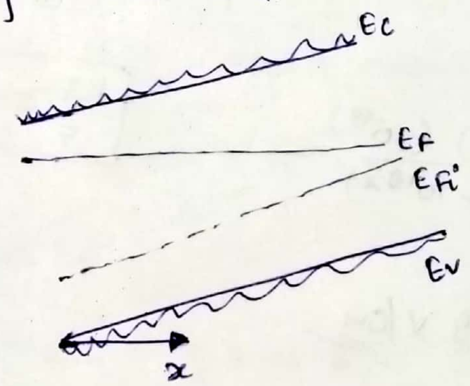
Carrier Transport Phenomenon

* Graded impurity distribution :-

In most cases, we have assumed that the sc is uniformly doped. In many SC, however, there may be regions that are non-uniformly doped. We'll investigate how a non-uniformly doped sc reaches thermal equilibrium.

→ Induced Electric field :-

Consider a sc that is non-uniformly doped with donor impurity atoms. If the sc is in thermal equilibrium, the fermi energy level is constant through the crystal. So, the energy band diagram may qualitatively look like that



The doping concn decreases as $x \uparrow$ in this case. There will be diffusion of majority carrier e^- from region of higher concn to lower concn, which is in the $+x$ dir. The flow of (-vely) charged e^- leaves behind +vely charged donor ion. This creates a E that opposses the flow. When eqlb is reached, the mobile carrier concn is not exactly equal to the fixed impurity concn.

The electric potential ϕ is related to electric potential energy by charge $(-e)$ is

$$\phi = \frac{1}{e}(E_F - E_{Fi})$$

$$\left[E_x = -\frac{d\phi}{dx} = \frac{1}{e}\frac{dE_{Fi}}{dx} \right] \quad -①$$

$$n_o = n_i \exp\left[\frac{E_F - E_{Fi}}{KT}\right] \approx N_d(x)$$

So,

$$E_F - E_{Fi} = KT \ln\left(\frac{N_d(x)}{n_i}\right)$$

$$-\frac{dE_{Fi}}{dx} = \frac{KT}{N_d x}\frac{d(N_d(x))}{dx}$$

$$\boxed{E_x = \left(-\frac{KT}{e}\right)\frac{1}{N_d(x)}\frac{d\,N_d(x)}{dx}}$$

Ques.

$N_d(x) = 10^{16} - 10^{19}x \ (cm^{-3})$ $\qquad 0 \le x \le 1\ \mu m$

$$\frac{d}{dx}N_d(x) = -10^{19}$$

$$E_x = -\frac{(0.0259)(-10^{19})}{(10^{16} - 10^{19}x)} \qquad \boxed{\frac{KT}{e} = 0.0259}$$

at $x = 0$

$$E_x = 25.9 \ V/cm$$

→ **The Einstein Relation :-**

In thermal equilibrium, the individual e^- & hole current must be zero.

$$J_n = 0 = en\mu_n E_x + eD_n\frac{dn}{dx}$$

$$n \approx N_d$$

$$0 = e\mu_n N_d E_x + eD_n\frac{d}{dx}(N_d(x))$$

Interrupt Control Unit:

- It receives hardware interrupt signals and sends an acknowledgement for receiving the interrupt signal.

$$0 = -e\mu_n N_d(x)\left(\frac{KT}{e}\right)\frac{1}{N_d(x)}\frac{d}{dx}N_d(x) + e D_n \frac{d}{dx}(N_d(x))$$

$$\boxed{\frac{D_p}{\mu_p} = \frac{KT}{e}}$$

* **Hall effect :-** Whenever a s.c specimen carrying current is placed in a transverse mag. field, then ⊥ dir. to both current & magnetic field, an E will produce. This is known as Hall effect

