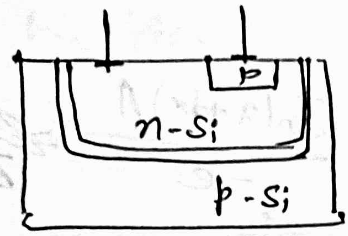
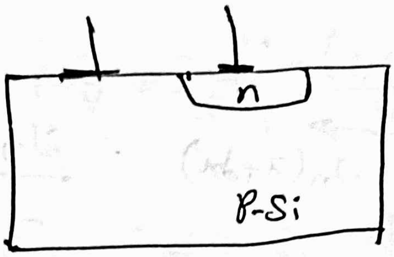
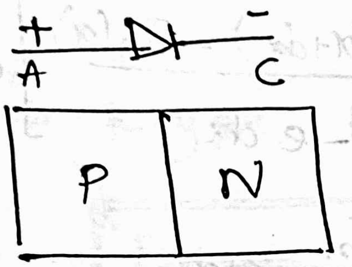
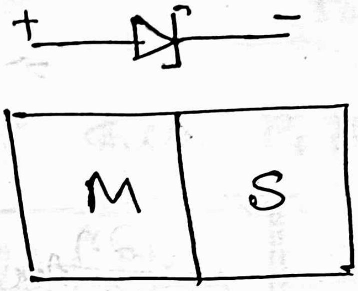
PN junction :-



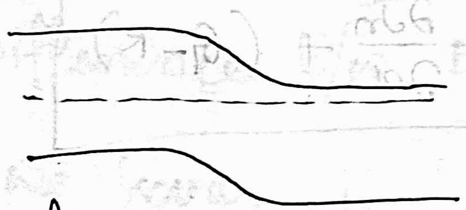




PN junction

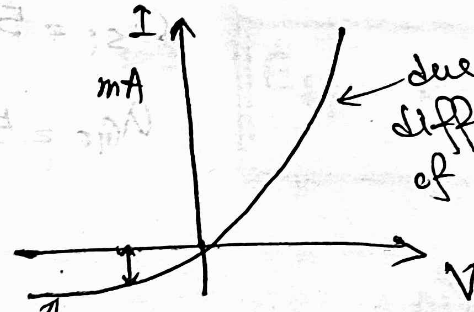


Schottky junction



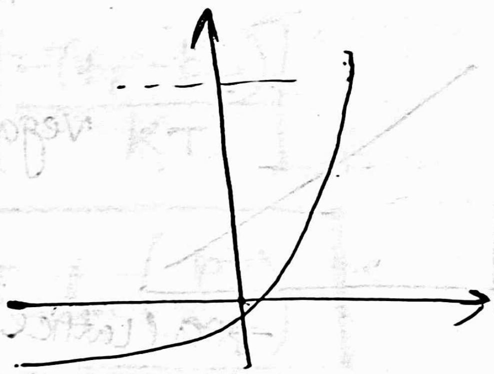
→ Thermal field emission

→ drift-diffusion mechanism



due to diffusion of e^-/hole

due to drift of minority carrier.



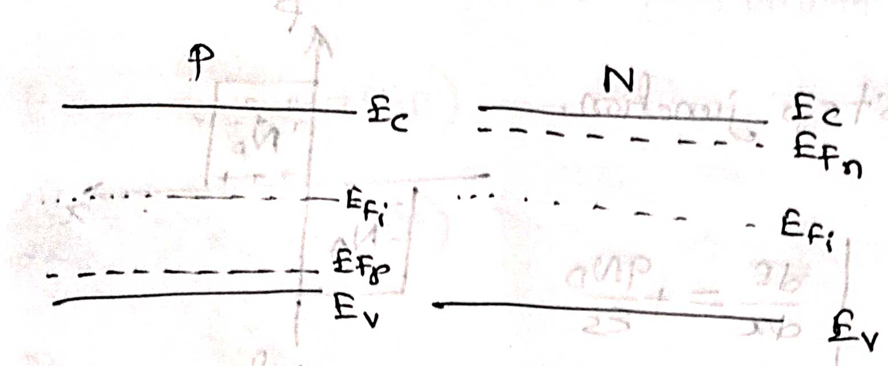
→ only drift mechanism

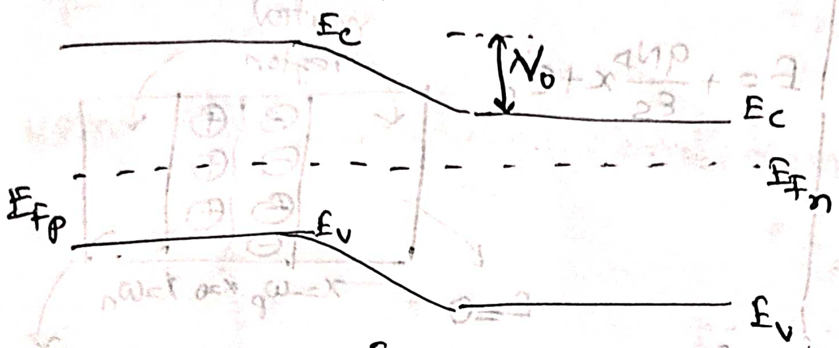
→ Ohomic

Tunnel Diode

→ Tunneling mechanism

→ very fast switching application.





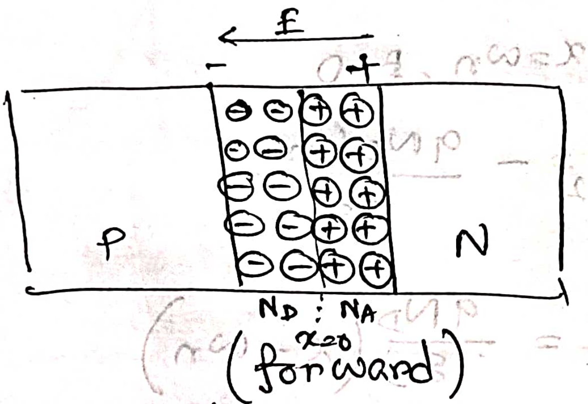
$$\boxed{V_0 = \frac{KT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)}$$

10^{15} 10^{13} 10^{20}

$\boxed{V_0 = 0.4}$

V_0 can't be greater than E_g.

$E_g = 1.12\ V$



If we apply voltage, then $V_0 \longrightarrow V_0 - V$; $V_0 < V$ ~~V_0~~

If we apply <u>reverse</u> voltage, then $V_0 \longrightarrow V_0 + V$

<u>Starting point:</u>

Gauss's law, $\nabla \cdot E = \frac{\rho}{\varepsilon_s}$; $\varepsilon_s = \varepsilon_{s_i} \varepsilon_0$

$\rho = q(p - n + N_D - N_A)$

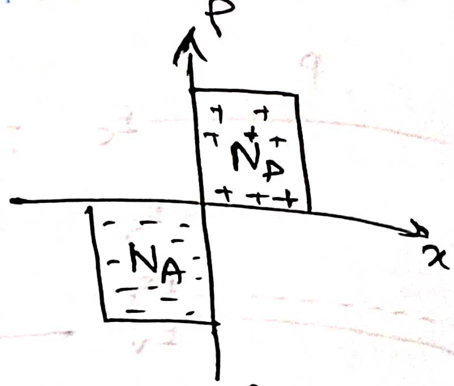
In 1D, $\frac{dE}{dx} = -\frac{qN_A}{\varepsilon_s}$, in p type

$\frac{dE}{dx} = +\frac{qN_D}{\varepsilon_s}$ in n-type

<u>1st assumption:</u>

→ In depletion region there is no free charge ~~free~~ carriers. $[n = p = 0]$

2nd assump: step junction.



$$\frac{dE}{dx} = -\frac{qN_A}{\varepsilon_s}$$

$$\Rightarrow E = -\frac{qN_A}{\varepsilon_s}x + C_1$$

at $x = -\omega_p$, $E = 0$

$$0 = \frac{qN_A\omega_p}{\varepsilon_s} + C_1$$

$$\Rightarrow C_1 = -\frac{qN_A\omega_p}{\varepsilon_s}$$

$$\therefore E = -\frac{qN_A}{\varepsilon_s}(x + \omega_p)$$

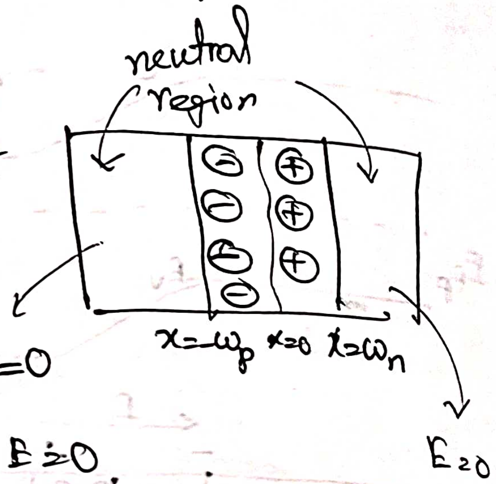
$$\frac{dE}{dx} = +\frac{qN_D}{\varepsilon_s}$$

