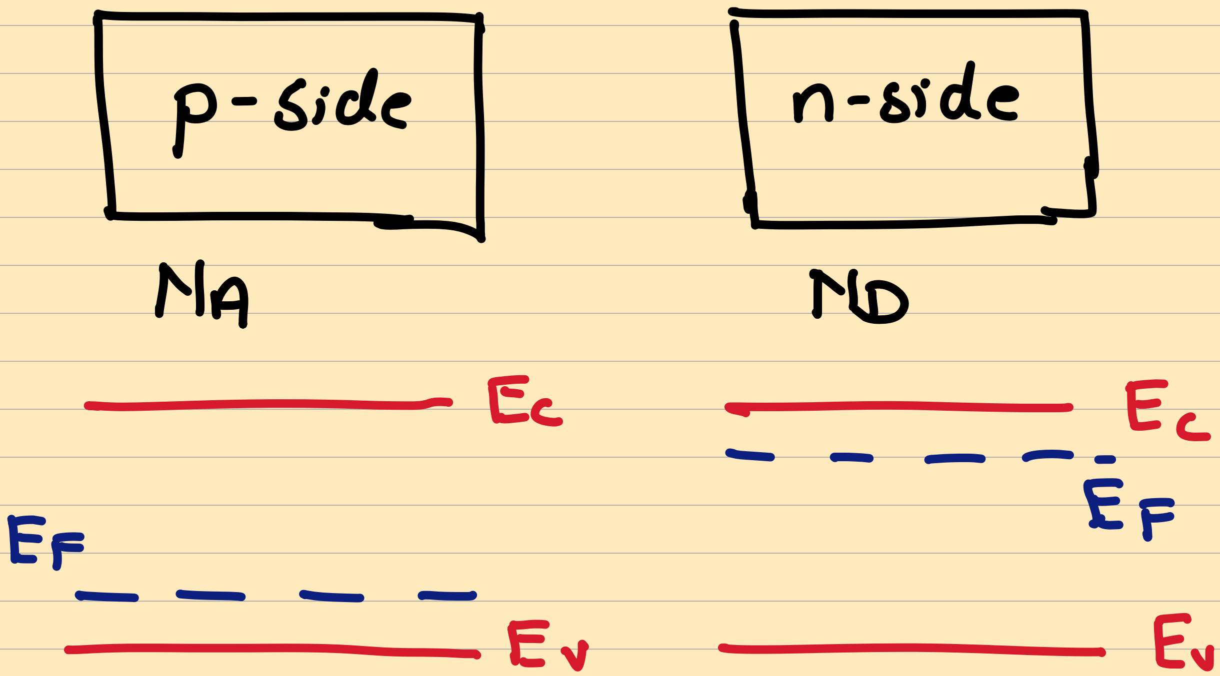
DIODE SUMMARY



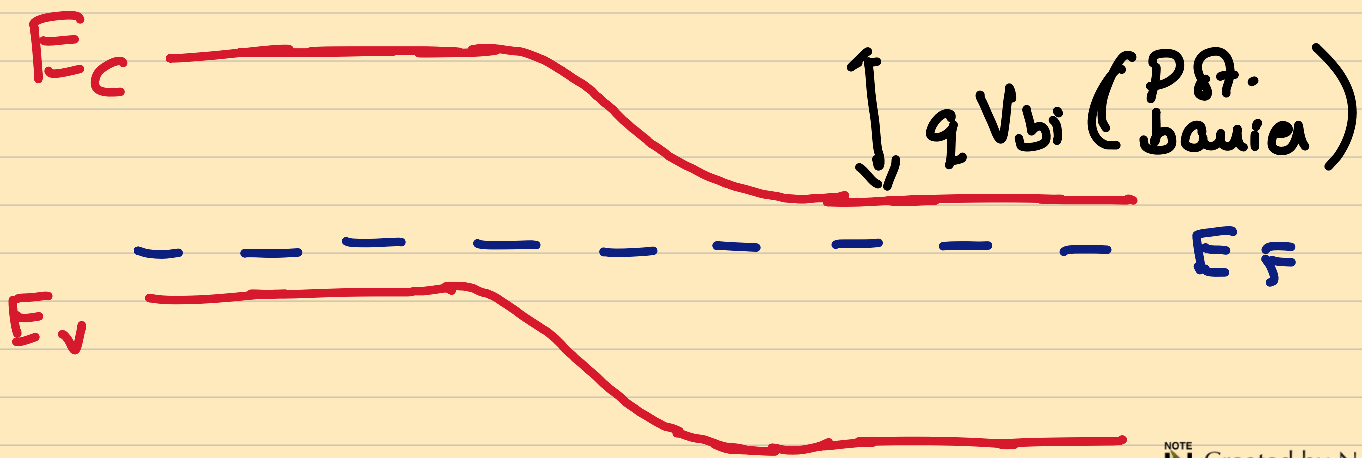
Concentration Gradient

↳ Diffusion of e^- from n- to p-side.

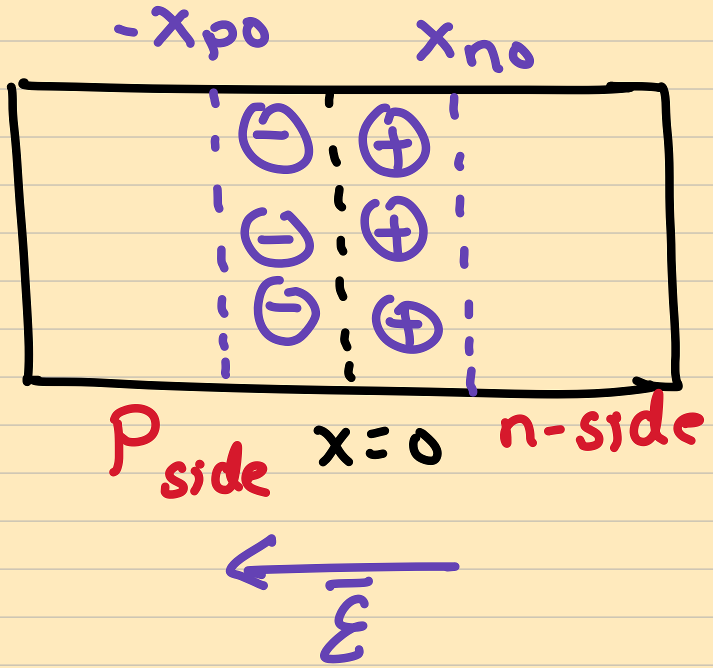
→ Diffusion of h^+ from p- to n side.

