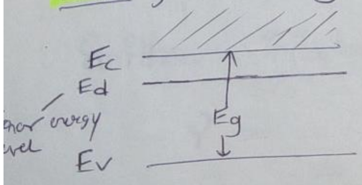
D] Emitter Bandgap narrowing:

- Another phenomenon affecting the emitter injection efficiency (γ) is "bandgap narrowing".

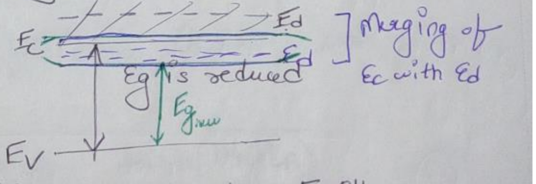
$$\gamma \approx \frac{1}{1+\frac{N_B}{N_E}\frac{D_E}{D_B}\frac{W_B}{W_E}} \quad \text{— ①}$$

From eq^n, it is clear that γ approaches unity as ratio of base doping to emitter doping continue to ↓se ie as $\left(\frac{N_B}{N_E}\right)$ ↓ses. $\Rightarrow \gamma \rightarrow 1$.

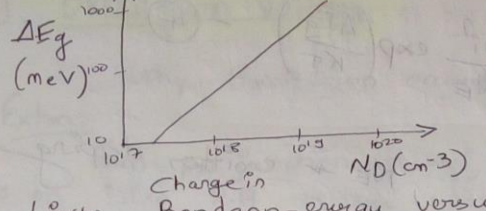
- As Silicon becomes heavily doped, the discrete donor energy level in an ntype-emitter splits into a band of energies.
- The distance between donor atoms ↓ses as the concentration of impurity donor atom ↑ses and the splitting of donor level is caused by the interaction of donor atoms with each other.
- As doping N_E (emitter) continues to ↑se, the donor band widens and moves up toward the conduction band, eventually merging with it. (as shown in fig(a)).



EBD of ntype emitter



fig(a) EBD of ntype Emitter (heavily doped)



fig(b). Change in Bandgap-energy versus donor impurity concentration in Silicon.

Fig(b) shows a plot of change in bandgap-energy ΔE_g versus N_D.

- A reduction in the E_g ↑ses the intrinsic carrier concentration.
- The intrinsic carrier concentration is given by,

$$n_i^2 = N_C N_V \exp\left(\frac{-E_{g0}}{KT}\right) \quad -① \qquad \boxed{E_{g0} = E_C - E_V}$$

band-gap → at low doping

- In a heavily doped emitter, the n_i will become.

$$n_{iE}^2 = N_C N_V \exp\left(-\frac{(E_{g0} - \Delta E_g)}{KT}\right)$$

$$\boxed{n_{iE}^2 = n_i^2 \exp\left(\frac{\Delta E_g}{KT}\right)} \quad -②$$

where, E_{g0} is band-gap energy at a low doping and ΔE_g is bandgap narrowing factor.

Emitter injector efficiency factor was given by,

$$\gamma = \frac{1}{1 + \frac{P_{E0} D_E L_B}{n_{B0} D_B L_E} \cdot \frac{\tanh(W_B/L_B)}{\tanh(W_E/L_E)}} \quad -③$$

$$P_{EO} \simeq \frac{n_{iE}^2}{N_E} = \frac{n_i^2}{N_E}\exp\left(\frac{\Delta E_g}{KT}\right) \quad - ④$$

$\downarrow$
equilibrium minority carrier concentration in the emitter. , $N_E \rightarrow$ emitter doping

As N_E ↑ses, ΔE_g ↑ses, thus it causes P_{EO} to ↑se (becoz of bandgap narrowing)

· As P_{EO} ↑ses, γ ↓ses, this then causes the transistor gain to ↓se.

$\gamma \rightarrow$ emitter injection efficiency.

Thus, a very high emitter doping may result in a smaller current gain that anticipated because of band-gap narrowing effect.

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E] Breakdown voltage

Why Breakdown occurs?

Extra:

From pn junction theory, we know that as you go on ↑sing R.B voltage across a junction, impact ionization within depletion layer sets in. and because of impact-ionization (there is generation of extra EHP's), reverse current that is flowing through depletion layer starts getting multiplied (EHP generation process). As a result, there is a rapid ↑se in reverse current in the device, & this is the reason for breakdown.

Qualitatively: Breakdown means ⇒ (sudden/rapid) change in current.