$$E = +\frac{qN_D}{\varepsilon_s}x + C_2$$

at $x = \omega_n$, $E = 0$

$$C_2 = -\frac{qN_D\omega_n}{\varepsilon_s}$$

$$E = \frac{qN_D}{\varepsilon_s}(x - \omega_n)$$



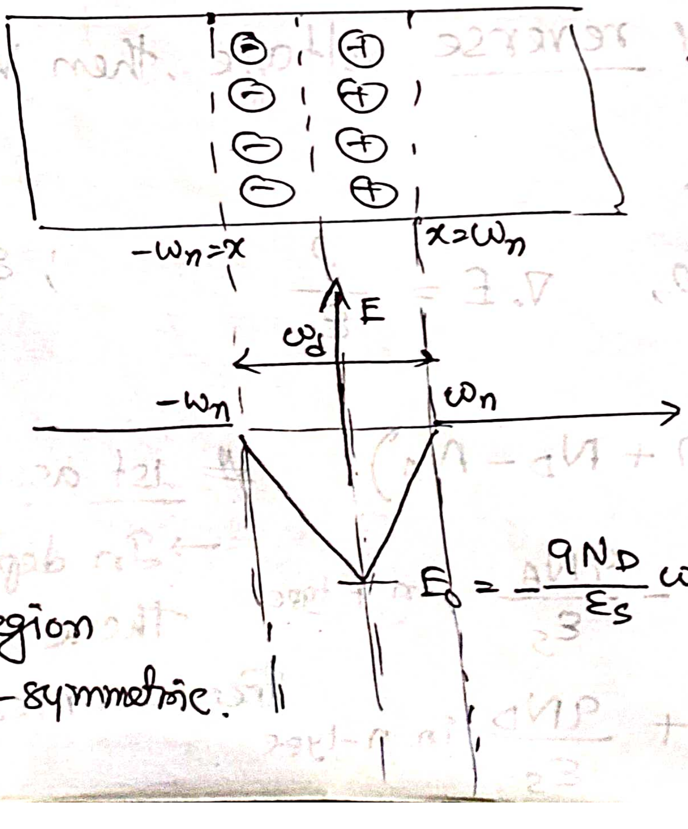
3nd assumption

→ E=0 in neutral region.

→ p^+n

→ n^+p

→ $p^{++}n$



as $N_A = N_D$

$$E_0 = -\frac{qN_D}{\varepsilon_s}\omega_n = -\frac{qN_A}{\varepsilon_s}\omega_p$$

→ Depletion region can be anti-symmetric.

$$E = -\frac{qN_A}{\varepsilon_s}(x+\omega_p)$$

$$\Rightarrow -\frac{dV}{dx} = -\frac{qN_A}{\varepsilon_s}(x+\omega_p)$$

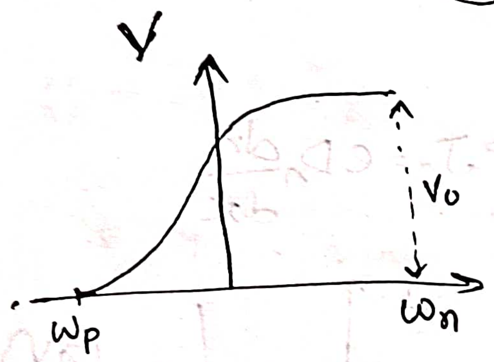
$$\Rightarrow V_p = +\frac{qN_A}{2\varepsilon_s}\omega_p^2$$

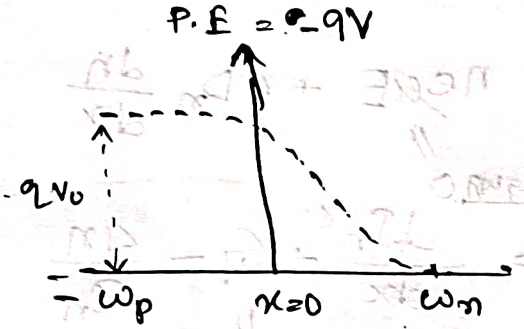
$$E = \frac{qN_D}{\varepsilon_s}(x-\omega_n)$$

$$\Rightarrow -\frac{dV}{dx} = \frac{qN_D}{\varepsilon_s}(x-\omega_n)$$

$$V_n = +\frac{qN_D}{2\varepsilon_s}\omega_n^2$$

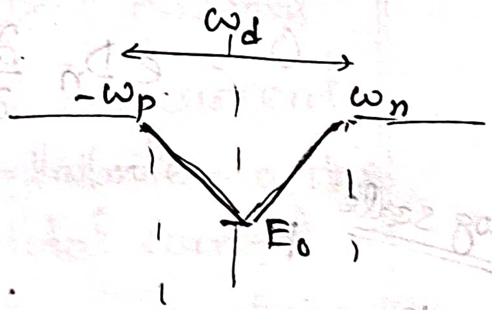
using the boundary condition at $x=0$, $V=0$



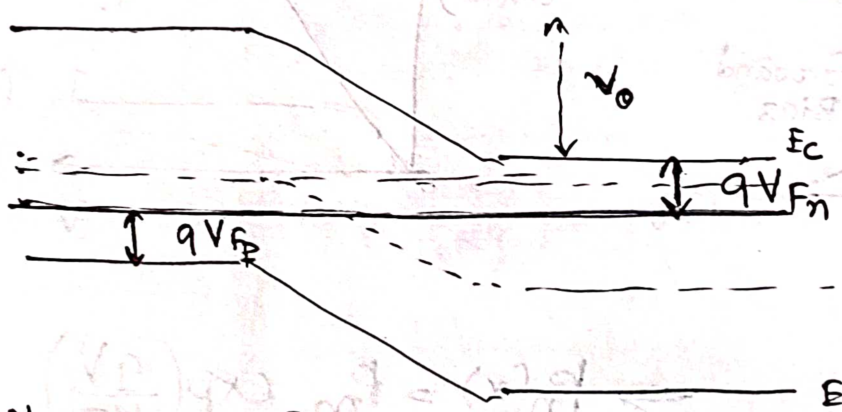


potential curve

$$\boxed{V_0 = \frac{q}{2\varepsilon_s}\left(N_A\omega_p^2 + N_D\omega_n^2\right)}$$



$$\boxed{V_0 = \frac{1}{2}\omega_d E_0}$$



$$N_D = n_i \exp\left[\frac{E_F - E_{F_i}}{KT}\right]$$

$$= n_i \exp\left[-\frac{qV_{F_n}}{KT}\right] \Rightarrow \boxed{V_{F_n} = -\frac{KT}{2}\ln\left(\frac{N_D}{n_i}\right)}$$

$$N_A = n_i \exp\left[\frac{E_{Fi}-E_F}{KT}\right]$$

$$\boxed{V_{Fp} = \frac{KT}{q}\ln\left(\frac{N_A}{n_i}\right)}$$

I-V characteristics.

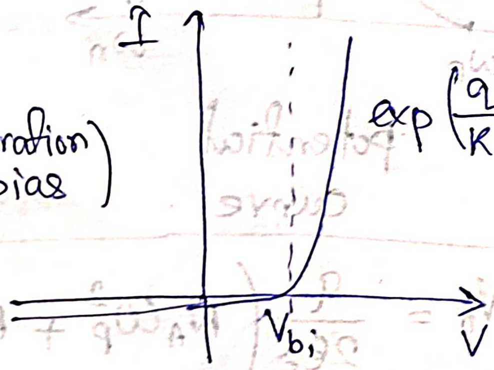
$$J_n = n e\underbrace{\mu E}_{=0} + eD_n\frac{dn}{dx} \quad \Rightarrow J_n = eD_n\frac{dn}{dx}$$

Continuity equn.

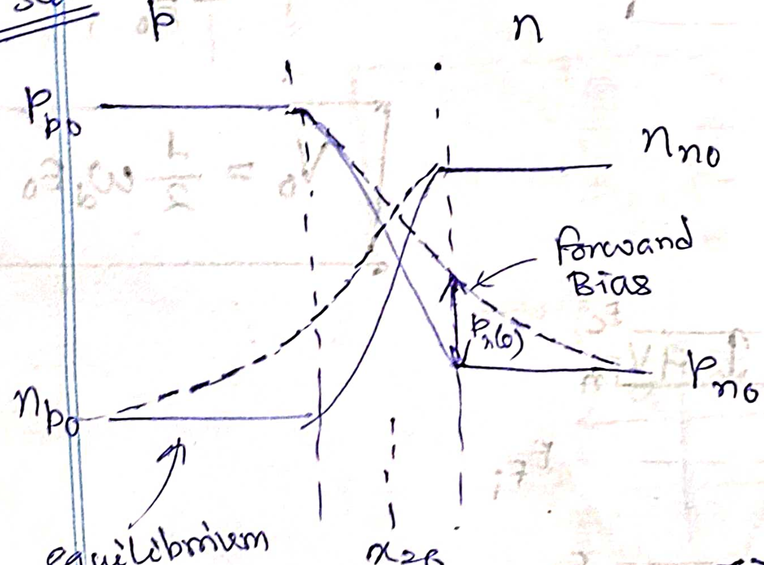
$$\underbrace{\frac{\partial n}{\partial t}}_{=0} = \frac{dJ_n}{dx} + \underbrace{G}_{=0} - \frac{\Delta n}{\tau_n}$$