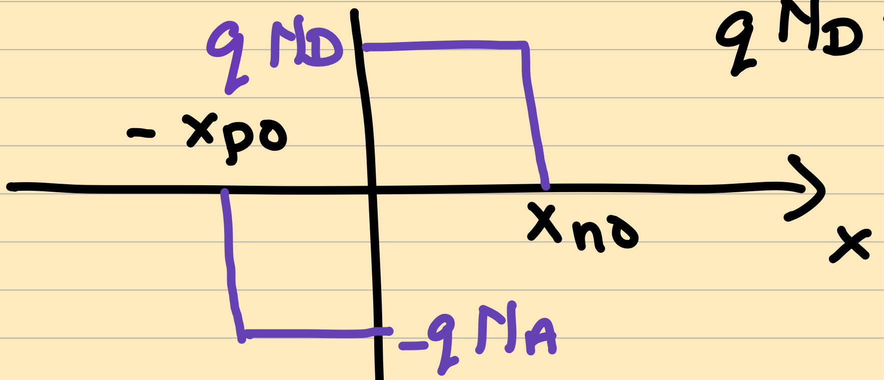
Depletion Region → leaving behind immobile charges (ionized dopants)

→ Leads to the formation of $\bar{E}$

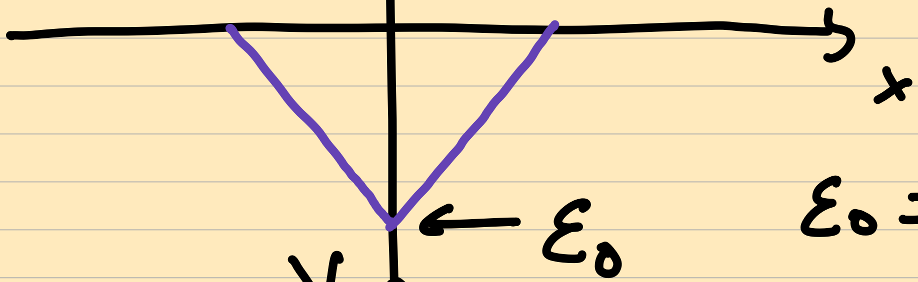


$$W_{D0} = x_{n0} + x_{p0}$$

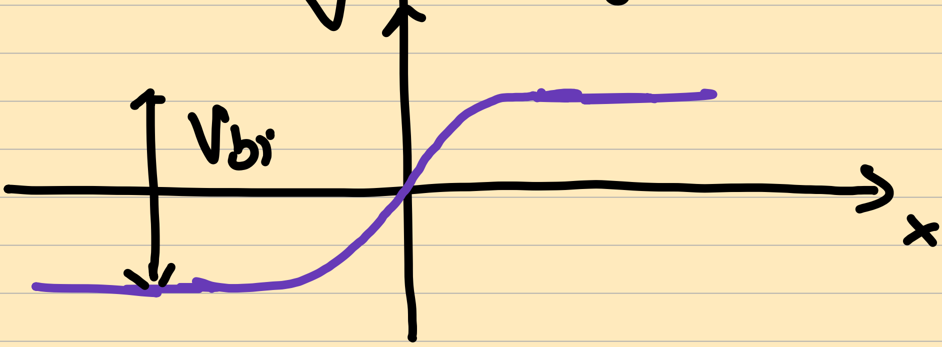




$$qN_D x_{n0} = qN_A x_{p0}$$

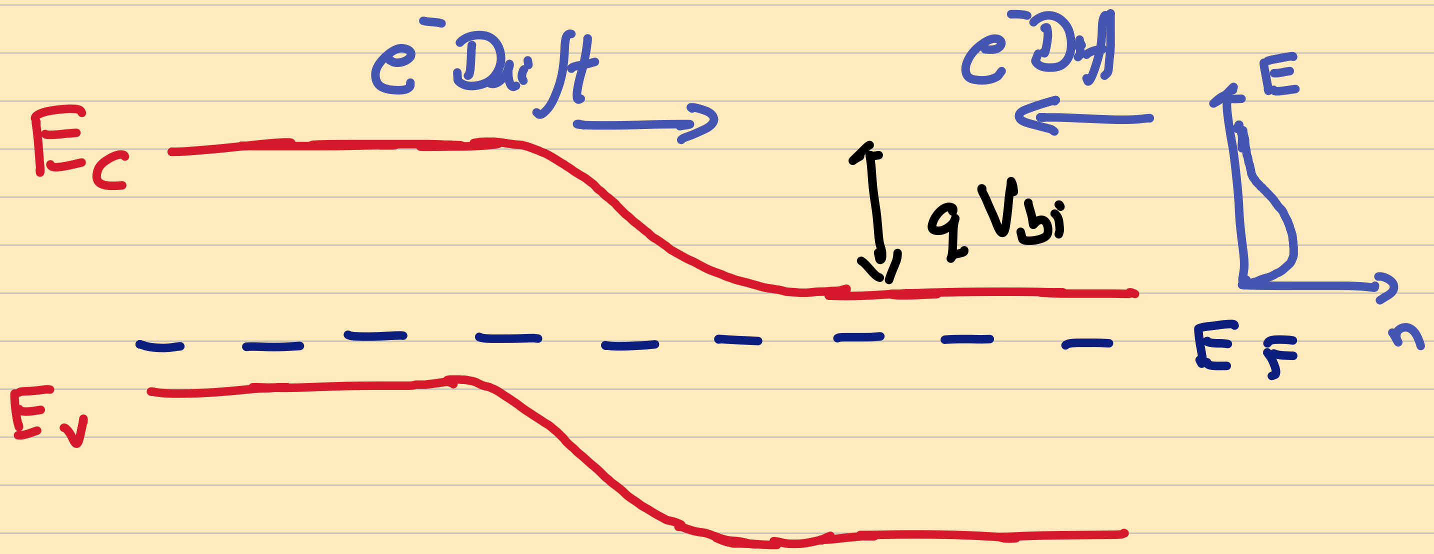


$$\mathcal{E}_0 =$$



$$V_{bi} = \frac{k_B T}{q} \ln\left[\frac{N_A N_D}{n_i^2}\right]$$

At Equilibrium V_{bi} is such that the e^- diffusion current balances the net e^- drift. IIIly for holes as well.

