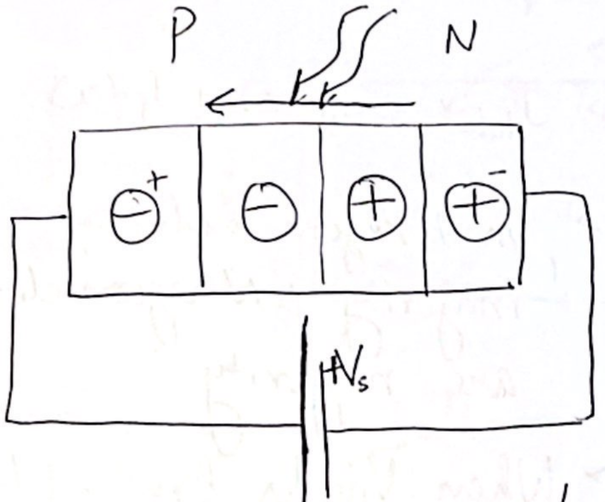
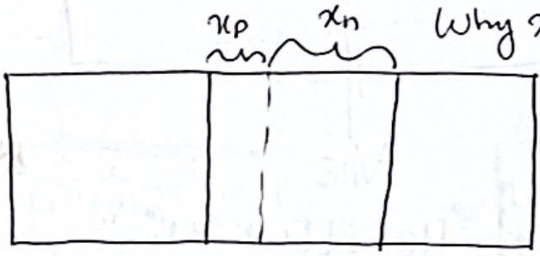
Lec 11

Photodiodes & Photovoltaic cells

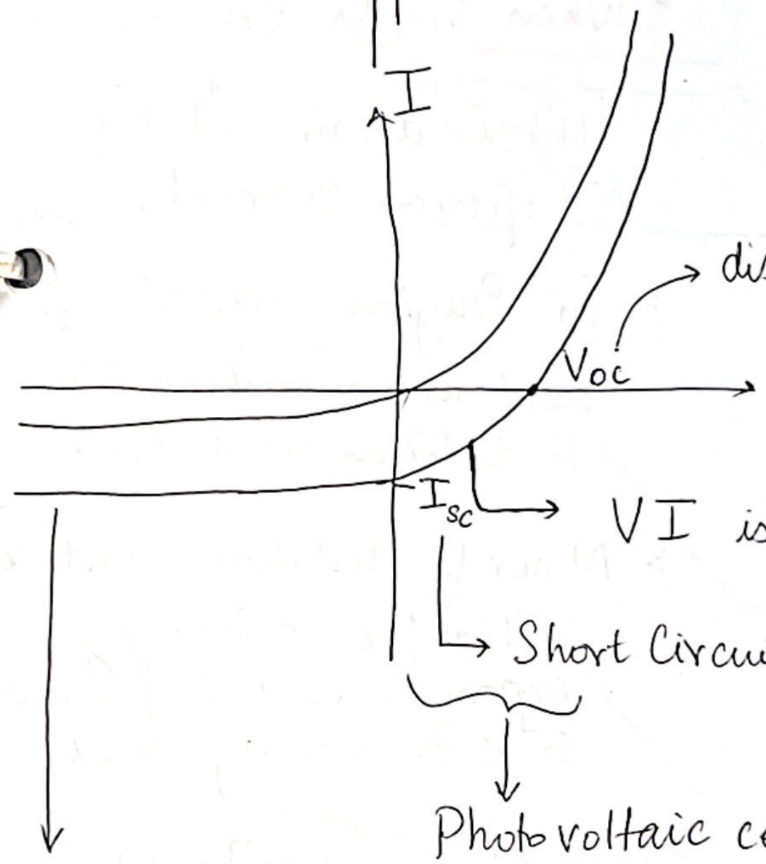


$$I_D = I_s\left(e^{\frac{qV_s}{KT}} - 1\right) - I_{sc}$$

↑ photo current.



Why $x_n > x_p$ — we want electron & hole to reach electrode at same time.



