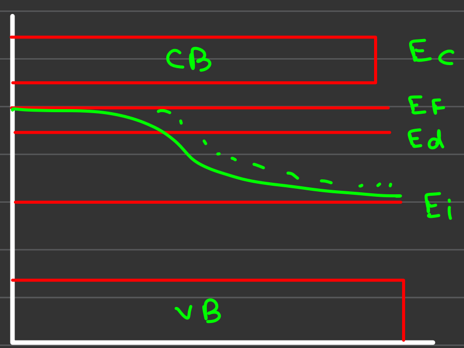
$$E_F = \frac{E_c + E_d}{2}$$

T ↑ , Fermi-lvl ↓ , donor ions ↑ , e^--hole pair ↑

As T inc , Fermi lvl drops , for given T lvl ↑ as conc. ↑

Further ↑ in T results in gen. of e-h pair.

The Fermi lvl gradually move toward the intrin. fermi lvl.



② Fermi-level in P typ

i) Tri-valent imp
ii) eg Al is Si semi

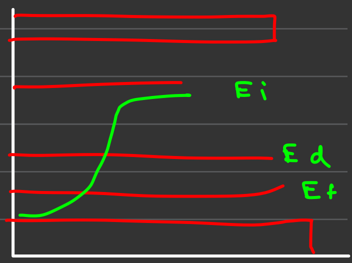
When Al doped with Si . 3 outermost e^- and the 4^{th} extra e^- comes from neighbouring Si creating a hole

It energy lvl is close to top of VB , at high T, e-h pairs are gen due to brking of covalent bonds.

$$E_F = \frac{E_a + E_v}{2} + \frac{kT}{2} \ln\left(\frac{2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2}}{N_a}\right)$$

at $T = 0K$

$$E_F = \frac{E_v + E_a}{kT}$$



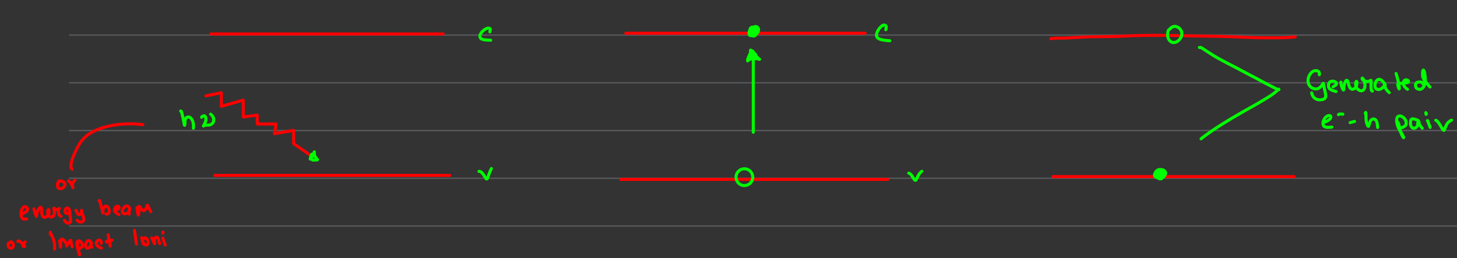
T ↑ , E_F ↑ , acceptor ions ionse ↑ , e⁻-hole pair ↑

further inc in T & tends to behave in intrin man

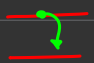
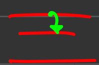
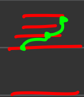
- **Carrier Generation and recombination**

e⁻ in val. band get energy , they absorb it and jump to cond band.