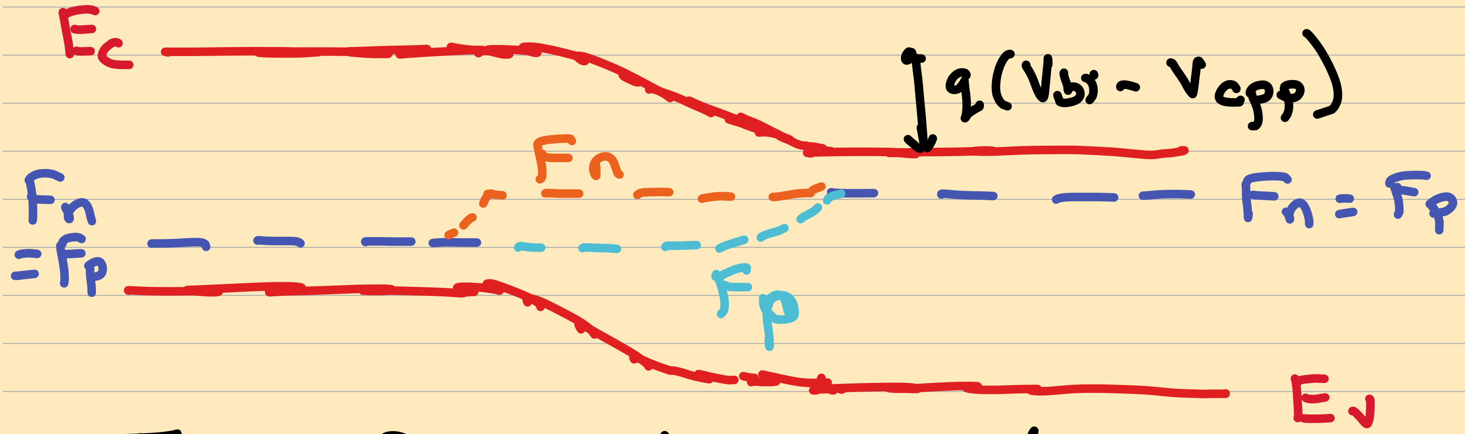


$J_{n,Diff} = J_{n,Drift}$ IIIly for holes

e^- Diffusing from n to p side
= # e^- Drifting from p to n side

Origin of Carrier Drifting : Generation in the vicinity of the Depletion region

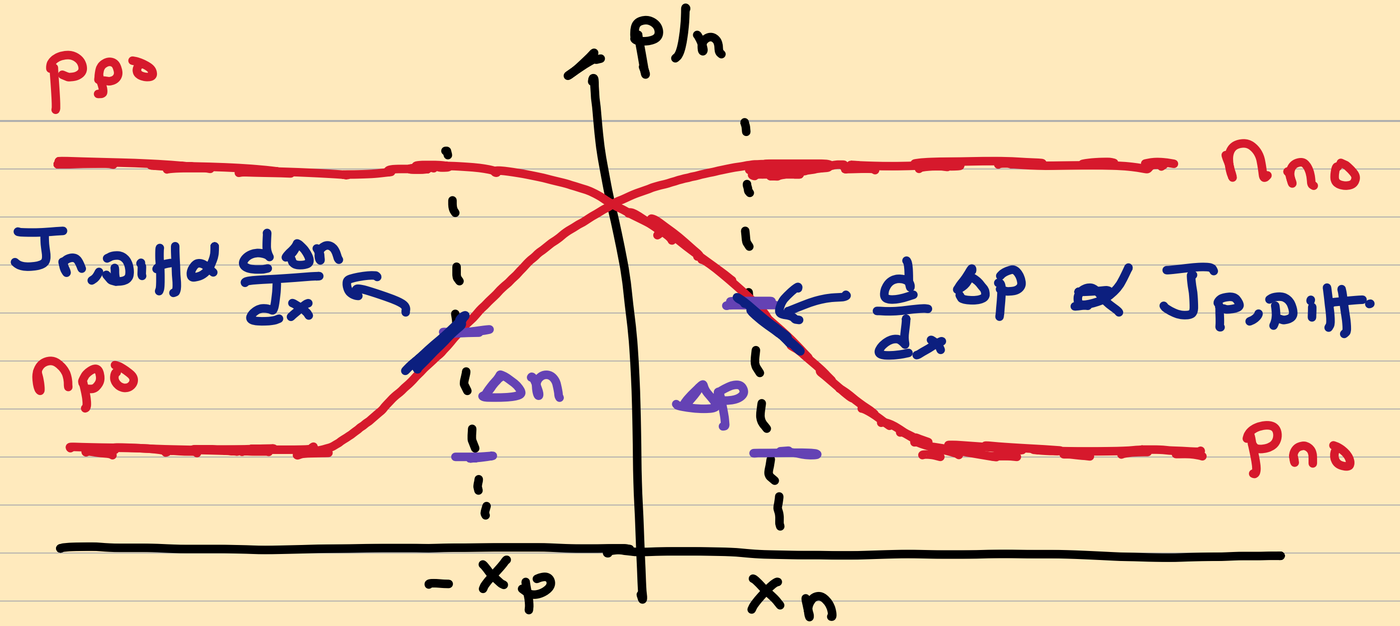
FORWARD BIAS → Potential applied on p-side is >0



The potential barrier reduces
↳ More carriers can diffuse over the barrier (Exponentially more)
→ Thus the diffusion component increases