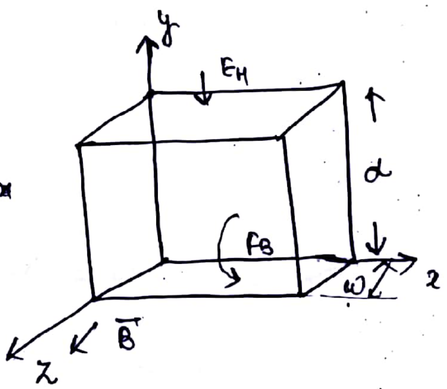
- Used to distinguish b/w p or n type
- Used to measure majority carrier concn & majority carrier mobility
- Used to experimentally measure s.c parameters
- Used as magnetic probe
- ~~Used as~~ Using in magnetic flux leakage
- to detect rotation speed
- Ferrite Toroid Hall Effect current transducers
- Analog multiplication
- Position & motion sensors

$$F = q[E + v \times B] = 0$$

$$qE_y = qv_xB_z \Rightarrow E_y = v_dB_z$$

$$\& \; V_H = E_H d$$

$$\cancel{V_H = v_x w B_z}$$



$$V_H = E_H \cdot d$$

$$V_H = v_d \cdot B \cdot d$$

$$\left[v_d = \frac{V_H}{Bd}\right]$$

Also, $\rho = ne$

$$\boxed{n = \frac{iB}{V_H e w}}$$

also $J = i/A$

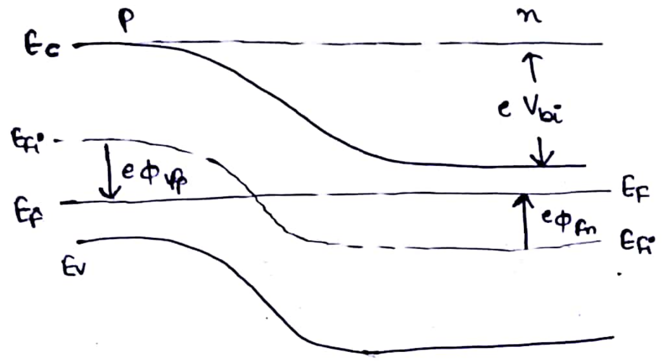
$$\Rightarrow i/wd$$

$$J = \rho v_d$$

$$\frac{i}{wd} = \rho v_d$$

$$\frac{i}{wd} = \frac{\rho V_H}{Bd} \Rightarrow \boxed{\rho = \frac{iB}{V_H \cdot w}}$$

* Built in Potential Barrier :-



In thermal equilibrium,

diffusion current of e^-/holes = drift current of e^-/holes

~~[illegible]~~ at the condn, eqlb occured & flow of e^- stopped.

So,

$$D_p \frac{dp}{dx} \times q = \mu_p \times p \times E \times q$$

$$\int_{p_n}^{p_p} D_p \frac{dp}{p} = \int_{x_1}^{x_2} \mu_p E \, dx$$

$$D_p \log \frac{p_p}{p_n} = \mu_p \left[V_{x_1} - V_{x_2}\right]$$

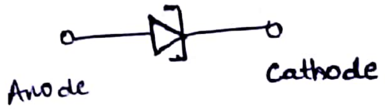
$$D_p \log \frac{N_a \times N_d}{n_i^2} = \mu_p V_0$$

$$\boxed{V_0 = \left(\frac{D_p}{\mu_p}\right) \ln\left(\frac{N_a N_d}{n_i^2}\right)}$$

$$\left[V_0 = \frac{KT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right)\right]$$

Tunnel Diode

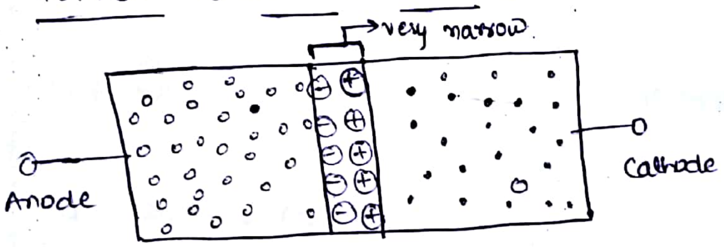
* Tunnel Diode symbol



* Tunnel Diode Basic :- invented by Leo Esaki in 1957.
  - → ~~used in~~ has fast switching
  - → used in microwave app.

* Based on quantum mechanical tunneling.
* Highest freq. Room temp solid state oscillator are based on RTD (resonant tunneling diode)
* metal insulator metal (MIM).

