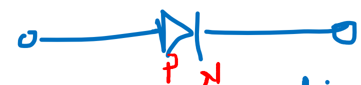
Zener diode

It is a specially designed diode with usually step junction and higher doping so as to operate in the reverse bias at breakdown point.

Zener diode

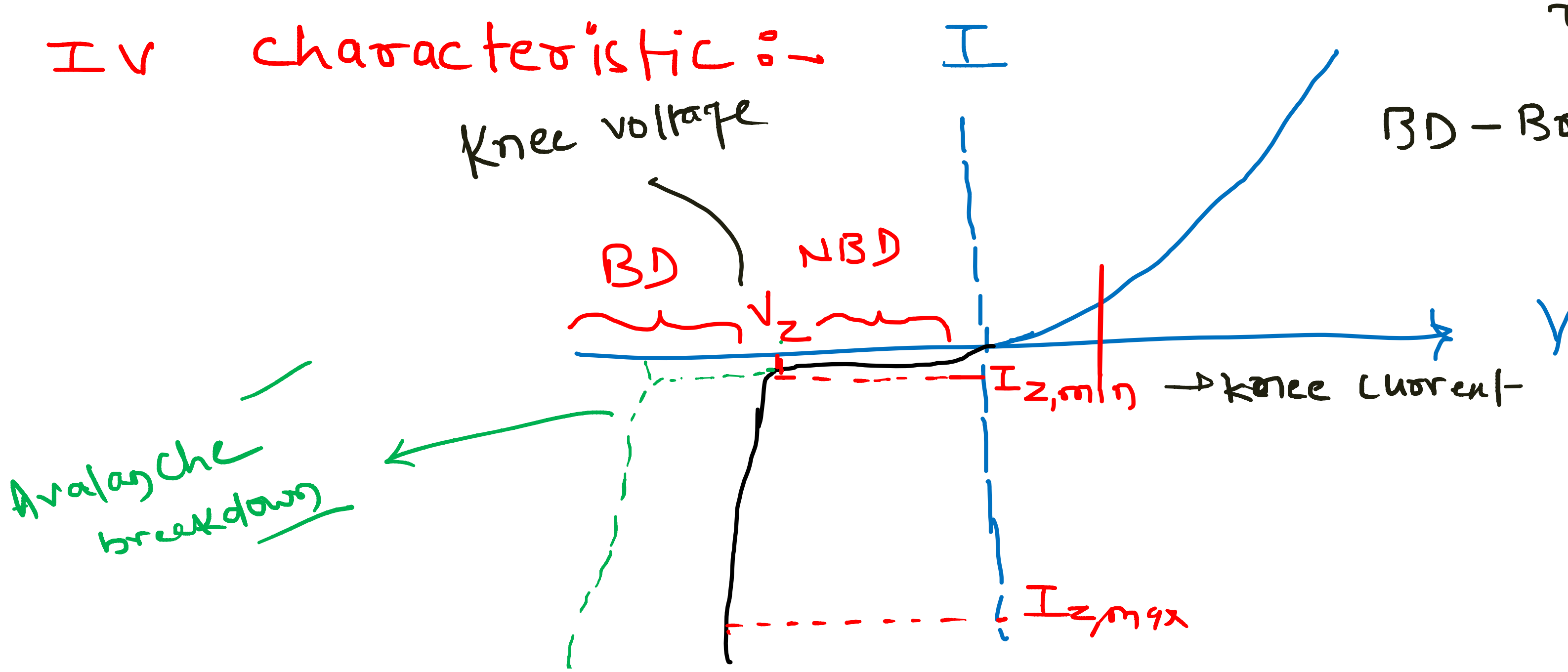


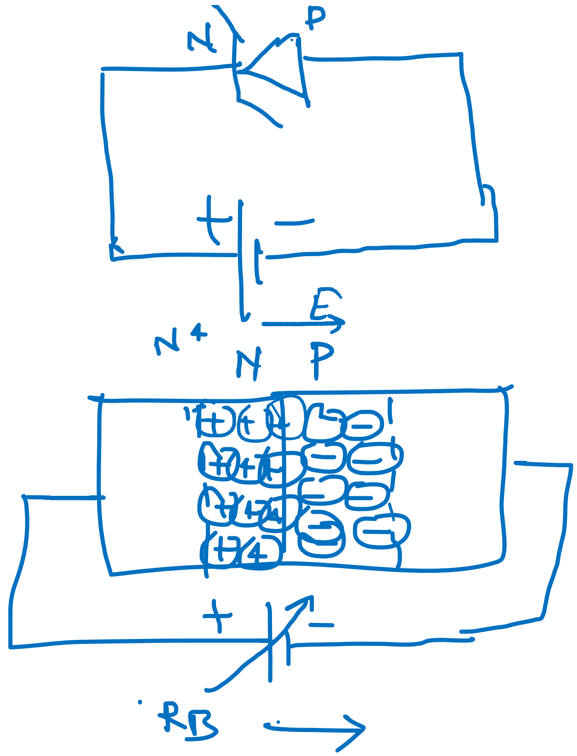
Normal diode

NBD - non breakdown region

BD - Breakdown region

IV characteristic :-



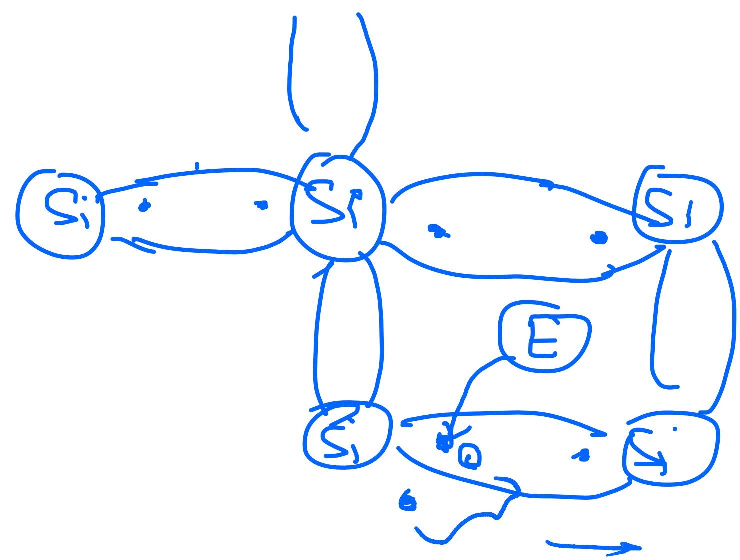


overall electric field across diode ↑
↳ very high

* Zener diode is operating in Reverse bias.
* As the RB voltage is ↑, depletion width ↑ charge density region ↑, Electric field across the region is also increased.