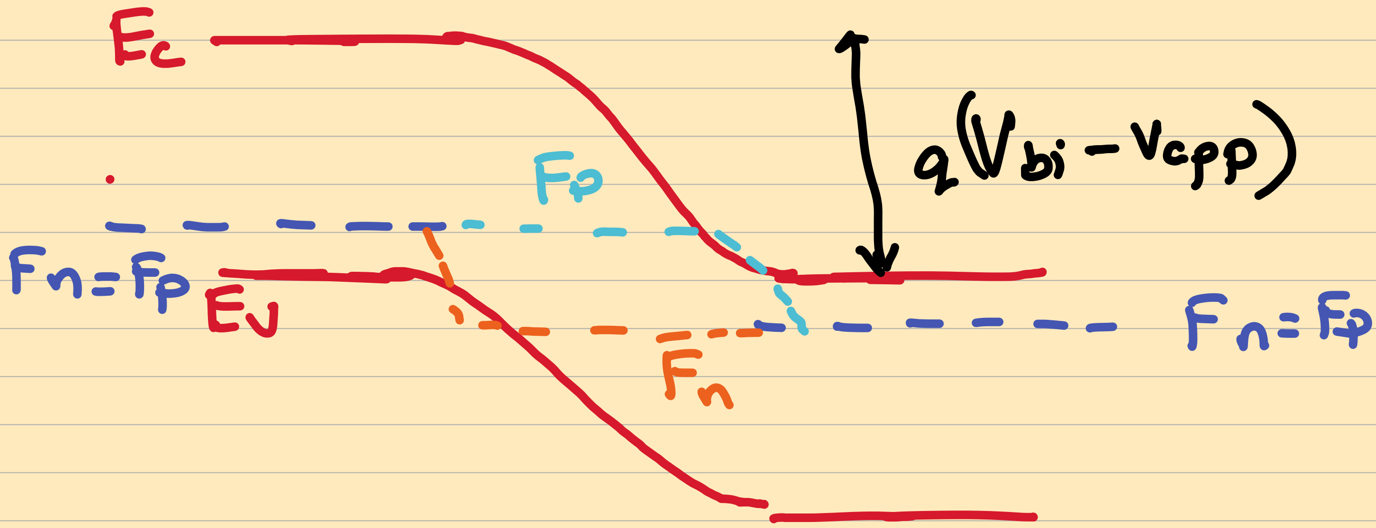
The no. of carriers being generated remains <u>almost</u> the same (material is same as equilibrium)
→ Thus the drift component remains same as equilibrium.

$J_{n,Diff} > J_{n,Drift}$
Thus the current flows



$\Delta n(x) / \Delta p(x)$ are the excess minority carrier that are injected.

REVERSE BIAS – Potential applied on p-side < 0



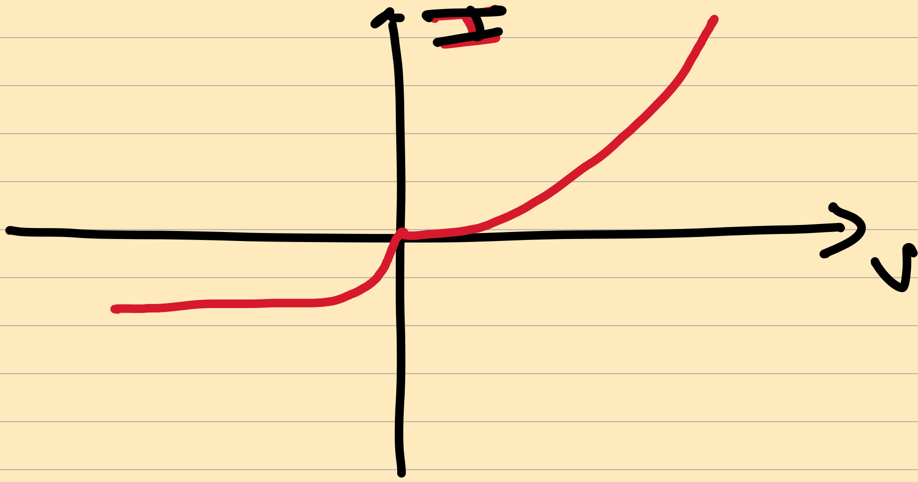
→ Applied bias increases the potential barrier
→ Lesser carriers can diffuse over the barrier

→ Carriers being generated near depletion region remains almost as in Equilibrium

→ Thus the drift component remains same as equilibrium.

$J_{n,\text{Drift}} > J_{n\,\text{Diff}}.$

QUALITATIVE $\underline{I}$ – V



QUANTITATIVE EXPRESSION

$$J_D = q\left[\frac{D_p}{L_p} p_{no} \coth\left(\frac{W_n - x_n}{L_p}\right) + \frac{D_n}{L_n} n_{po} \coth\left(\frac{W_p - x_p}{L_n}\right)\right]\left(\exp\left[\frac{V_{app}}{V_T}\right] - 1\right)$$

Assumptions

1. CURRENT FLOWS ONLY IN X
2. APPLIED BIAS DROPS ONLY ACROSS DEP. REGION
3. Low level injection
4. No Recombination / Generation
5. Maxwell Boltzmann statistics are valid.
6. Steady state $\frac{dn}{dt} = 0$ $\frac{dp}{dt} = 0$

Long base diode

$W_n - x_n \gg L_p$

$W_p - x_p \gg L_n$

$$J = q\left[\frac{D_p}{L_p} p_{n0} + \frac{D_n}{L_n} n_{p0}\right]\left(\exp\left[\frac{V_{app}}{V_T}\right] - 1\right)$$

Short base diode.