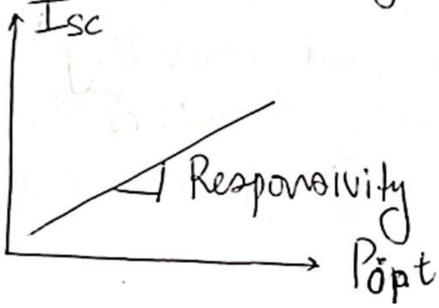
V_{oc} → disconnect load & V_s & measure V.

→ VI is Negative ⇒ can extract power.

I_{sc} → Short Circuit current ⇒ Photocurrent from Drift.

→ Photovoltaic cell → Supplies power (Negative resistor)

Photodiode → converts light to current (current source)

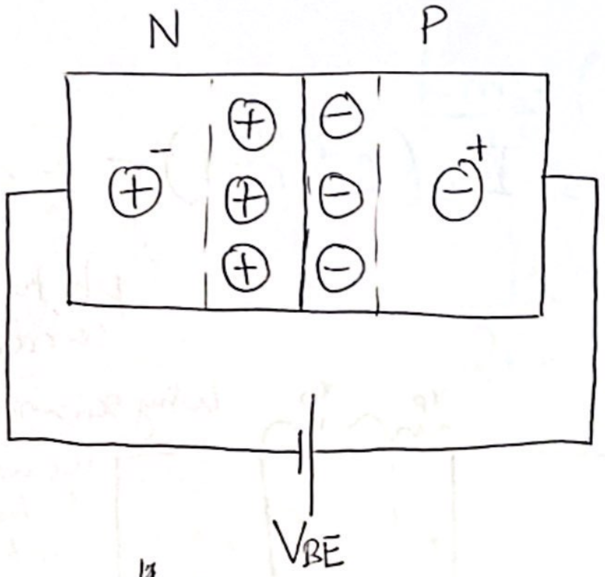


> PIN Diode → increase depletion region.

> APD → uses avalanche

Bipolar Junction Transistor

→ We want to make a "Trans Resistor" (VCCS)

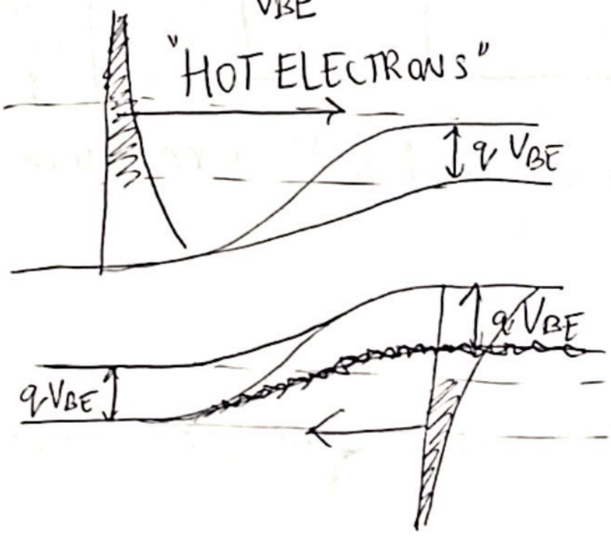


> $J_{total} = J_n(x) + J_p(x)$

> In P region holes are majority & N region electrons are majority

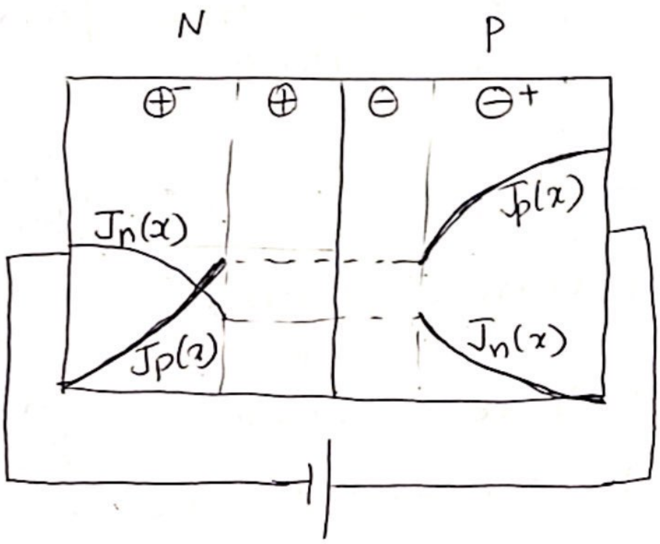
> When V_{BE} is forward biased

J_{total} is dominated by diffusion current.