* Tunnel Diode structure :-



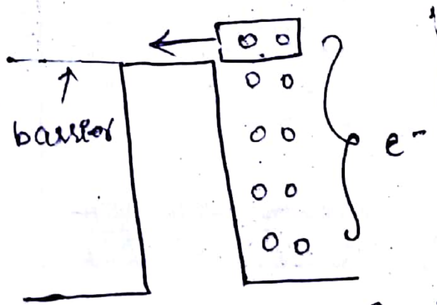
→ GaAs
→ GaSb
→ Si

fabrication.

* doping level in p-type as well as in n-type is very high.

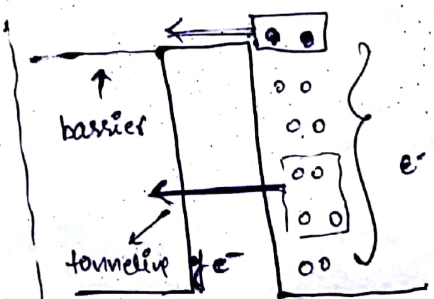
* Tunnel Diode characteristics:-

* Tunnel Diode working :



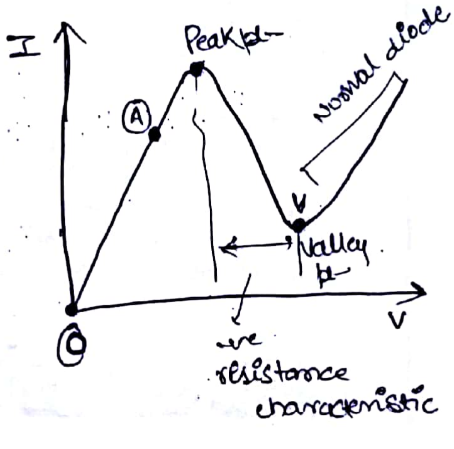
in normal PN junction

e⁻ having ~~more~~ higher potential energy than barrier will jump from N side to P side

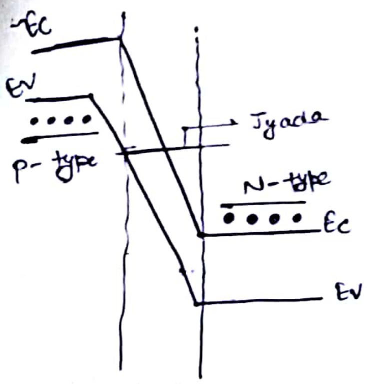


in tunnel diode

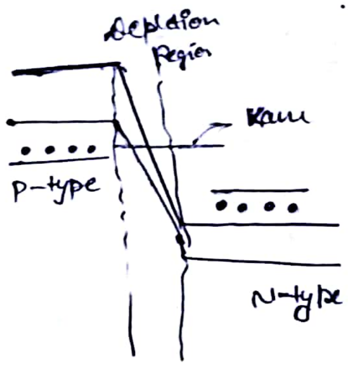
in this having lower energy, e⁻ penetrate through depletion region coz of heavy doping.



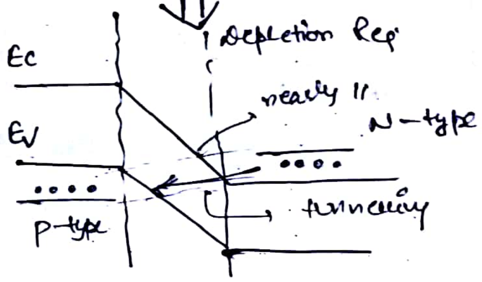
* Tunnel Diode Band Diagram :-



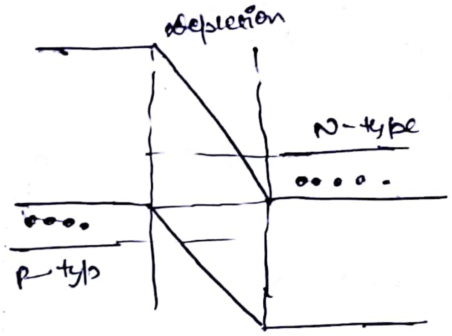
No bias (point O)



forward bias (point A)



forward bias (pt. P)



forward bias (pt V)

* BJT :- 3 terminal device

→ Amplification of weak signals
→ switching operation