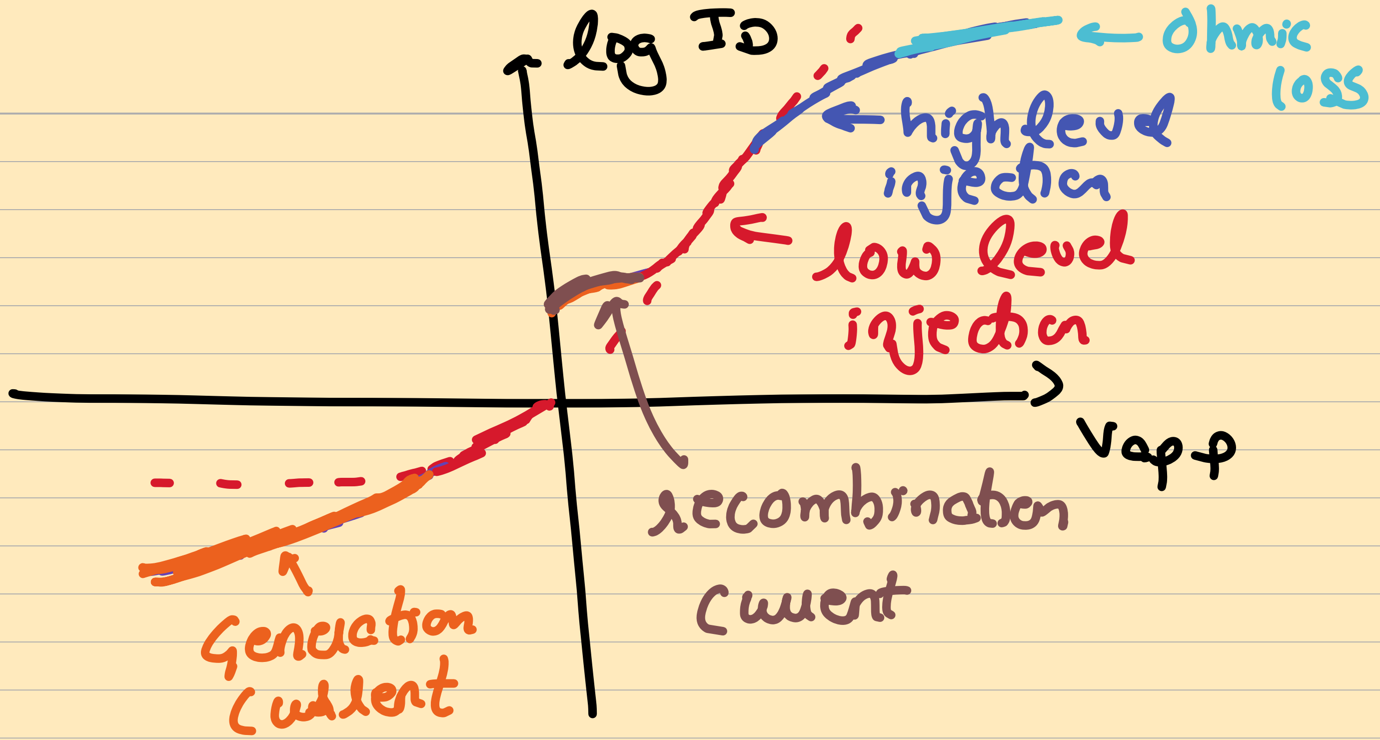
$W_n - x_n << L_p$

$W_p - x_p << L_n$

$$J = q\left[\frac{D_p}{(W_n - x_n)} p_{n0} + \frac{D_n}{(W_p - x_p)} n_{p0}\right]\left(\exp\left[\frac{V_{app}}{V_T}\right] - 1\right)$$

Reverse saturation current in short base diode is more

NOTE: As excess minority carriers recombine leading to δp (or δn) $\to 0$, leading to $J_{p,Diff} \to 0$ (on n-side) & $J_{n,Diff} \to 0$ (on p side) the drift current from the majority carriers compensates for it thus enforcing total current through the device to be constant



$$J_{total} = J_0 \exp\left[\frac{V_{app}}{V_T}\right] + J_{R0} \exp\left[\frac{V_{app}}{2V_T}\right]$$

At small biases. $\because J_{R0} > J_0$

→ Recombination current dominates

Moderate to high biases : The injected carriers are comparable to the background doping (i.e. high level injection)

→ In this regime the current increases by $\exp\left[\frac{V_{app}}{2V_T}\right]$

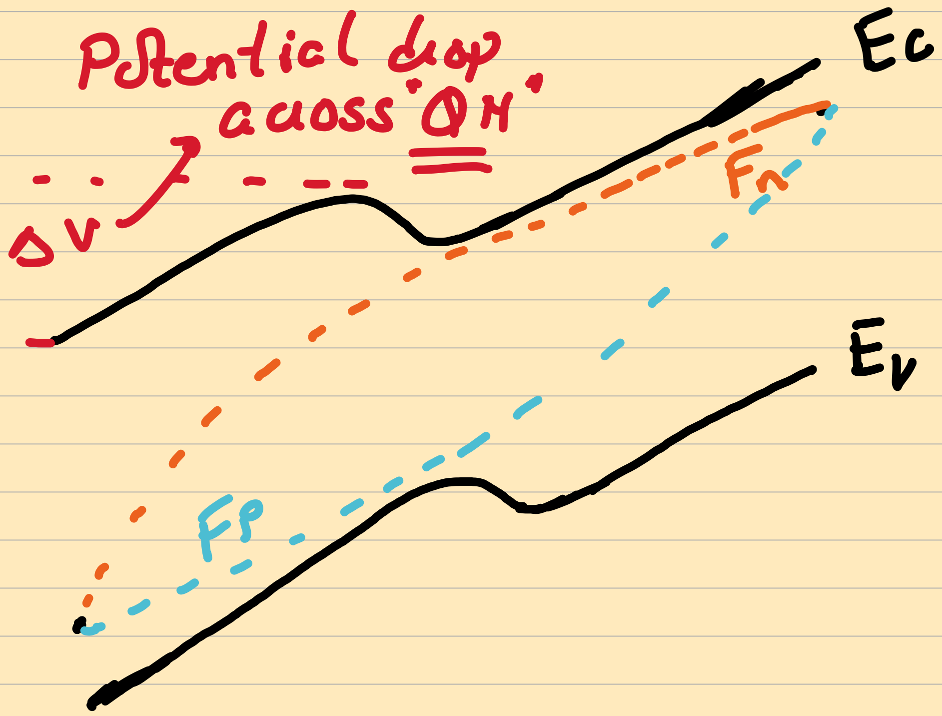
→ RATE OF INCREASE in I REDUCES

At high biases : The potential drop across QN becomes significant

This translates into electric field across QN region. This is represented in the band diagram