> In P region injected electrons recombine close to depletion band edge.

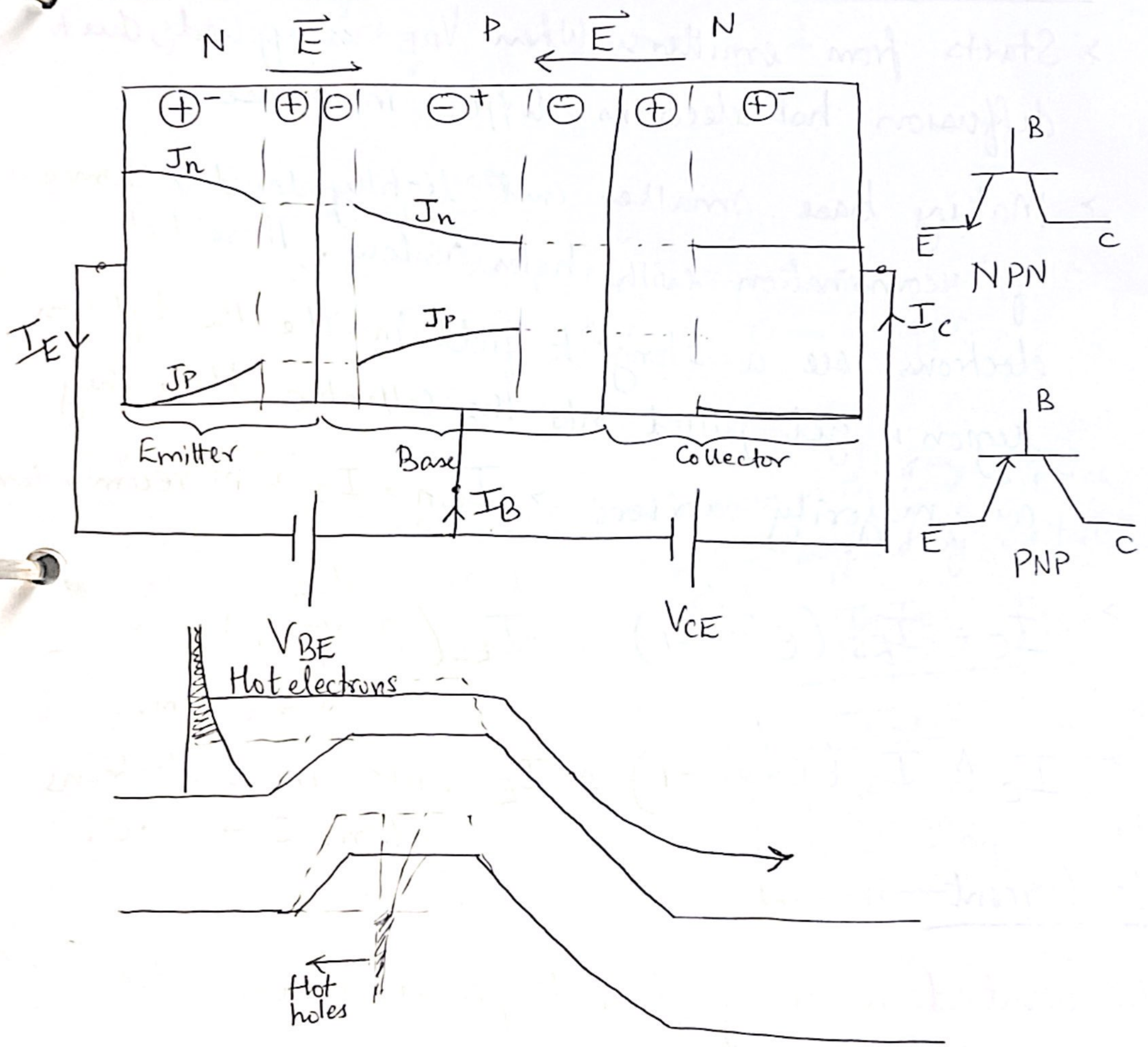
> Minority distribution wrt x is therefore a decaying exponential. Rate of Recomb is $\propto$ to minority concentration.