* As the RB voltage is increased to V_z, a strong electric field is generated in the depletion region.

* The external E and electric field in the depletion region are in same direction, so overall electric field across the diode is very high.

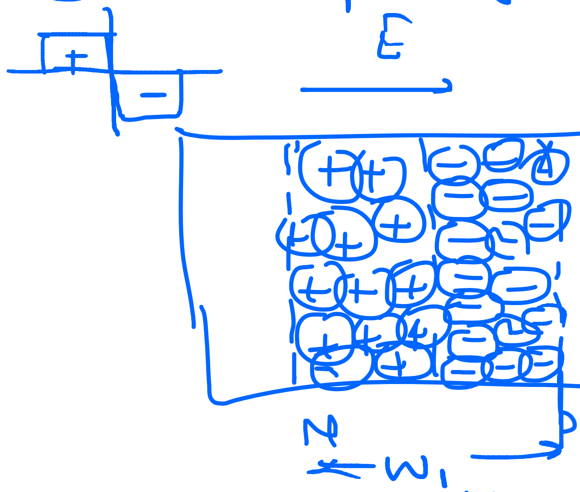
* This strong Electric field exerts sufficient energy on bound electrons (or VB electrons) and frees them, resulting in e⁻ hole pair. This process is called field ionization



Reason of Field ionization

① Heavily doped PN diode

② Step junction

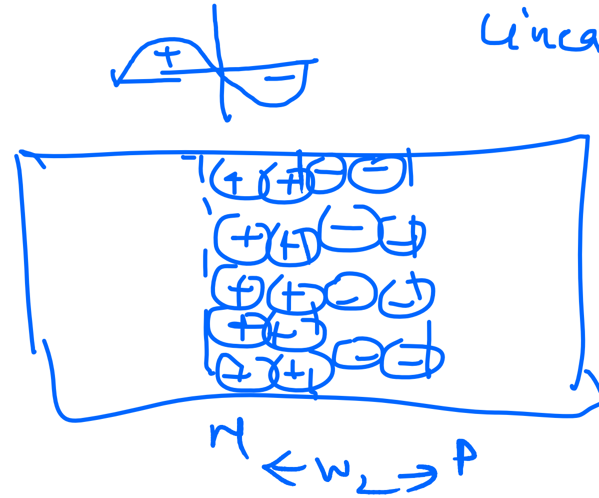


Zener diode

"suppose"