→ RATE OF INCREASE IN 'I' REDUCES FURTHER

The potential drop across QN is determined by the doping ∵ $\sigma = q n \mu$



The gradient in the band edges illustrate the $\vec{E}$

REVERSE BIAS : As the applied reverse bias increases → The depletion region width increases

→ The region in which the carriers can get generated & be swept away also increases in addition to the increase in $\bar{\mathcal{E}}$

→ Reverse current increases

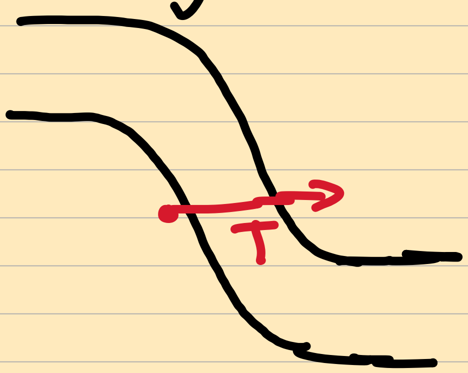
DIODE BREAKDOWN

Zener

→ Current due to e^- tunnelling

→ high doping

→ $-$ve temp. coefficient

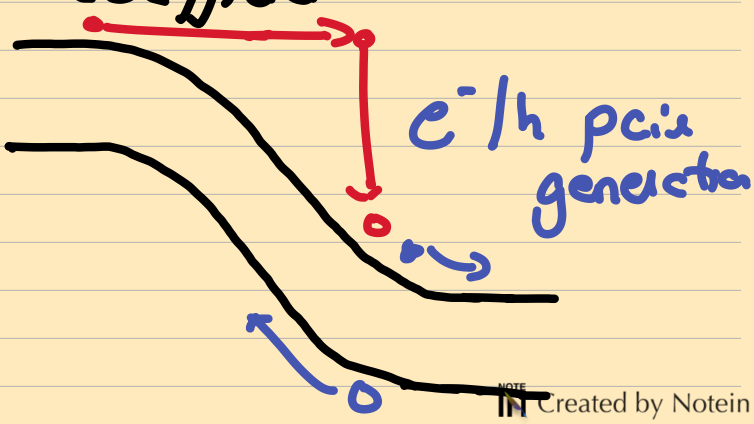


Avalanche

→ Current due to impact ionization

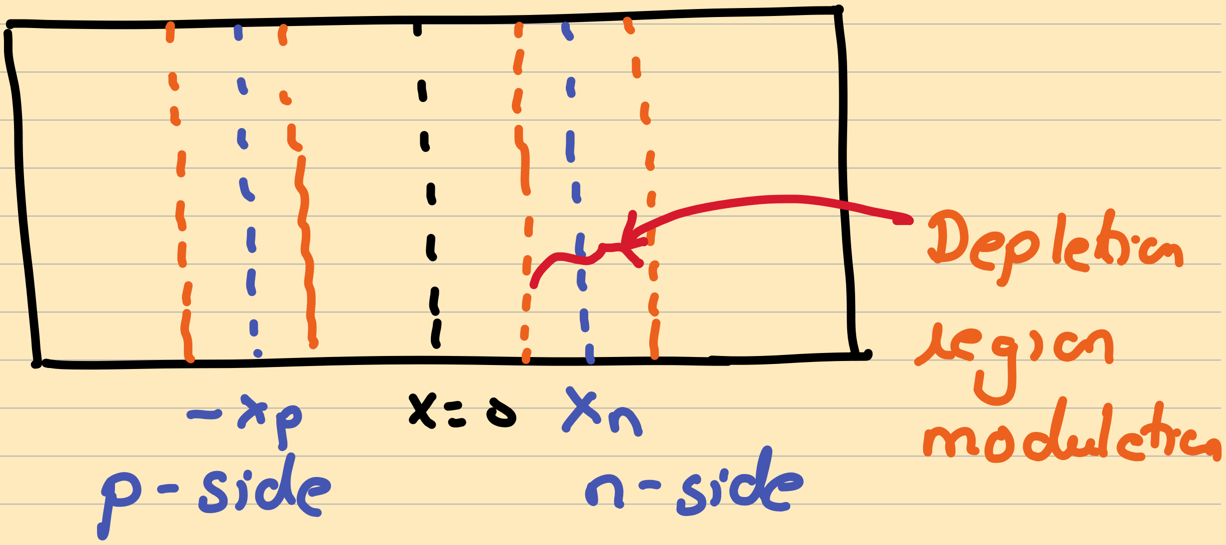
→ low doping

→ +ve temperature coefficient



CAPACITANCES

DEPLETION CAPACITANCE

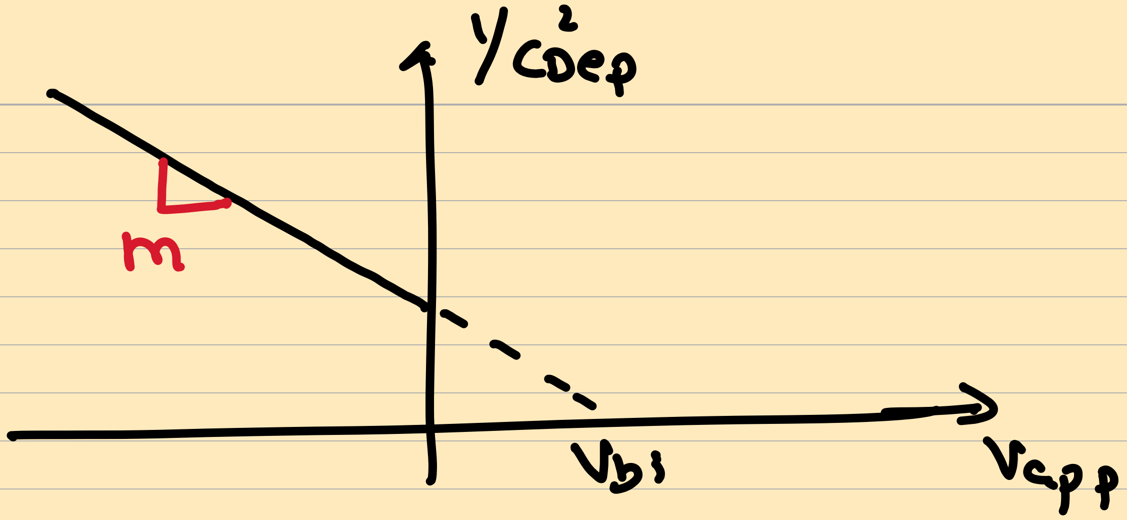


$$C_{DEP} = \frac{\Delta Q}{\Delta V} =$$

$$A\left[\frac{q\,\varepsilon}{2(V_{bi}-V_{app})}\;\frac{N_A N_D}{N_A+N_D}\right]^{1/2}$$