This e⁻ is called thermally generated free e⁻ and hole is generated



The process of falling back of thermally gen free e⁻ from cond band in val band is called recombination of carriers

i) band to band recom 
ii) Trap level (at some lvl then VB) 
iii) Auger (energy released to next lower lvl till VB) 

- Drift and Diffusion

When $\bar{E}$ is applied to semicon e^- & h accquire drift Vel (V_d) $\propto$ to mag of $\bar{E}$

holes move in directn of $\bar{E}$ while e^- move to opp directn

This directional movement of carriers is known as dirft current

$$V_d \propto \bar{E}$$
$$V_d = \mu \bar{E}$$

[μ = mobility of e^- & h]

Current density $J = ne V_d$
$= ne \mu E$

$\therefore$ For e^- : $J_n = ne \mu_n E$

h : $J_p = p e \mu_p E$

$\therefore$ Total drift Current : $J = J_p + J_n$
$= ne \mu_n E + p e \mu_p E$

for Int. semi con $n = p$

$$\therefore J = [ne(\mu_n + \mu_p)] E$$

$$J = \sigma E$$

$$\sigma = ne[\mu_n + \mu_p]$$

Diffusion

Due to thermally induced random motion, charged particles move from high conc. to low conc.

Let, $\Delta n \to e^-$ conc. w dist. 'x'

∴ rate of e^- flow $= \frac{\partial(\Delta n)}{\partial x}$

rate flow of e^- across unit area $= D_n \frac{\partial(\Delta n)}{\partial x}$

$J_n(\text{diffusion}) = e D_n \frac{\partial(\Delta n)}{\partial x}$

$J_p(\text{diffusion}) = -e D_p \frac{\partial(\Delta p)}{\partial x}$

$D_n \to$ diffusion coefficient

-ve signifies that direction of hole current is opposite to the direction of the increasing conc. gradient.

Current density eq^n's

When $\vec{E}$ & conc. gradient is present across a semiconductor, both drift & diffusion current flow.

Total current density is:

$$\therefore \text{net } J_p = J_p \text{ drift} + J_p \text{ diffusion}$$

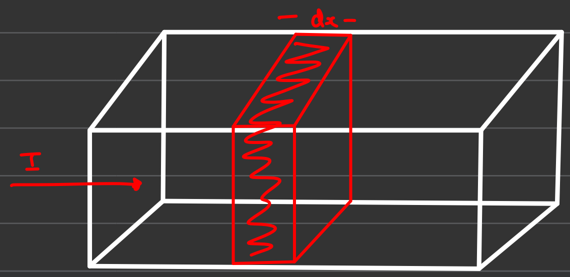
$$= p e \mu_p - e D_p \, d(\Delta p)/dx$$

$$\boxed{\begin{aligned} p &: q = e \\ n &: q = -e \end{aligned}}$$

$$\text{net } J_n = n e \mu_n + e D_n \, d(\Delta n)/dx$$

- **Continuity eq.**

The overall effect when drift, diffusion, generation as well as recombination of carriers in a semicon is expressed by the cont. eq.



$V = A \cdot dx$

The rate of inc in no. of e^-s $\frac{\partial x}{\partial t}$ on the given vol. $(A \cdot dx)$

is given by algebraic sum of :-

Rate of flow in $\to x$

out $\to x + dx$

Generat^n $\to G_n$

Recom $\to R_n$

$$\frac{\partial n}{\partial t} A\,dx = \frac{J_n(x+dx)\,A}{q} - \frac{J_n(x)\cdot A}{q} + (G_n - R_n)\,A\cdot dx$$

$$\frac{\partial n}{\partial t} A\,dx = \frac{J_n(x+dx)\,A}{q}\cdot\frac{dx}{dx} - \frac{J_n(x)\cdot A}{q}\cdot\frac{dx}{dx} + (G_n - R_n)\,A\cdot dx$$

$$\frac{\partial n}{\partial t} A\,\cancel{dx} = \left[\frac{J_n(x+dx)}{q\cdot dx} - \frac{J_n(x)}{q\cdot dx} + G_n - R_n\right] A\,\cancel{dx}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\left[\frac{J_n(x+dx)}{dx} - \frac{J_n(x)}{dx}\right] + G_n - R_n$$