$W_1 = W_2$

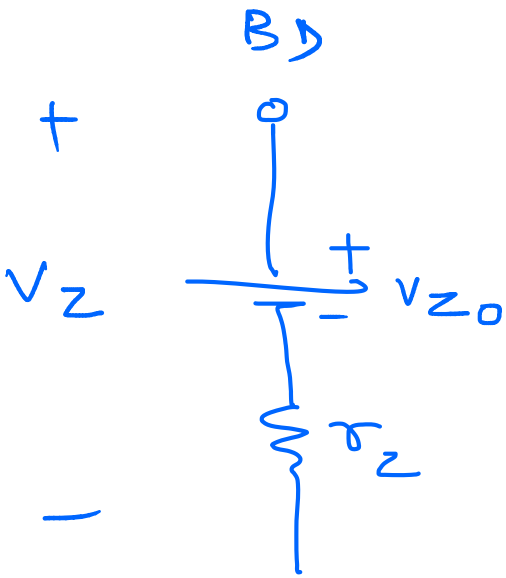
Linearly graded



Normal diode

High charge density
↓
High electric field
↓
sufficient to free the bounded e^- (field ionization)

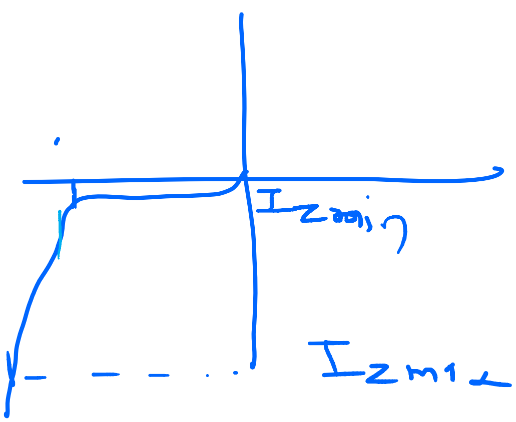
Low charge density
↓
low electric field
↓
Not sufficient to free the bounded e^-



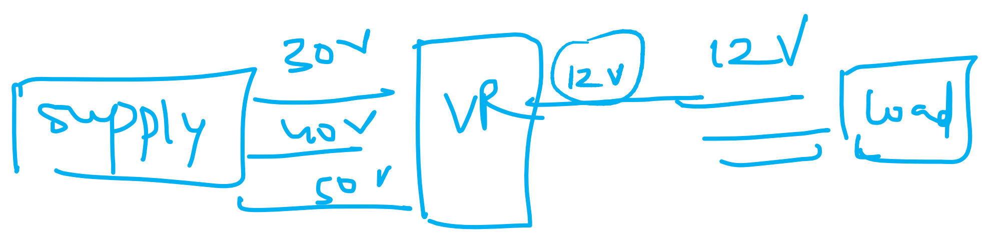
$$r_z = \frac{\Delta V}{\Delta I} \quad (\Omega)$$

$r_z \rightarrow$ very small

$\rightarrow$ known as dynamic resistance



Application $\rightarrow$ voltage regulator (VR)