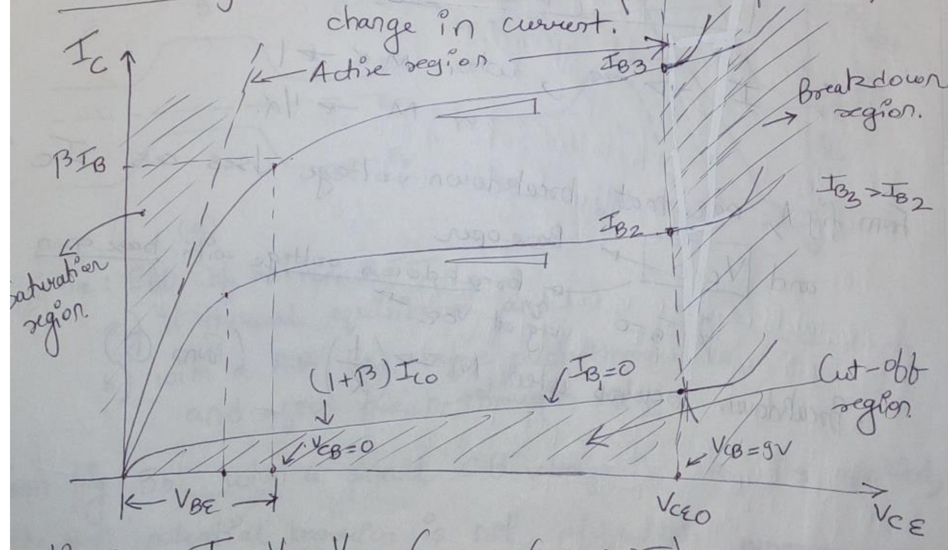

fig (A) I_C Vs V_{CE} Curve (npnTr.)

E] Breakdown voltage:

- There are two breakdown mechanisms in a BJT
  1) Punch-through breakdown
  2) Avalanche breakdown.

⇒ Punch-through breakdown:-

As R B.vtg V_{BC} ↑ses, the B-C depletion region widens and extends further into the neutral base.

- It is possible for the B-C depletion region to penetrate completely through the base and reach the B-E depletion region, the effect is called "punch-through".

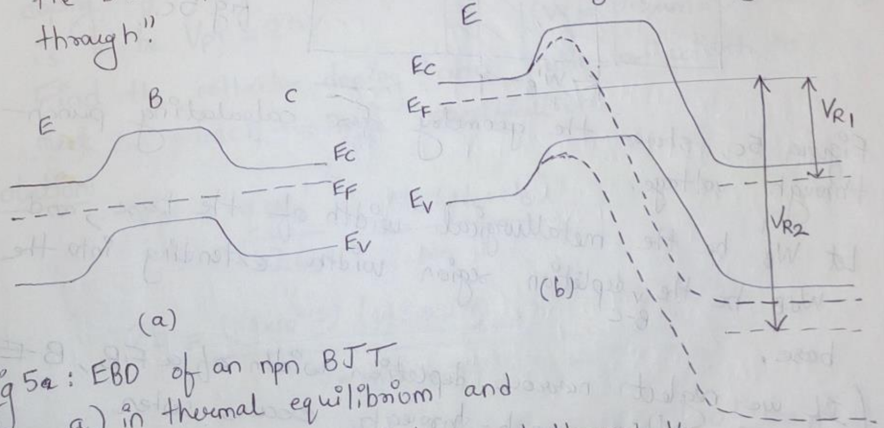

fig 5a: EBD of an npn BJT
a) in thermal equilibrium and
b) with a R.B V_{BC} before punch-through V_{R1} and after punch-through V_{R2}

From fig 5b, when a small C-B voltage i.e V_{R1} is applied, the B-E potential barrier is not affected.

- When a large reverse-bias voltage (V_{R2}) is applied, the B-C depletion region extends through the base region and B-E junction potential barrier is lowered because of CB voltage.
- The lowering of potential barrier at BE junction produces a large ↑se in current, with a very small ↑se in CB voltage. This effect is called the "punch-through breakdown" phenomenon.

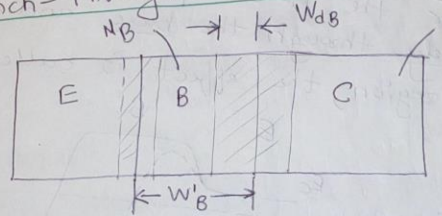

fig 5c.

- Figure 5c, shows the geometry for calculating punch-through voltage.

Let W_B' be the metallurgical width of the base, and W_{dB} be the B-C depletion region width extending into the base.

(If we neglect narrow depletion width of a F.B, B-E junction, then punch-through occurs when

$$W_{dB} = W_B'$$

$$W_B' = W_{dB} = \left[\frac{2\epsilon_s(V_{bi}+V_{pt})}{q}\frac{N_C}{N_B}\left(\frac{1}{N_C+N_B}\right)\right]^{1/2} \quad \text{—①}$$

where, V_{pt} is R.B, B-C voltage at punch-through.

- If we neglect $V_{bi} << V_{pt}$, and solve for V_{pt} from equation ①, we get

$$W_B'^2 = \frac{2\epsilon_s V_{pt}}{q} \frac{N_C}{N_B}\left(\frac{1}{N_C+N_B}\right)$$

ie $$\boxed{V_{pt} = q\frac{W_B'^2 \, N_B(N_C+N_B)}{2\epsilon_s N_C}} \quad \text{— ②}$$

E.1. Consider a uniformly doped Si BJT with a

0.5 µm and a base