$\because$ $dx \approx 0$; $J_n(x+dx) = J_n(x) + \frac{\partial J_n}{\partial x}\cdot dx$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\left[\frac{\cancel{J_n x}}{\cancel{dx}} + \frac{\partial J_n}{\partial x}\cdot\cancel{dx}/\cancel{dx} - \frac{\cancel{J_n(x)}}{\cancel{dx}}\right] + G_n - R_n$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\left(\frac{\partial J_n}{\partial x}\right) + G_n - R_n \quad \text{[for e}^-\text{s]}$$

$$\frac{\partial n}{\partial t} = -\frac{1}{q}\left(\frac{\partial J_n}{\partial x}\right) + G_n - R_n \quad \text{[for holes]}$$

- **Metal Semicon Junction**

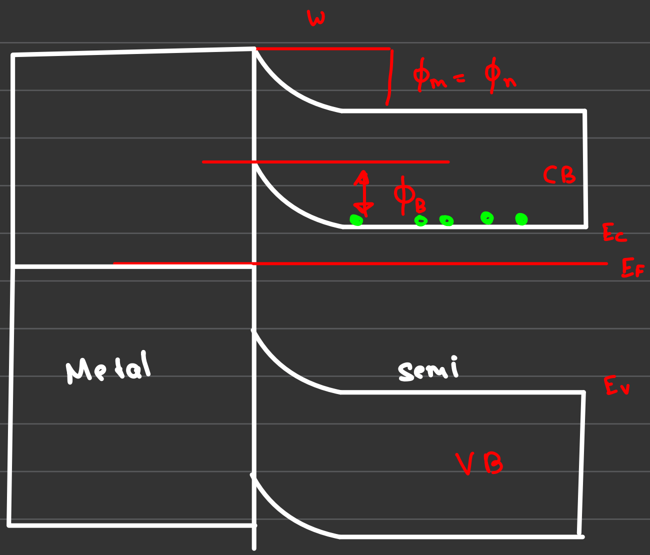
The type of electrical junction in which a metal comes in close contact to semicon mat

i) Rectifying Schottky Junction

Work functⁿ of n-type semicon is less than of metal

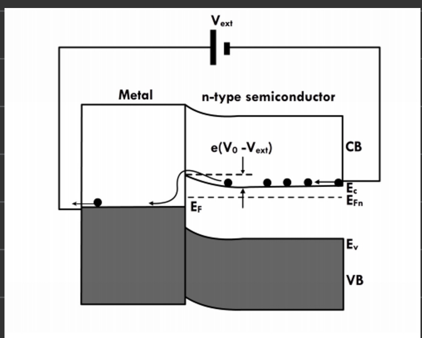
$$\phi_m > \phi_s$$

when the two come in contact, e- flow frm semi to metal until E_f of both becomes equal so metal (-ve) & semi (+ve) as Potential barrier of $\phi_m - \phi_s = eV$

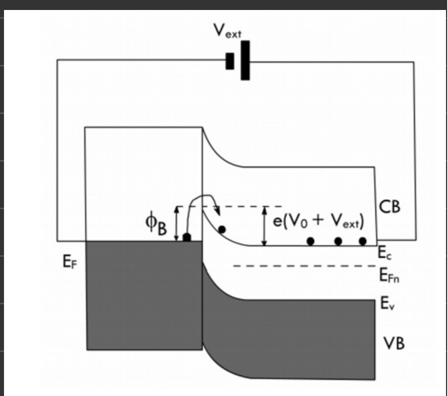


When potential is applied :-

c-1] N-type sem (+ve) & metal (-ve))
height of Pot. barr ↑ by (Vs + V) for semi
Metal remains unchanged
Reverse biased



c-2] sem (-ve) & met (+ve)
height ↓ by (Vs - V)
Metal remain unchanged
forward biased