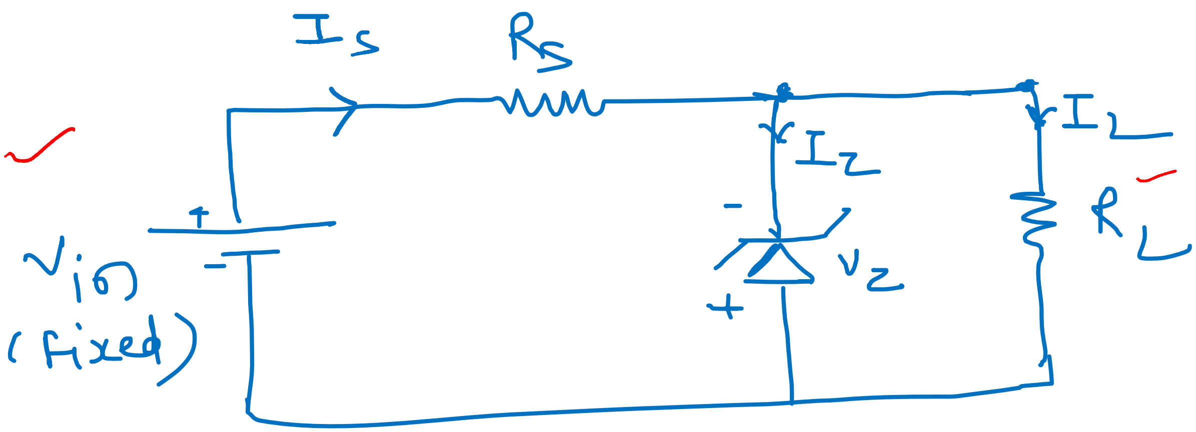


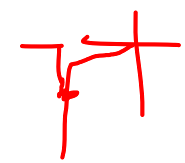
Zener diode acts as a voltage regulator

only if, (1) $I_Z \geq [I_{ZK}$ (or) $I_{Z,min}]$

(2) RB voltage $V \geq V_Z$

Case 1: In BD, input supply is fixed & load is variable

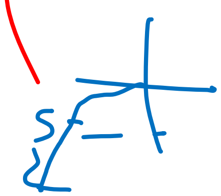




+

$V_L = V_Z$ constant

−



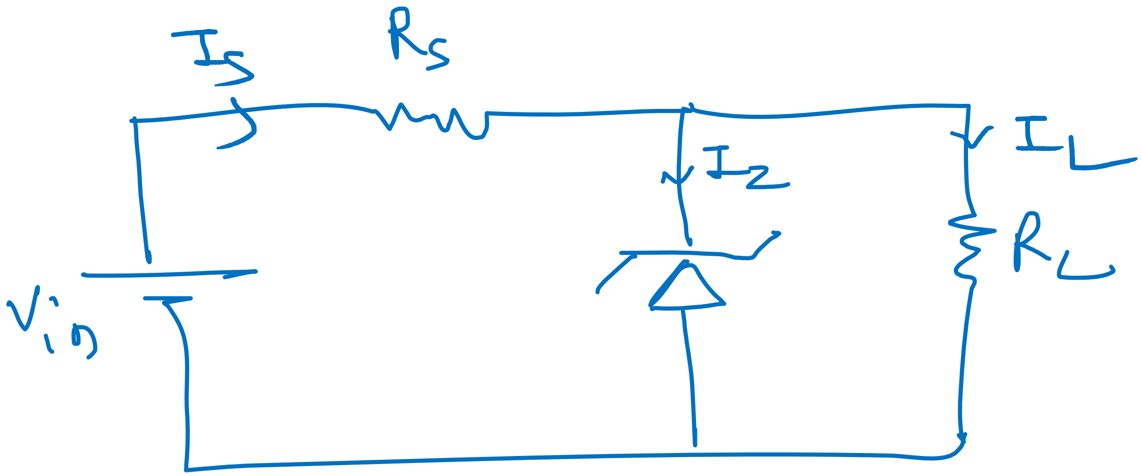
$I_{S\,(fixed)} = I_Z + I_L$

$R_L \to V_L = I_L R_L$.

$R_L\uparrow \to V_L = I_L\downarrow R_L\uparrow$, I_S (fixed) $= I_Z\uparrow + I_L\downarrow$

$R_L\downarrow \to V_L = I_L\uparrow R_L\downarrow$, I_S (fixed) $= I_Z\downarrow + I_L\uparrow$

case 2:- In BD, input is varied, and load is fixed



$\underline{V_L = V_z}$

$I_s = I_z + I_L$

$V_{in} \uparrow$, $I_s \uparrow = I_{L(\text{fixed})} + I_z \uparrow$, $I_z \leq \underline{I_{z\,max}}$

$V_{in} \downarrow$, $I_s \downarrow$, $I_{L(\text{fixed})} + I_z \downarrow$, $I_z \geq I_{z\,\underline{min}}$

Q1) A zener diode has resistance in breakdown region ($r_z \rightarrow$ dynamic resistance) of $20\,\Omega$. If voltage across the zener diode is 5.2 volt at $I_z = 1$ mA, then determine voltage across the zener diode at $I_z = 10$ mA.

Q2) find the range of source voltage for which zener diode is 'ON' safely. Given, the minimum current needed to switch on the zener diode is 1 mA and maximum current it can handle is 60 mA.

(1) Integrated circuit → Milman Halkiyas
(2) Electronic devices → Sedra Smith

Tunnel diode

* Also known as Esaki diode
  ↳ It was invented by Leo Esaki in 1957.

→ Noble prize for this invention in 1973.

→ It's working principle is based on "Tunneling effect", so known as Tunnel diode.