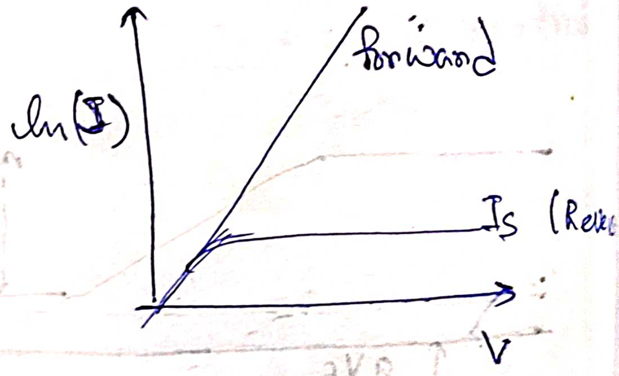
(no extra generation only bias)

$$0 = eD_n\frac{\partial^2 n}{\partial x^2} - \frac{\Delta n}{\tau_n}$$



log scale





$$\Rightarrow p_n(x) = p_{no}\exp\left(\frac{qV}{KT}\right)$$

Fig: Forward Bias Picture

\# minority carrier injected from p-side to n-side

$$-\frac{1}{q}\frac{dJ_p}{dx} - \frac{p_n}{\tau_{p_n}} = 0 \quad , \quad J_p = -q D_p \frac{dp}{dx}$$

$$\Rightarrow \boxed{D_p \frac{d^2 p}{dx^2} - \frac{p_n}{\tau_p} = 0} \quad , \quad \Delta p_n(x) = \Delta p_n(0)\exp\left(-\frac{x}{L_p}\right)$$

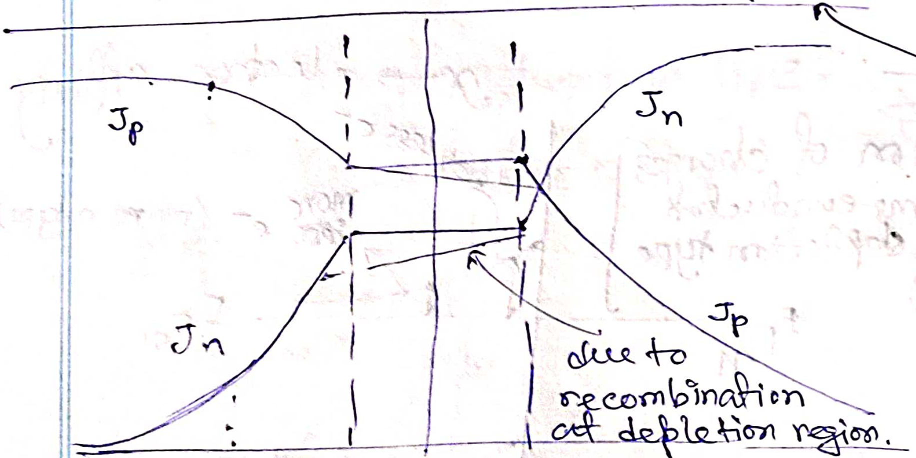
where, $\Delta p_n = p_n - p_{n0}$

$$L_p = \sqrt{D_p \tau_p}$$

$$J = J_n + J_p$$

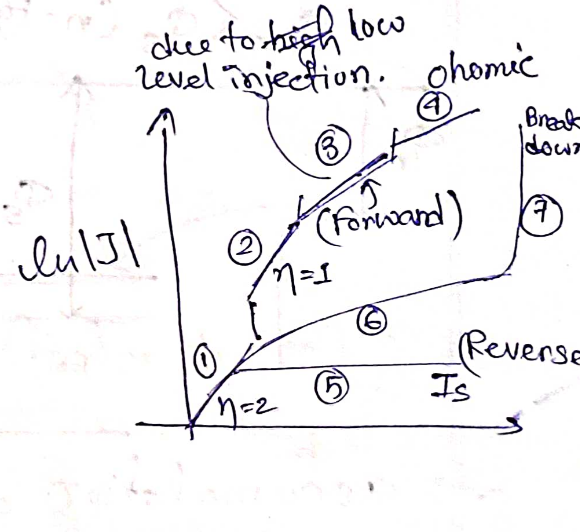
$$= q\left[\frac{D_p p_{n0}}{L_p} + \frac{D_n \cdot n_{p0}}{L_n}\right]\left[\exp\left(\frac{qV}{KT}\right) - 1\right]$$

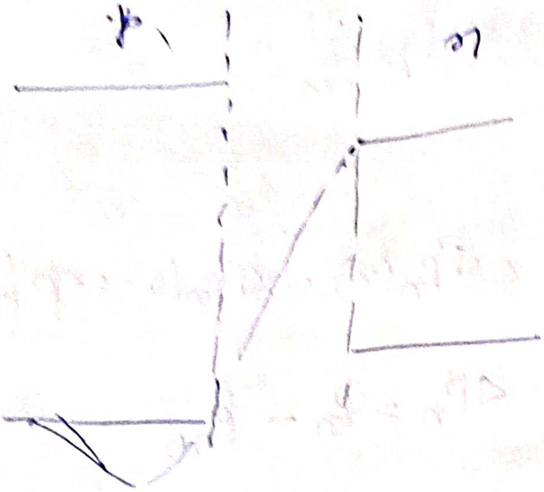
$J = J_n + J_p$ ← Total current constant



This two current contribute to the total current.

$$\boxed{J = J_s \exp\left[\left(\frac{qV}{KT}\right) - 1\right]}$$

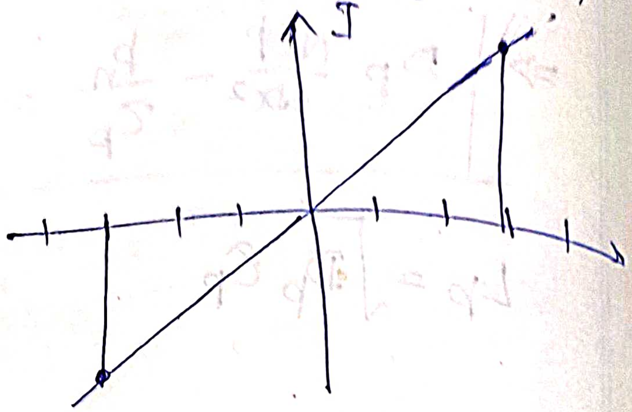




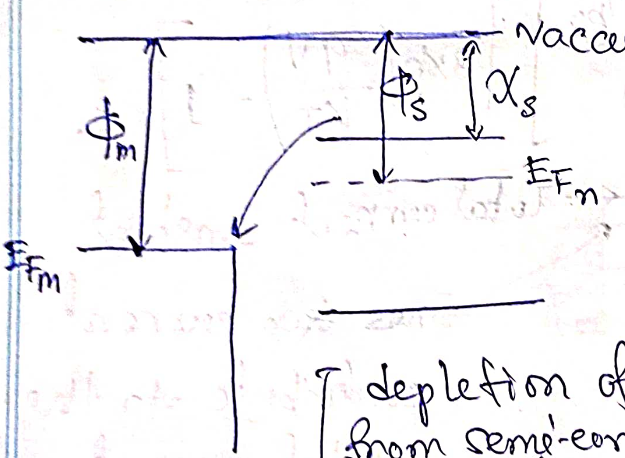
Reversed Bias

Ohomic junction

↳ reversible junction



symmetric junction.

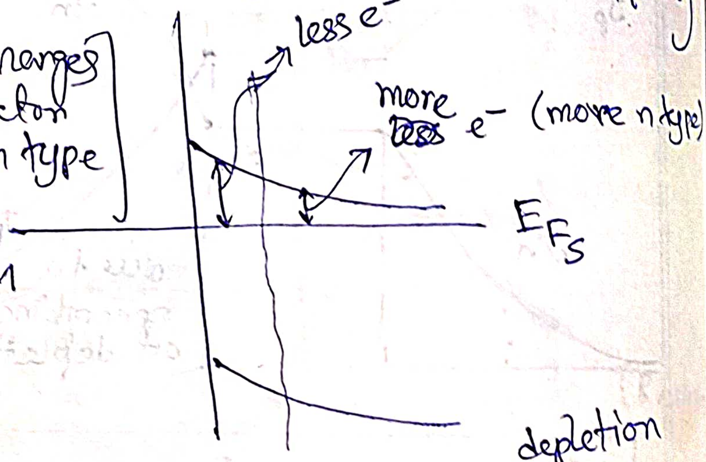


vaccume level [zero K.E, just bring the e^- from metal, that level is vaccume level.]