> $J_p(x) = J_{total} - J_n(x)$
(majority) (minority)

> Note that controlling the minority carriers determines the majority carrier distribution.

NPN BJT



> BE is FB & CE is RB

> By proper design we can control I_c with VBE
> ⇒ VCCS.

Electron Current

> Starts from emitter. When V_{BE} is applied, due to diffusion hot electrons diffuse into base.

> Making base smaller and lightly doped ⇒ chance of recombination with holes is low. These hot electrons see a strong E field in the BC depletion region & get pulled into the collector. Here they are majority carriers ⇒ $I_{C,n} = I_C$ & no recombination.

> $$I_E = I_{ES}\left(e^{\frac{qV_D}{KT}}-1\right) = I_{ES}\left(e^{\frac{V_{BE}}{V_T}}-1\right)$$
(V_T → 25.9mV.)

> $I_C \triangleq I_S\left(e^{\frac{V_{BE}}{V_T}}-1\right) \simeq I_E$ since most electrons go from E → B → C.

Hole Current

> We want to minimize this to prevent recombination with electrons in Base & Emitter. So we heavily dope emitter & reduce Base doping ⇒ electrons even (they a minority carrier) in Base dominate.

Emitter Injection Efficiency

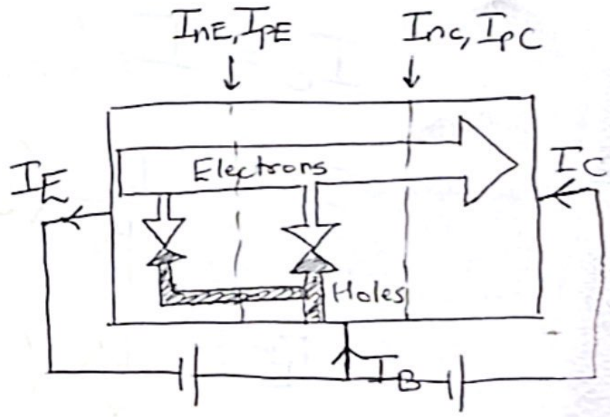
$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}}$$ we want $\gamma \simeq 1$

Base Transport Factor

$$\alpha_T = \frac{I_{nC}}{I_{nE}}$$ → How many electrons make to to Collector from Emitter.

Base Current

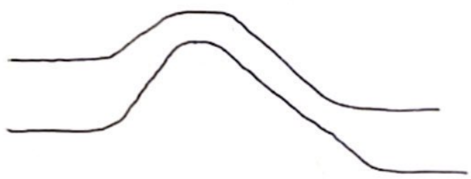
> Holes that recombine with electrons in the base & holes that go from B→E FB junction are supplied by the base current which is not zero.



> Total efficiency

$$\alpha_0 = \frac{I_C}{I_E} \simeq \alpha_T \cdot \gamma$$

> To reduce holes from B → E we can use a lower bandgap material in the base (Heterojunction Bipolar Transistor)



KCL $\Rightarrow$ $I_C + I_B = I_E$

$$\Rightarrow I_C = \frac{\alpha_0}{1-\alpha_0} I_B$$

$$\Rightarrow \beta_0 = \frac{I_C}{I_B} = \frac{\alpha_0}{1-\alpha_0}$$

$$I_E = I_{ES}\left(e^{V_{BE}/V_T} - 1\right)$$

$$I_C = \alpha_0 I_E = \alpha_0 I_{ES}\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

Since $I_C = I_S\left(e^{\frac{V_{BE}}{V_T}} - 1\right) \Rightarrow I_S = \alpha_0 I_{ES}$.

$$I_B = \frac{I_S}{\beta_0}\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

$$I_E = \frac{I_S}{\alpha_0}\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

Note

> For diffusion currents FB $\Rightarrow$ Majority "hot" carriers cross over; RB $\Rightarrow$ minority carriers are pulled across by $\vec{E}$. We are ignoring drift due to EH pair generation in the depletion region.