→ Doping concentration

Tunnel diode > Zener diode > PN diode

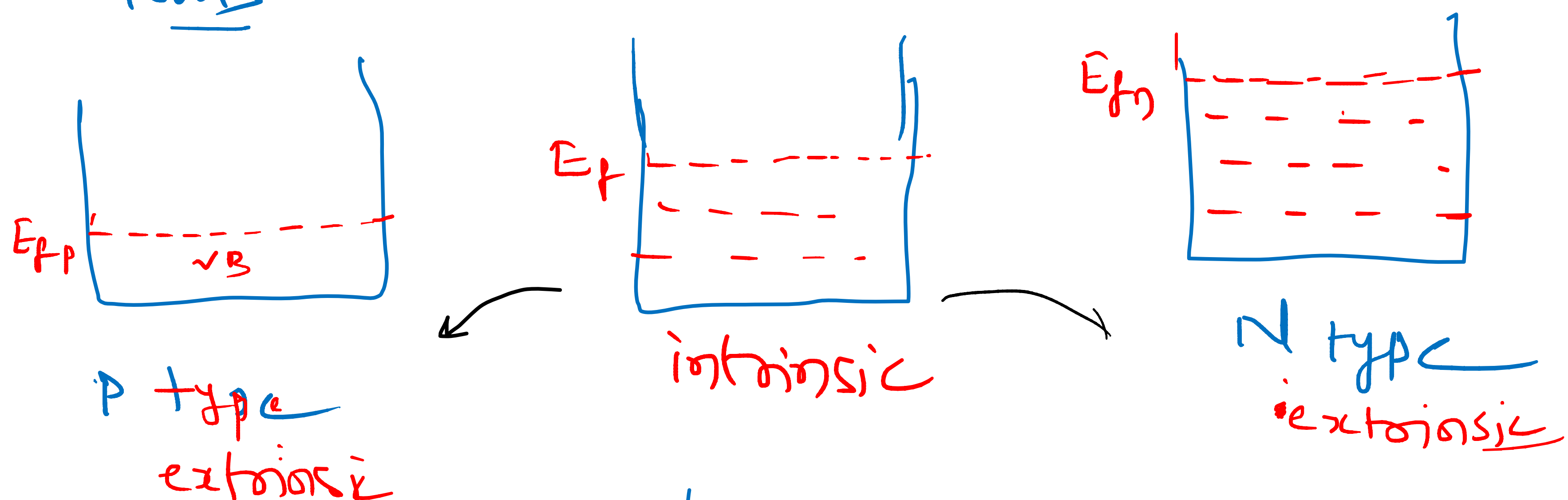
Doping concentration :-

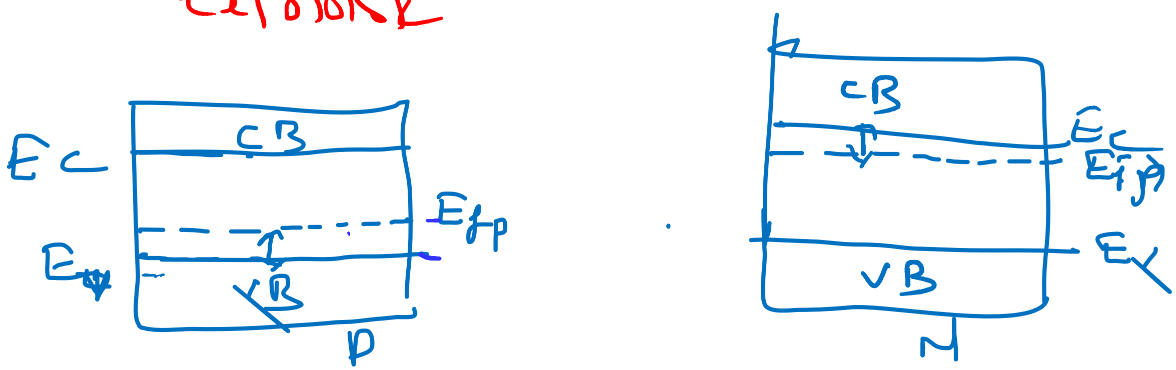
Tunnel diode > Zener diode > PN diode

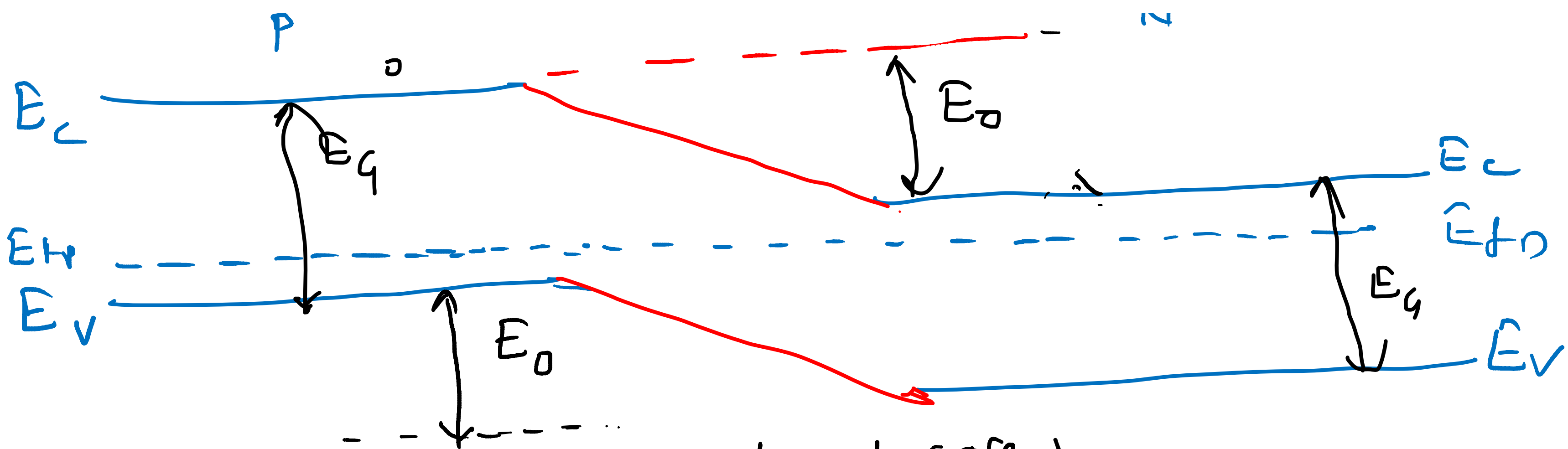
1 Dopant for every 10^3 Si atoms

1 in 10^5

1 in 10^8







(Normal case)

at equilibrium & no bias is applied

$P^+ \rightarrow N_A \uparrow$ $N^+ - N_D \uparrow$

$E_{fp} \downarrow$ towards the VB $E_{fn} \uparrow$ towards the CB

* In FB, E_0 decreases because shift between the band edges.

* In RB, E_0 increases because shift between band edges increases.

→ For any diode, we have equations:-

Fermi level of P type SC

$$E_{fp} = E_V + KT \ln\left(\frac{N_V}{N_A}\right)$$

Fermi level of N type SC

$$E_{fN} = E_C - KT \ln\left(\frac{N_C}{N_D}\right)$$

N_A – Acceptor doping concentration

N_D – Donor doping concentration

N_V – Effective density of state of VB.

N_C – ——— " ——— of CB.

→ Shift between VB or CB energy levels