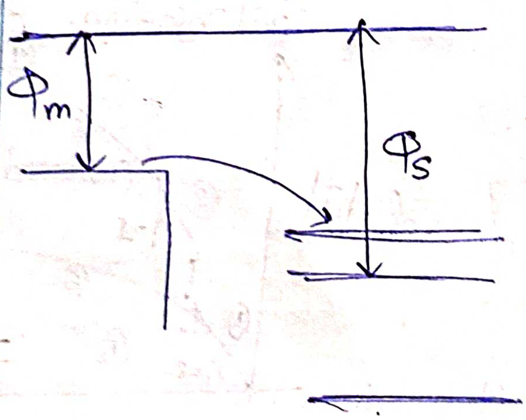
$\chi \rightarrow$ electron affinity

[depletion of charges from semi-conductor depletion type]

$\Phi_m < \Phi_s$ (n-type)



M-S junction



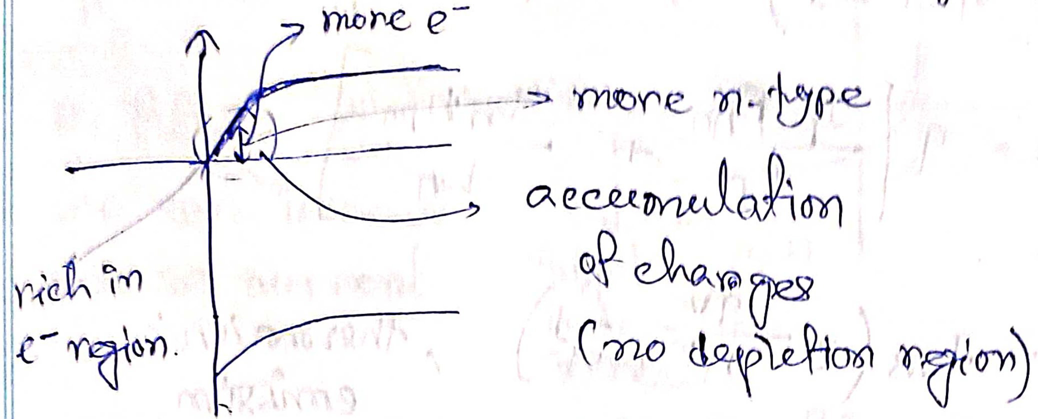
Schotky barrier junction.

→ accumulation of charges in semiconductor → (ohomic junction)

Any type of accumulation make by junction called Ohomic junct.

\# Accumulation type → Ohmic junction.

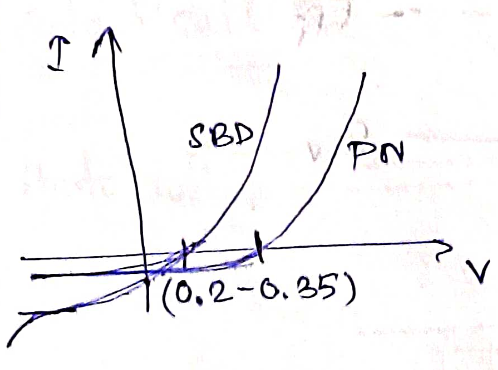
\# depletion type → Schottky junction.

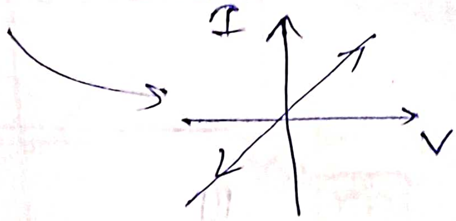


Next

MS Junction

- → Schottky Barrier type $\phi_m > \phi_s$ n-type, $\phi_m < \phi_s$ p-type
  (depletion type) [unipolar type]
- → Ohmic Junction type $\phi_m < \phi_s$ n-type, $\phi_m > \phi_s$ - p-type
  (accumulation type)





SBD → majority carrier device (faster device)
↳ High reverse bias current.

PN → minority carrier device
↳ low reverse bias current

PN junction

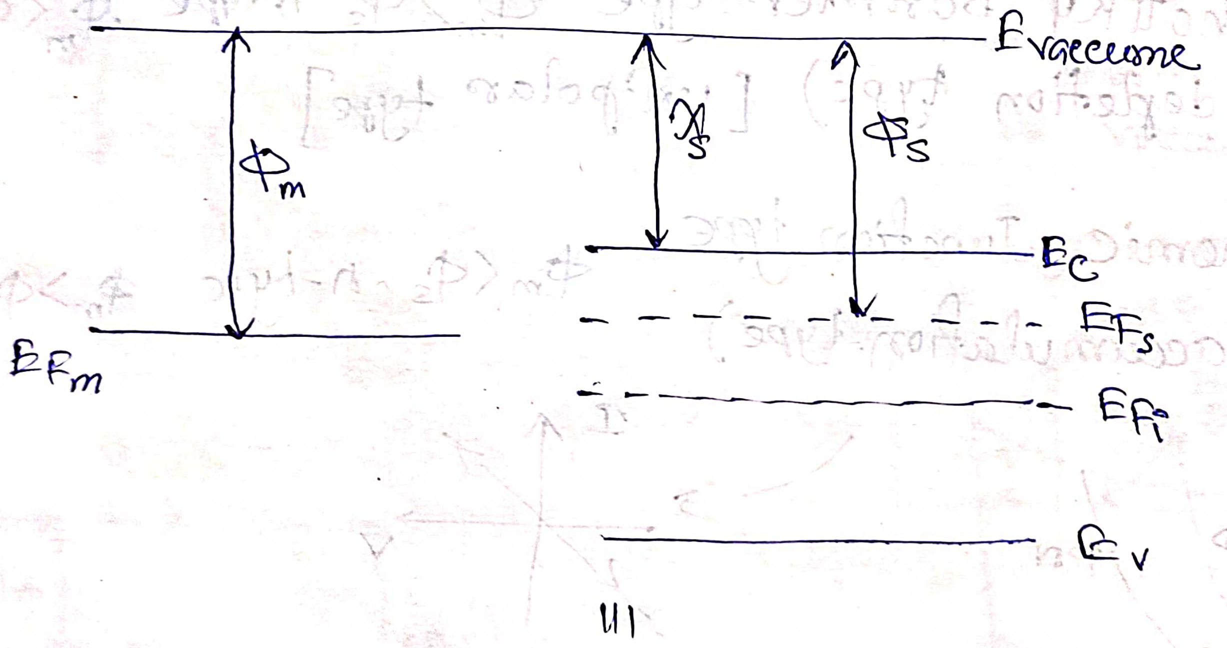
$$I = I_S\left(e^{\frac{qV}{\eta KT}} - 1\right)$$, Drift diffusion

$$\hookrightarrow I_S = q\left[\frac{D_p\, p_{n0}}{L_p} + \frac{D_n\, n_{p0}}{L_n}\right]$$

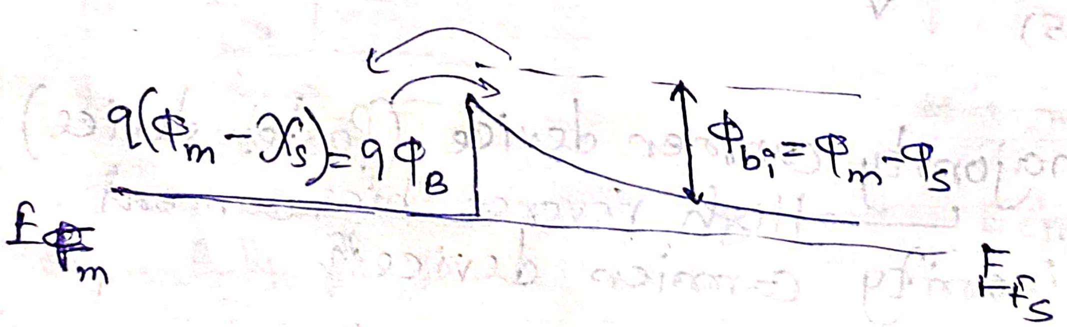
SBD

$$I = I_{SB}\left(e^{\frac{qV}{\eta KT}} - 1\right)$$, thermaionic emission

but $I_{SB} = AT^2 e^{-\frac{q\Phi_B}{KT}}$



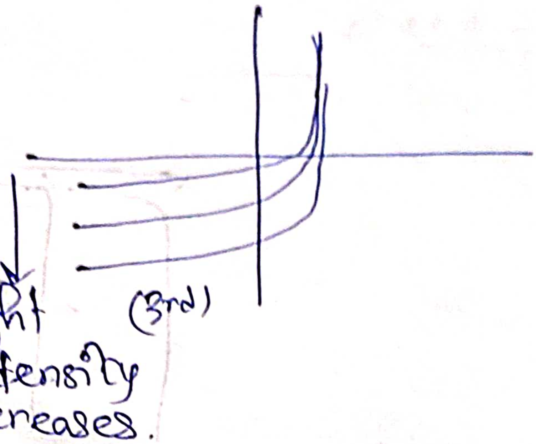
|||



Application: of PN junction:

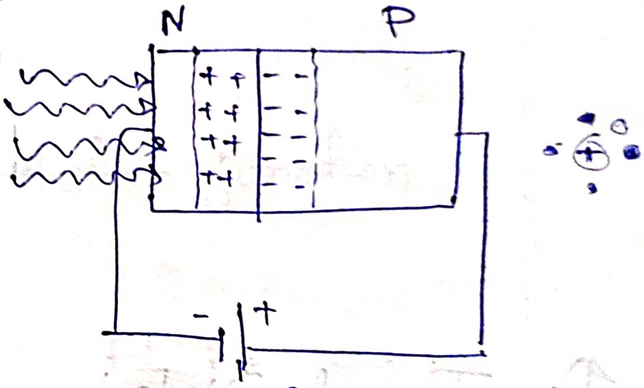
1) photodetector:

By falling light on R.B PN junc. we can increase reverse current.



procedure to ~~falling~~ fall light on PN junction

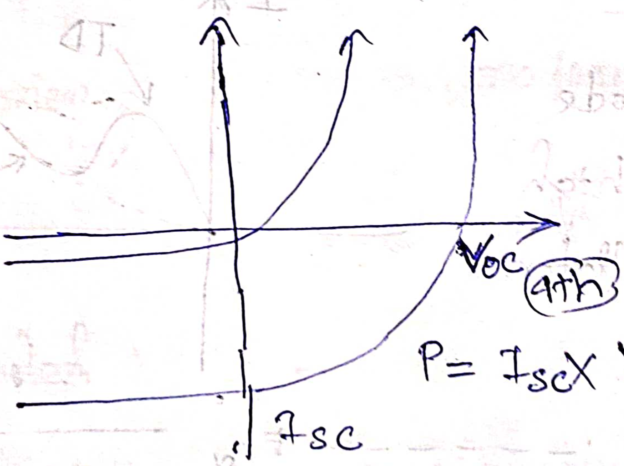
photon → e^-
photon → hole.



Reverse biased diode.

2) Solar cell:

Photo voltage

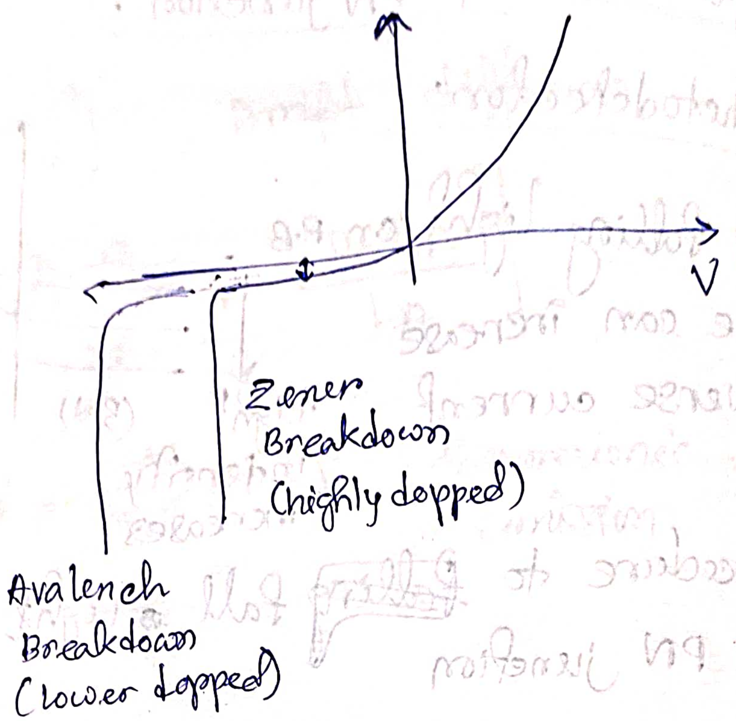


No Bias on PN Junction.

$P = I_{sc} \times V_{oc}$

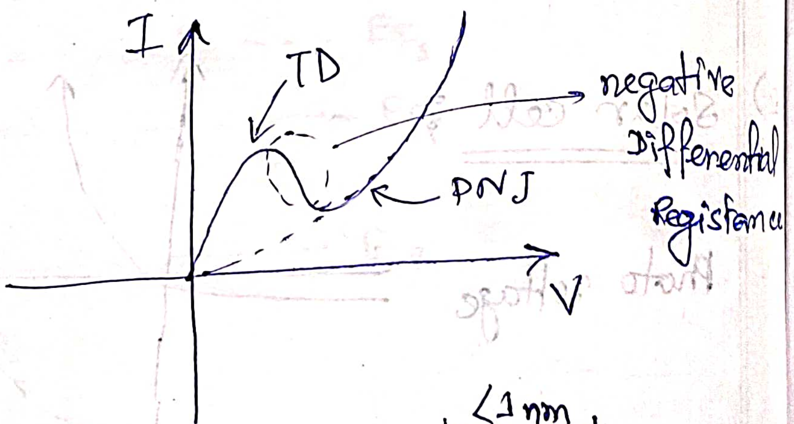
After falling the light, the light make the PN Junction forward bias. It creates power.

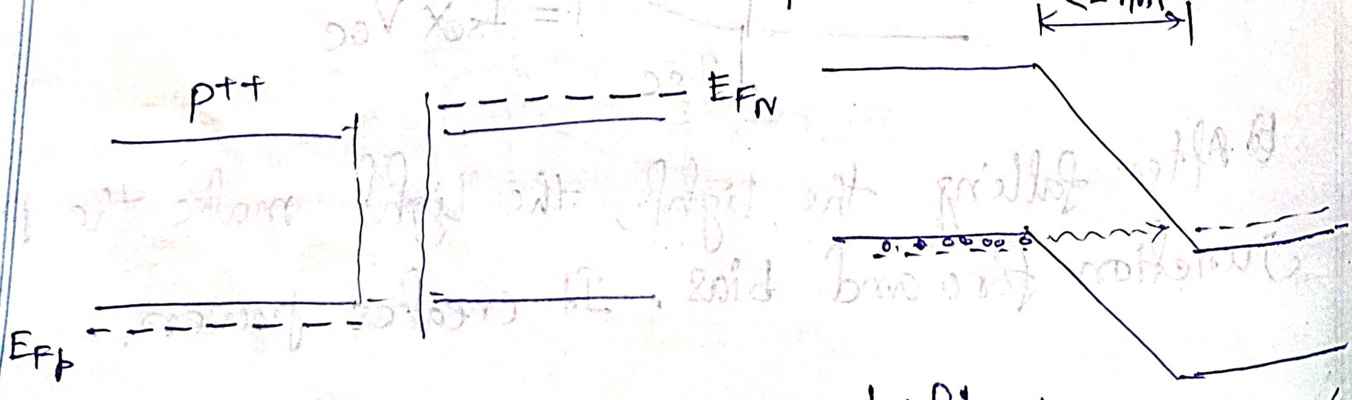
3) Zener diode :



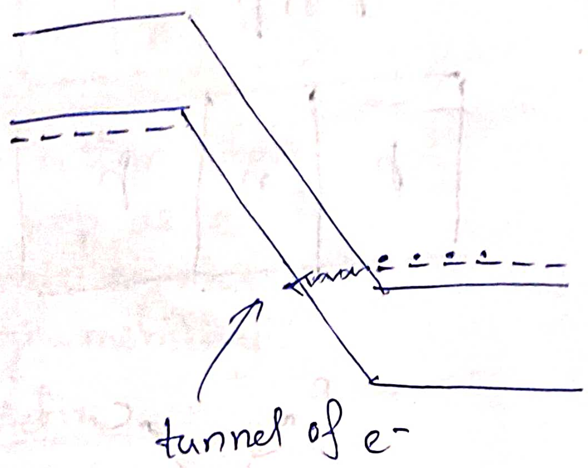
4) Tunnel Diode :

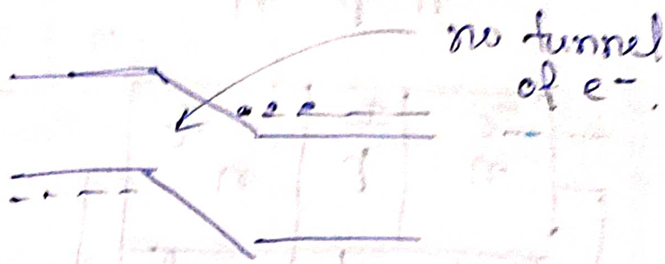
using tunnel diode we can make high frequency oscillator.





highly dopped → thin (one layer) depletion region.



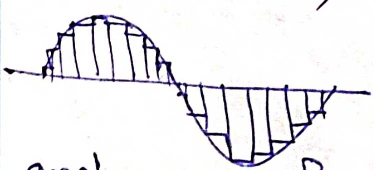


we get current as we increase bias.