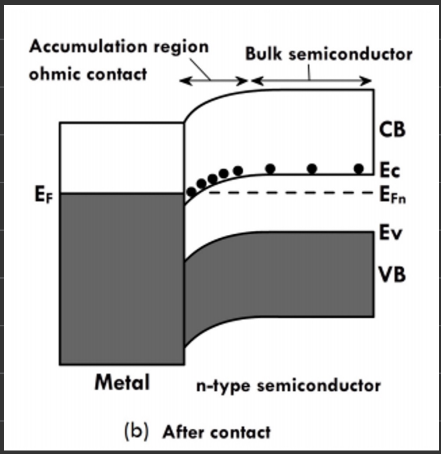


ii) Non- Rectifying Ohmic Junction

when ϕ of metal is less then n-type semi

$\phi_m < \phi_s$

When the two come in contact, e^- flow from metal to semi until E_F is equal, metal (+ve) & sem (-ve) at pot. bar. $\phi_s - \phi_m = eV$



(b) After contact

when voltage applied

C-1] sem (+ve) & met (-ve) → no chang to pot. barrier

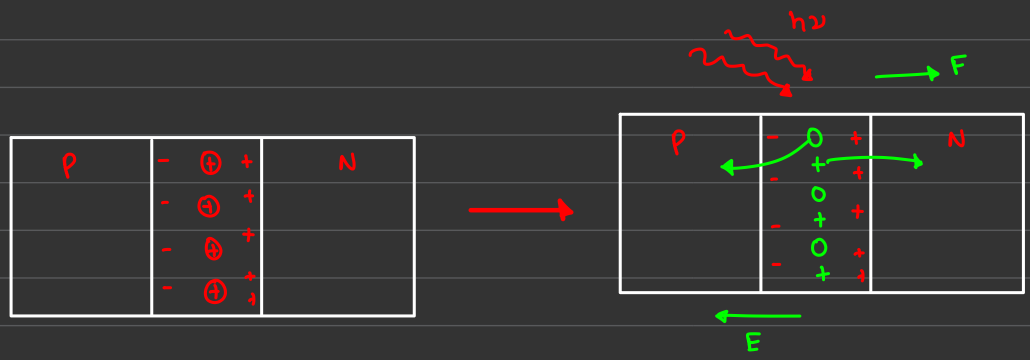
C-2] -ve +ve → "

i.e I ∝ Applied Voltage & it's called ohmic contacts

- ## Photodiode

In a photodiode, the incident optical signal generates e-h pair that gives rise to a photocurrent across PN junc. It is generated in RB cond^n

· **Working**



When light of photon energy $\geq E_g$, the photons are absorbed.

This results in release of e^- from atom structure, thus free e^- & holes are gen both in n & p region.

They are swept across the junc due to $\vec{E}$ in depletion regio^n

Due to direct^n of $\vec{E}$ from n to p, hole flow in same direct^n while e^- flow in opp i.e to n region.

Thus, they constitute the photocurrent I_L as its direct^n is opp to that in FB diode

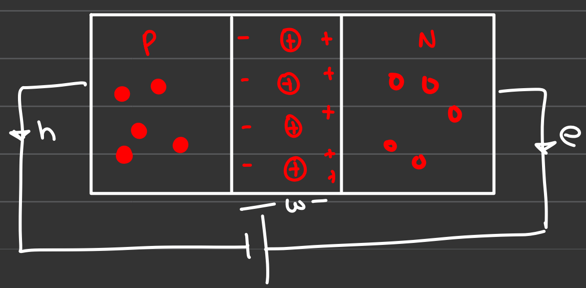
$$\therefore \quad I_L = I_{nL} + I_{pL} + I_d$$

Doubt

The photon absorption intensity $\propto$ photon energy

This process is known as Inner Photoelectric Effect

$$I = e\underbrace{G}_{\text{gen rate}}(\underbrace{L_p + L_n}_{\text{dist of dep region where e \& h are gen}} + \overset{\text{width}}{w})\underset{\text{Area}}{A}$$



- LED

LED (Light emitting diode) are P-N junctions that can emit spontaneous radiation in UV, Vis, IR regions.