$$E_0 = KT \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

→ Energy band gap

$$E_G = KT \ln\left(\frac{N_C N_V}{n_i^2}\right)$$

PN diode/zener diode

relatively low doping

$N_A < N_V$

$N_D < N_C$

Assume:- $N_A = 1$, $N_V = 2$

$N_D = 1$, $N_C = 2$

$n_i = 1$

$$E_{fp} = E_V + KT \ln\left(\frac{N_V}{N_A}\right)$$

$$= E_V + KT \ln\left(\frac{2}{1}\right)$$

$$\boxed{E_{fp} = E_V + 0.69\,KT}$$

$$\boxed{E_{fN} = E_C - 0.69\,KT}$$

Tunnel diode

relatively high doping

$N_A > N_V$

$N_D > N_C$

Assume: $N_A = 2$, $N_V = 1$

$N_D = 2$, $N_C = 1$

$n_i = 1$

$$E_{fp} = E_V + KT \ln\left(\frac{1}{2}\right)$$

$$\boxed{E_{fp} = E_V - 0.69\,KT}$$

$$\boxed{E_{fN} = E_C + 0.65\,KT}$$

$$E_{01} = KT \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$= 0.$$

$$E_g = 1.38KT$$

* $\boxed{E_0 < E_g}$

* In PN diode & zener diode, Fermi level is outside the CB and VB

$$E_0 = KT \ln(4)$$

$$= 1.38 \, KT$$

$$E_g = 0$$

* $\boxed{E_0 > E_g}$

* In tunnel diode, the fermi level is inside the CB and VB.

Symbol →