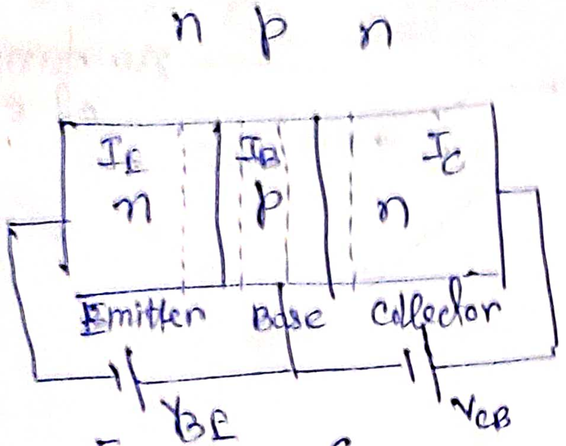
Next

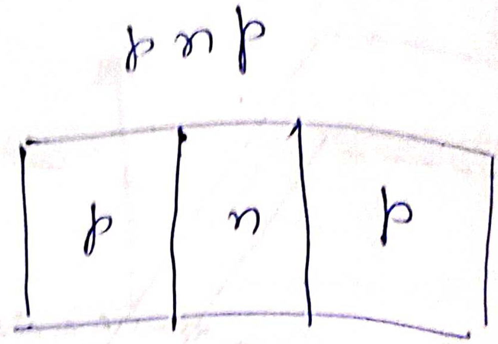
Two junction ⇒ Active junction

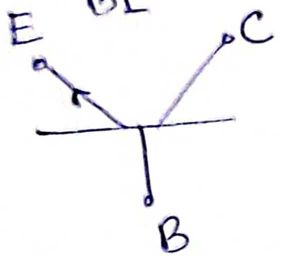
BJT	FET
→ minority carrier device	→ majority carrier device
→ Bipolar	→ unipolar
→ Current controled	→ voltage controled
→ discrete device (analog)	→ integrates device ⇒ Digital
	→ useful for communication, signal transfer

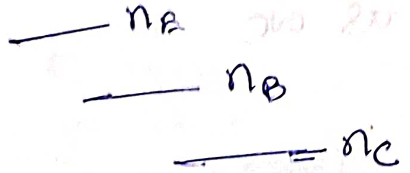


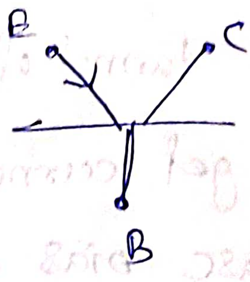
analog is best but in case of communication digital is good.

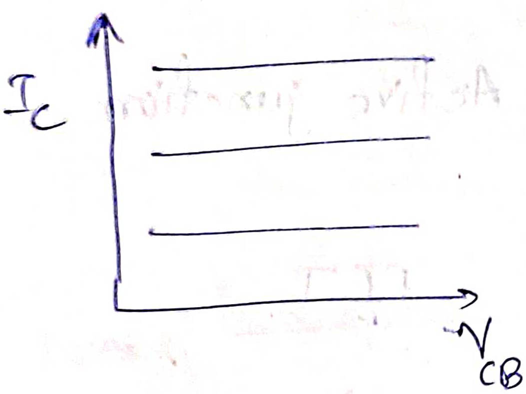












$$\alpha = \frac{I_C}{I_E} \approx 0.99 - 1.0$$

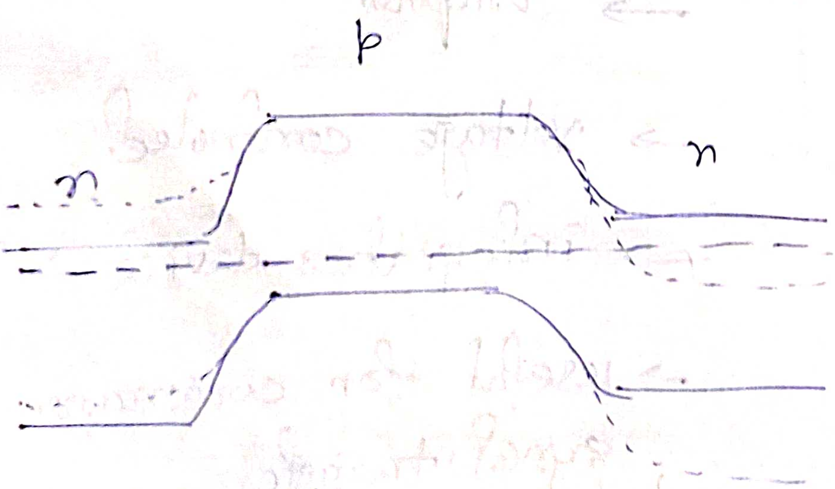
$$\beta = \frac{I_C}{I_B} \approx 99 - 100$$

I_C is controled by I_B not by V_{CB}

Emitter injection efficiency.

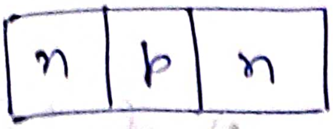
$$\gamma_E = \frac{I_{En}}{I_{En} + I_{Ep}}$$

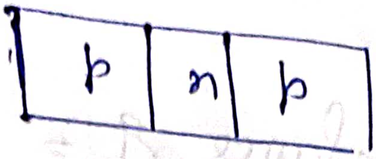
I_{Ep} → come from p side (Base)



Graded system can help to get less dependence on I_B.

Next

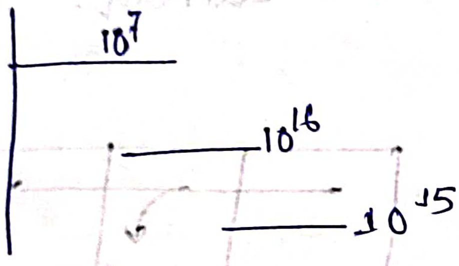




→ better than pnp as e^- is main carrier with high mobility.

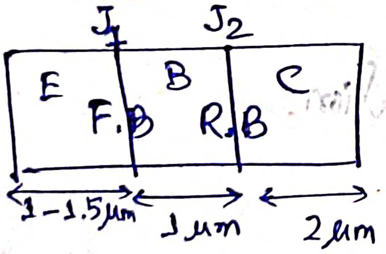
Active

① doping,



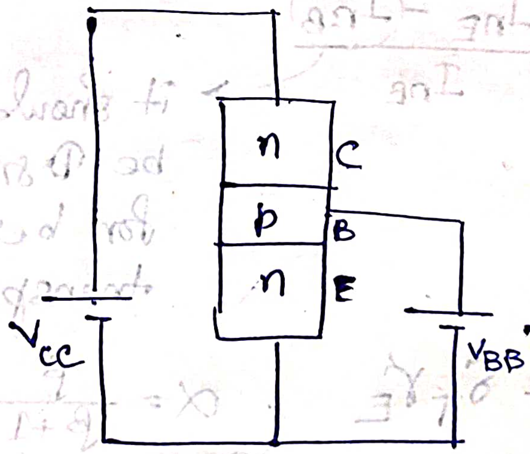
② base region small enough.

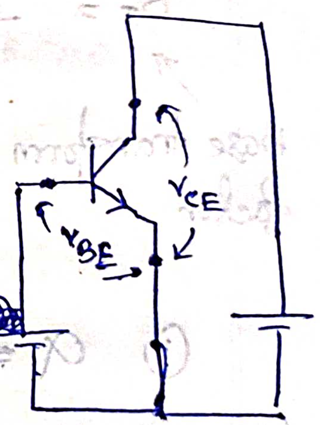
③



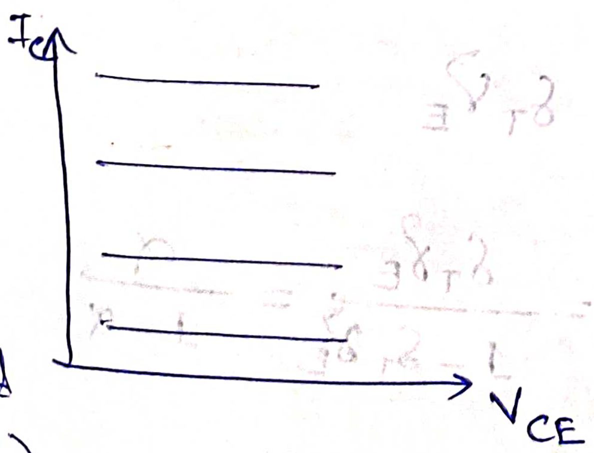
Three configuration

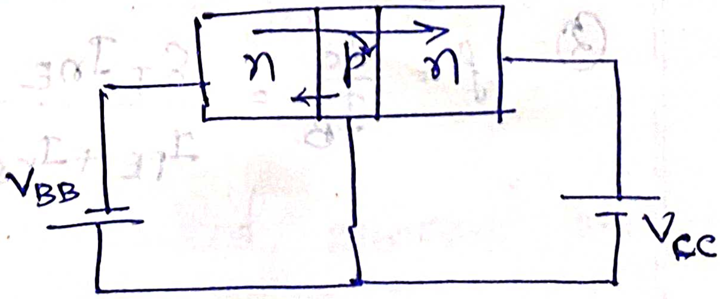
	I	V
CB →	×	✓
CE →	✓	✓
CC →	✓	×





CE config.