This device converts elec to optical energy under FB condⁿ

- Principle

Due to FB, maj cars from n & p regions cross the junc & become min cars

i.e e → maj in n & min in p
h → min in n & maj in p

This phenomenon is called minority carrier injection

If the biasing voltage is further inc, the xs min car diffuse away from junc & recombine with maj cars and emit light

In p → e + holes
min maj

n → e + holes
maj Min

This is called radioactive recombination.

It leads to photon emission w energy equal to $h\nu$

Rad. Recom ∝ Carrier Injectⁿ rate

$$I = I_0 \left[\exp\left(\frac{eV}{\beta KT}\right) - 1 \right]$$

Total curr Sat. curr β (1 - 2)

- Types

Leds are constructed in such a way that the light emitted by rad. recomb shld escape the structure

1) Surface Emitters : designed to reflect light from bottom edge to top surface to enhance output intensity.

2) Edge Emitters : Here light emission is relatively direct from one active region or deplition region.

- Quantum Efficiency

Internal quantum efficiency is 100 % but external dec becoz the emitting light strikes the surface at an angle greater that critical angle causing TIR and gets trapped within

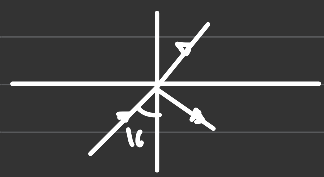
for TIR

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

air

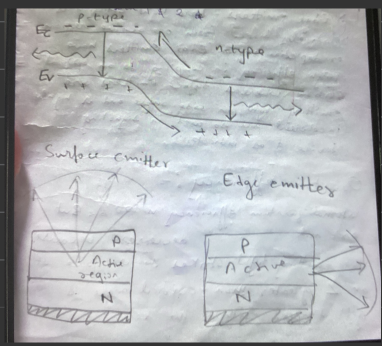
eg $n_1 = 3.5$

$$\theta = \sin^{-1}\left(1/3.5\right) = 16^\circ$$



The ray strikes the surface above 16° so it suffers TIR & is ref back

Note To improve external efficience loss caused by bulk absorption , hemispherical domes made of plastic are fused at the surface.



- **OLED**

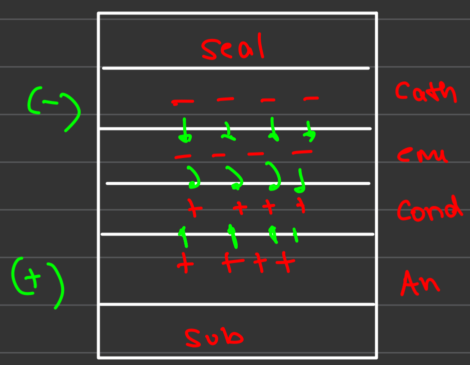
A type of LED where electroluminescent layer is a film of org. comp which can emit light in response to elec. current.

- **Structure**

Top & bottom layers are of protective glass / plastic (seal & substrate)

In b/w there Cathod (inject e-) & Anode (ejects holes)

In b/w those, there is an emissive & conductive layer



OLED emmit light thru a process called electro phosphorescence

- **Working**

A power supply applies V across OLED

Current flows frm Cath to Ano, Cath gives e^- to emm layer and anode removes e- from cond layer

At the boundary the emm & cond e^- find holes & fills emitting energy as photon of light

Intensity of light ↑, current ↑

Types of OLED

↳ Passive matrix OLED - have strips of (PMOLED)

of cathode, an organic layer & strips of ~~antode~~ anode that run perpendicular

Advantage - easy fabrication, suitable for small screen.

↳ Active matrix OLED - organic layer is b/w larger layer of cathode & anodes

Advantage - Less power requirements., suitable for large screen.

Advantages :-

less expensive, thinner compared to LED, less in weight, flexible, consumes less power, response time is 2x faster than LED.

Disadvantages :-

organic molecules are sensitive to water display does'nt last as ~~too~~ long.

Application :-

wrist watches, head sets, TV, camera, MP3 players, etc.