$$= \frac{\varepsilon A}{W_{dep}} = \frac{\varepsilon A / W_{dep0}}{\left(1-\frac{V_{app}}{V_{bi}}\right)^{0.5}}$$

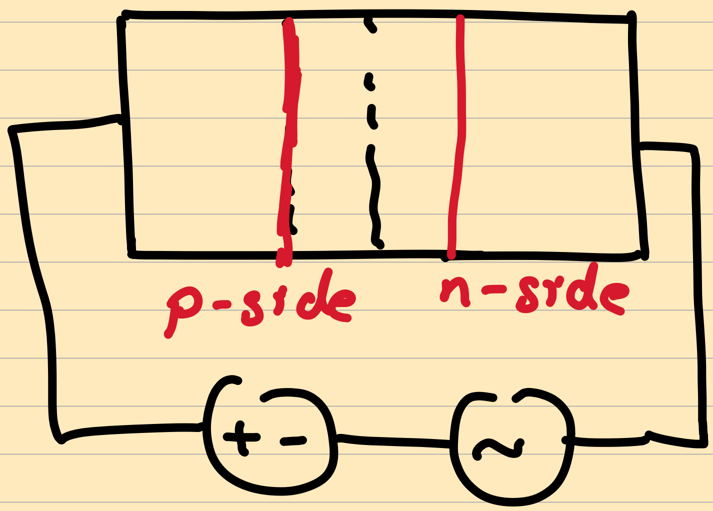
$$= \frac{C_{dep0}}{\left(1-\frac{V_{app}}{V_{bi}}\right)^{0.5}}$$

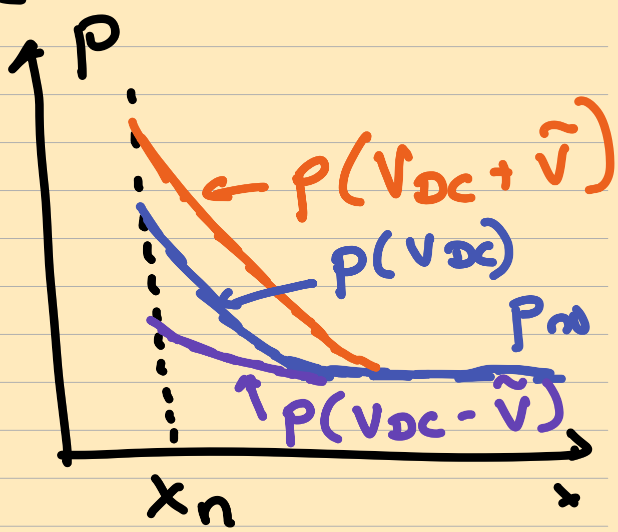


$$\frac{1}{C_{Dep}^2} = \frac{1}{C_{Dep0}^2}\left(1 - \frac{V_{app}}{V_{bi}}\right)$$

→ We can calculate the dopings.

DIFFUSION CAPACITANCE

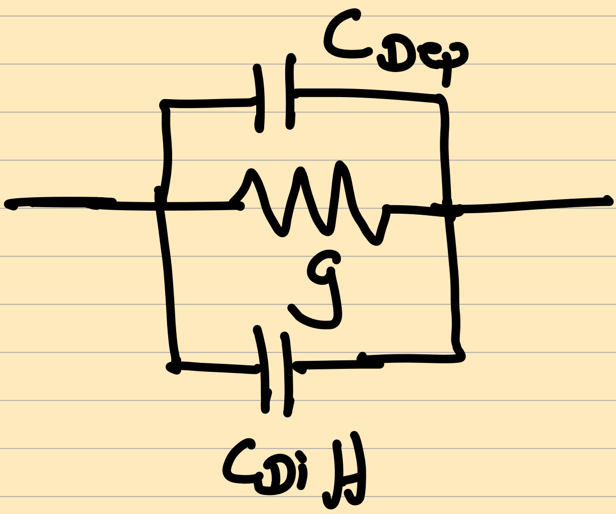




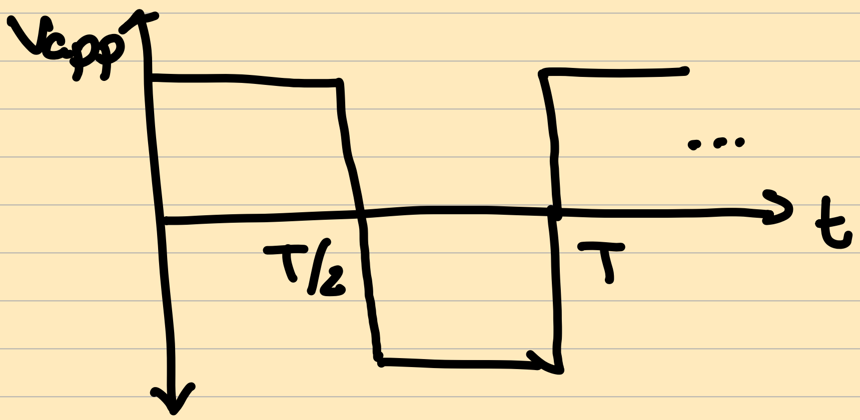
Performing full analysis - The diode impedance can be written as