It should be high.

$$\gamma_E = \frac{I_{nE}}{I_{nE} + I_{PE}}$$

→ it should be minimum (reverse current)

বিদ্যালয় শিক্ষা দপ্তর, পশ্চিমবঙ্গ সরকার

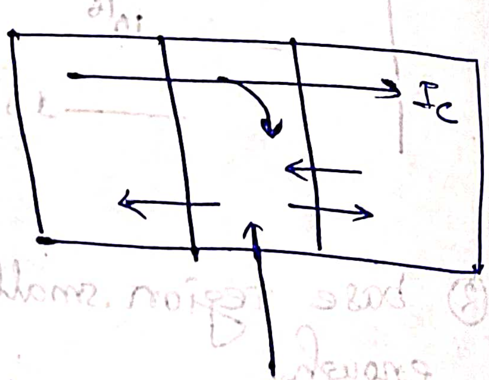
δ_T,

Transconductance, $g_m = \frac{\partial I_c}{\partial V_{BE}}$ → it should be very high.

$I_E = I_{nE} + I_{pE} + I_{r.d}$ → in the depletion region there is some recombination, due to this there is some current.

$I_C = I_{nE} - I_{r.B}$ → recombination in base.

$I_B = I_{pE} + I_{r.B} + I_{r.d}$



$$\delta_T = \frac{\overbrace{I_{nE} - I_{r.B}}^{I_c}}{I_{nE}}$$

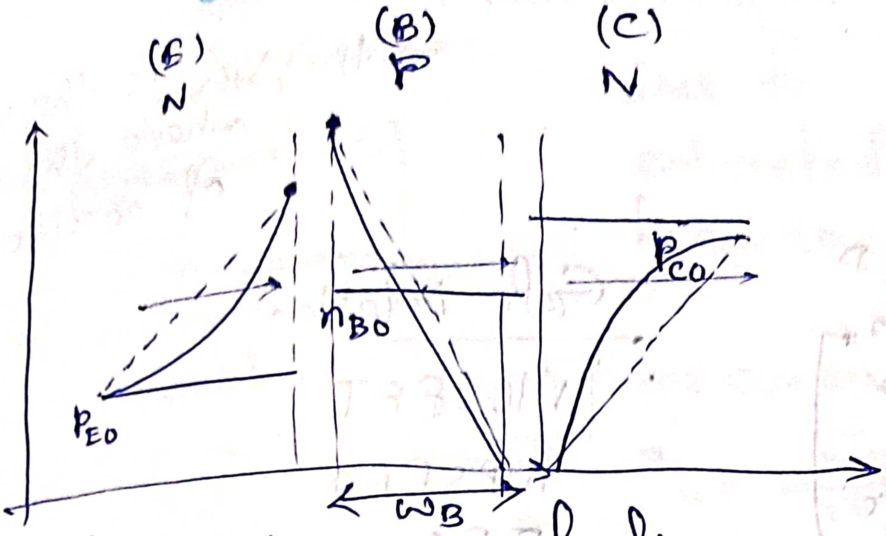
→ it should be small for best transportation.

Base transform factor

① $\alpha = \delta_T \gamma_E$, $\alpha = \frac{\beta}{\beta+1}$

$$\alpha = \frac{I_c}{I_E} = \frac{\delta_T I_{nE}}{I_{nE} + I_{pE}} = \delta_T \gamma_E$$

② $$\beta = \frac{I_c}{I_B} = \frac{\delta_T I_{nE}}{I_{pE} + I_{r.B}} = \frac{\delta_T \gamma_E}{1 - \delta_T \gamma_E} = \frac{\alpha}{1-\alpha}$$



minority carrier concentration.

zero → equilibrium

for R.B Junc.

$$n_B = n_{B0} \exp\left(\frac{qV_{BC}}{KT}\right) \approx 0$$

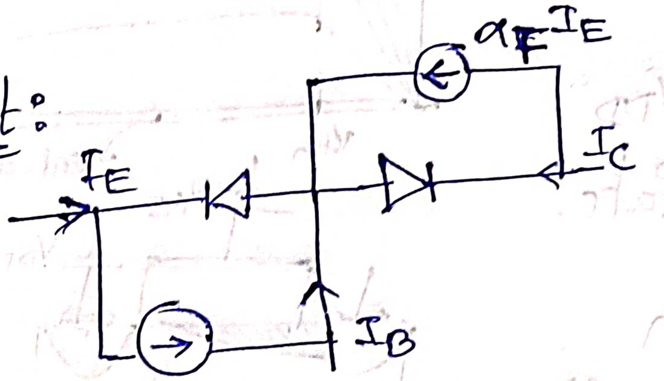
$$p_C = p_{C0} \exp\left(\frac{qV_{BC}}{KT}\right) \approx 0$$

Gummel ~~..~~. Pol - model

$$n_B = n_{B0} \exp\left(\frac{qV_{BE}}{KT}\right)$$

$$p_E = p_{E0} \exp\left(\frac{qV_{BE}}{KT}\right)$$

Circuit:



forward active mode.

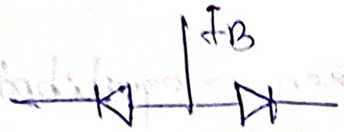
Reverse active mode

Eber. Moll model

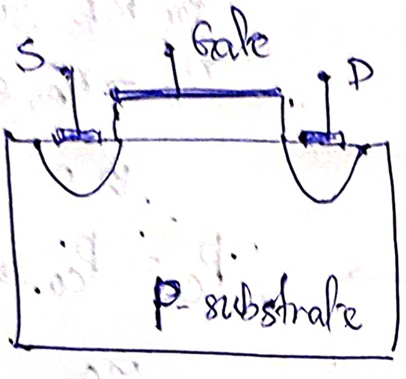
Next

FET: Field effect Transistor

- Unipolar
- Voltage controlled, current source



→ V_{th} is the voltage where the pinch off occure.



$V_G = V_{th}$

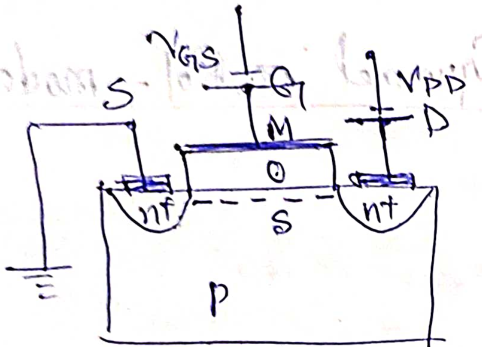
Gate isolation

$\boxed{\text{MOSFET}}$

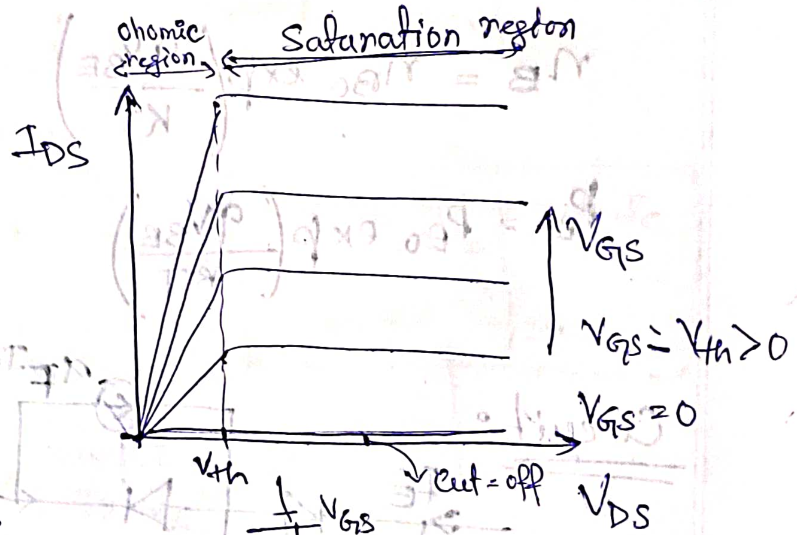
MESFET

JFET

MISFET

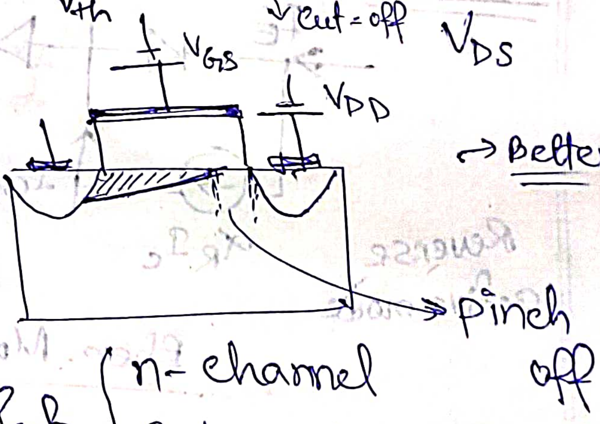


n-channel (E-MOSFET)

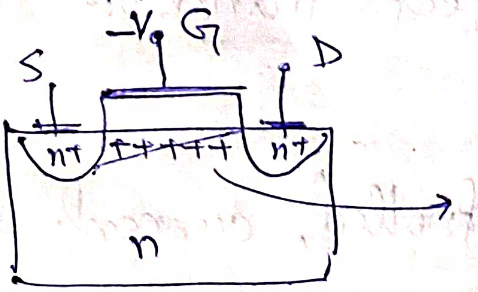


→ If we give more V_{DD} we got pinch off state.

→ Due to saturation velocity after pinch off The channel the e^- will pass. & we will get constant current.

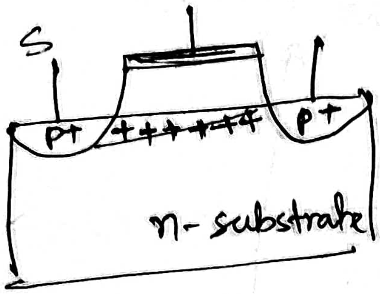


n-channel
Enhenced MOSFET
normally Off



→ Gate voltage deplete the e^- from the channel region

(P-channel - Depletion-MOSFET
→ normally-ON)



p-channel
E

Due to V_{DS} some carrier extracted out, so the channel become graded.

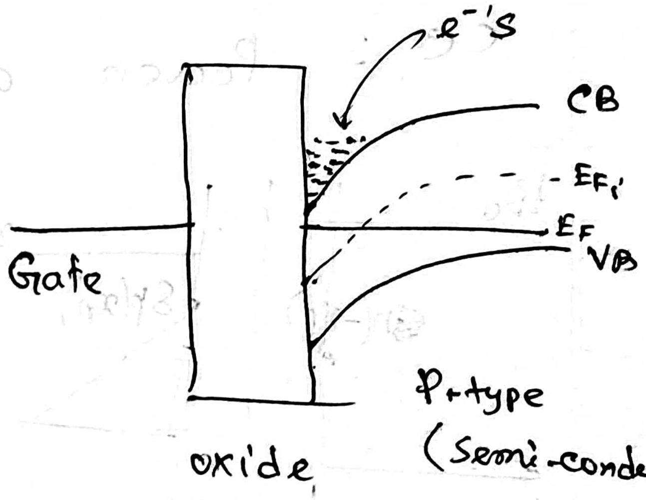
Trans conductance,

$$g_m = \frac{\partial I_{DC}}{\partial V_{GS}}.$$

$$I_{DS} = k\left[(V_{GS} - V_{th})V_{DS} - V_{DS}^2\right]$$

After threshold I_{DS} independent of V_{DS}.

$$I_{DS} = k\left[V_{GS} - V_{th}\right]$$



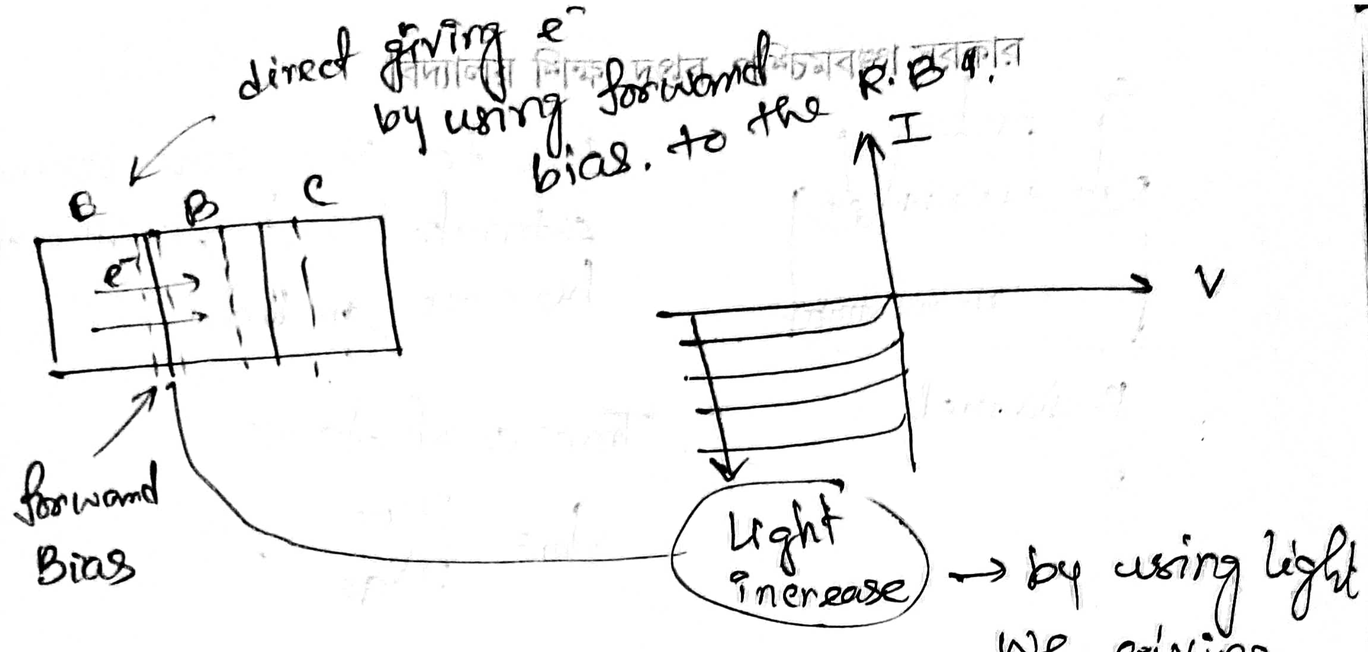
Next "Crystal fire" → Book

Comparison questions.

Syllabus:

(i) P-N diode ⇒ PDs, LEDs, APDs, PiN, Laser, solar cell
(ii) M-S contact → ohmic / schottky
(iii) Heterojunction
(iv) BJTs
(v) FETs

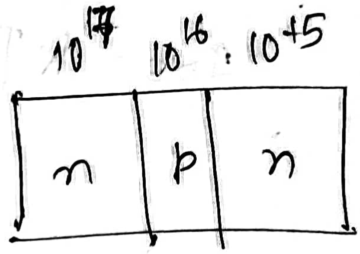
#

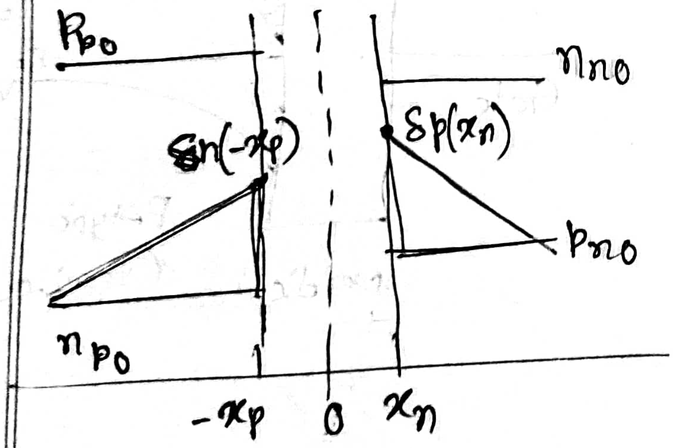


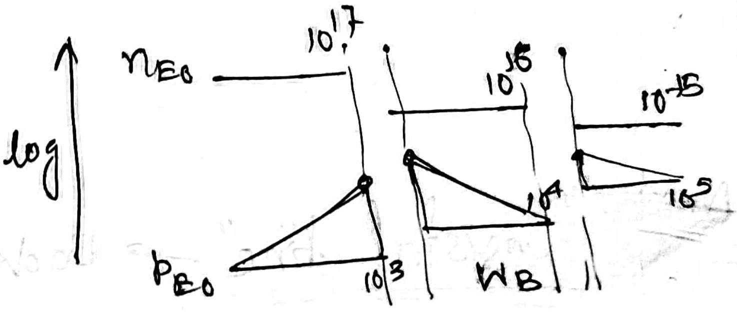
CB : Voltage amp.

CE : Current amp.

CC : Power amp.



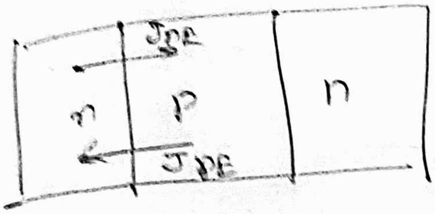




$$J_n = e D_n \frac{dn}{dx}$$

$$\Rightarrow \boxed{J_n = e D_n \frac{\delta n(-x_p)}{L_n}}$$

$$\boxed{J_p = e D_p \frac{\delta p(x_n)}{L_p}}$$



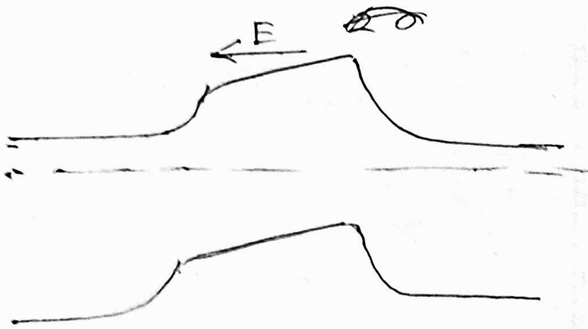
$$\gamma_E = \frac{J_{nE}}{J_{nE} + J_{pE}}$$

How to increase γ_E,

→ By less doping in Base region.

→ By using Heterojunction.
EB Junc. (high Band gap)

→ By using gradded junction (EB junc).



gradded junction will enhanse the motion of e^- & less recombination.

- Base transfer factor → (α_T)