$$y = \underbrace{g}_{\text{conductance}} + i\omega C_{Diff}$$

The small signal equivalent of diode



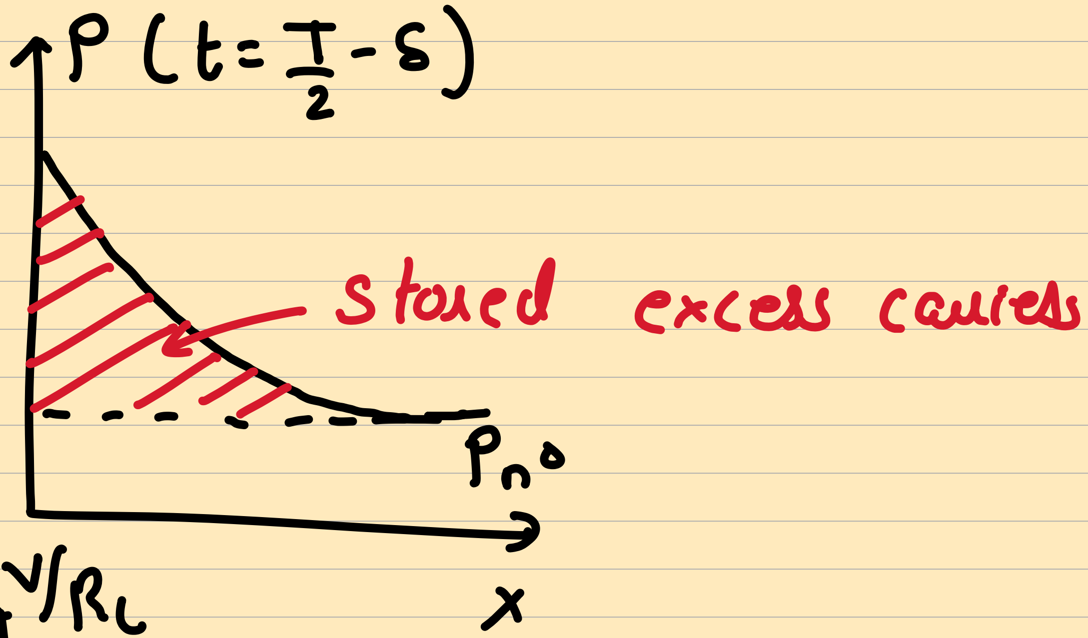
APPLICATION — RECTIFICATION

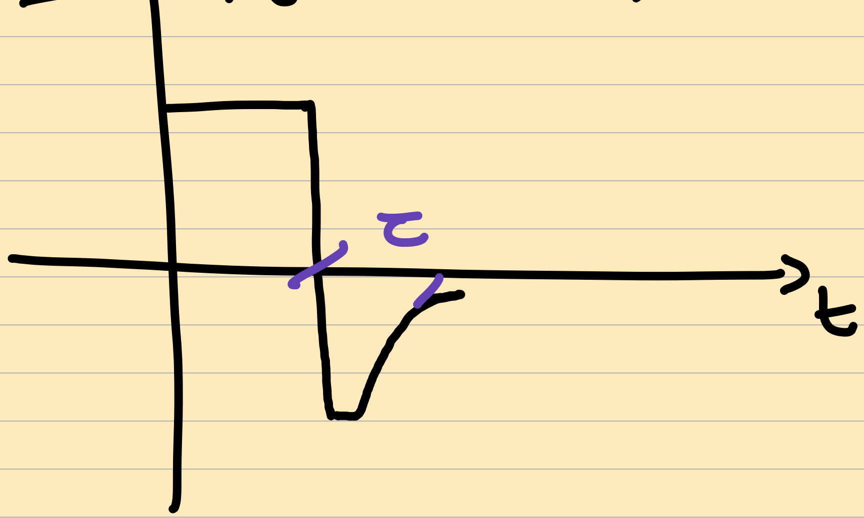


$R_L \rightarrow$ load.

Ideally from a rectifier we want only +ve half to go through

→ The presence of stored excess minority carriers can contribute to significant current as the diode enters reverse bias





If the applied bias switches faster than τ → there will not be any rectification

HOW DO WE DESIGN FASTER DIODE

For this we have to quickly remove the stored excess carriers

Method 1 : Add impurities that create deep traps

Created by Notein

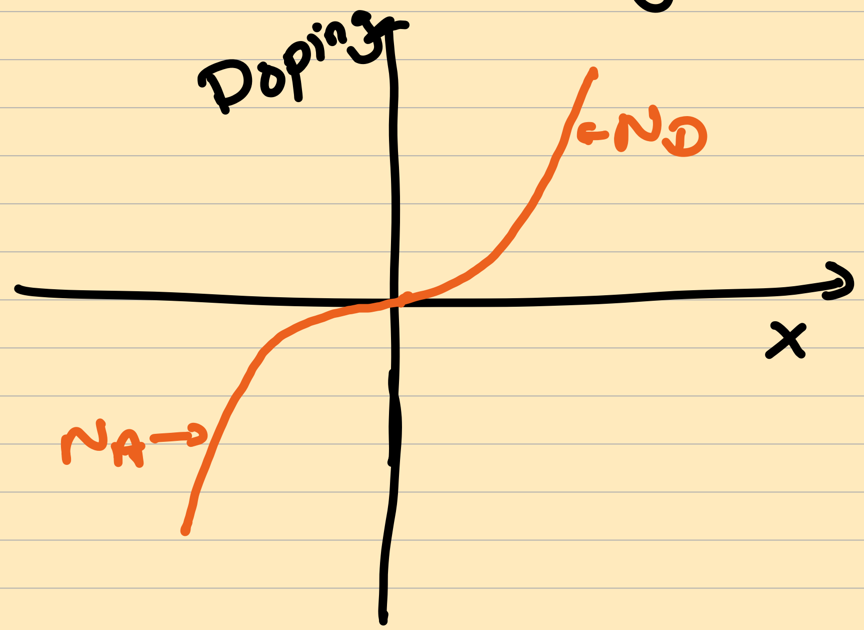
→ These can act as recomb. centers

METHOD 2 : USE Short base diode

Large reverse saturation current

Problem of punch through

METHOD 3 : Doping profiles



The non uniform doping profiles "restricts" the excess carriers closer to the depletion edge & hence reduces the time taken to turn off the diode.