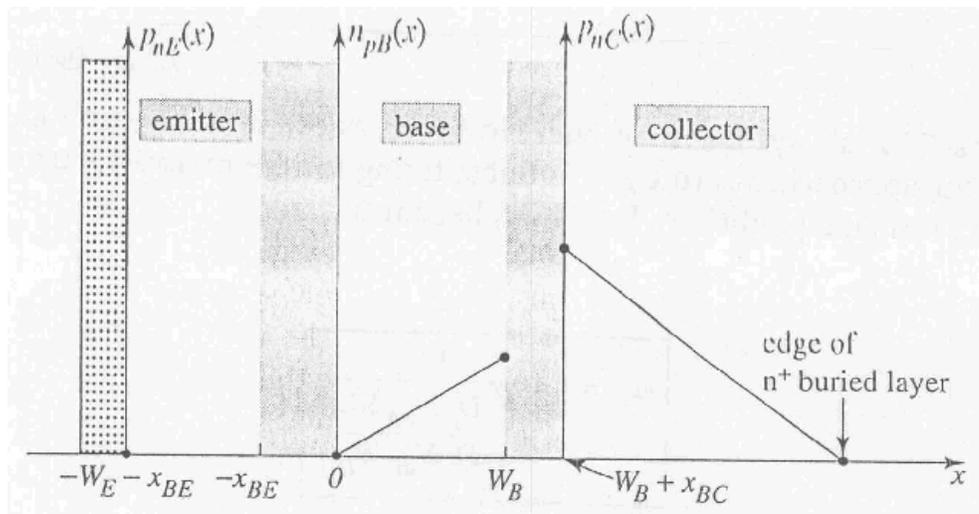
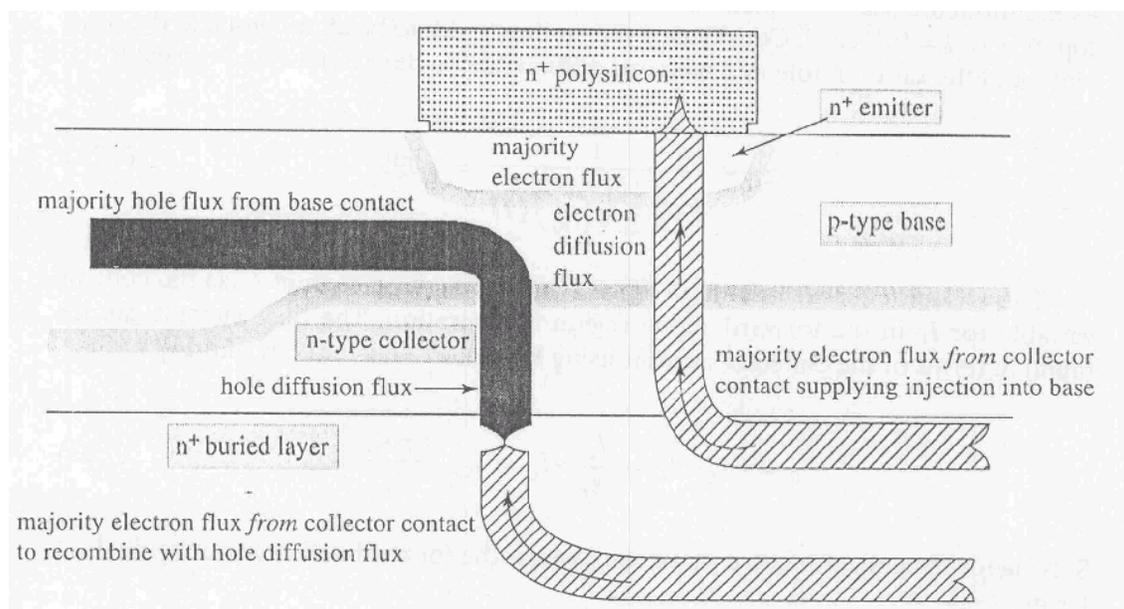


## Reverse-Active Region

- In reverse-active,  $I_B > 0$ , BC junction is forward biased and BE junction is reverse biased
- $V_{CE} < -0.1V$ ,  $V_{BC} \sim 0.7V$ ,  $V_{BE} < 0$
- Example:  $V_{BE} = -2V$ ,  $V_{BC} = 0.7V$

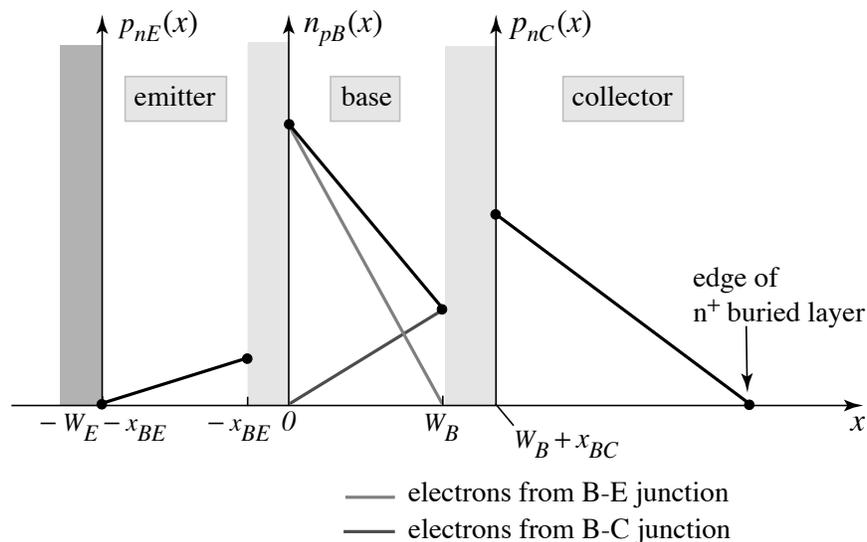


- BC junction injects electrons in the base, and they are swept into the Emitter. Larger base current.



## The Saturation Region

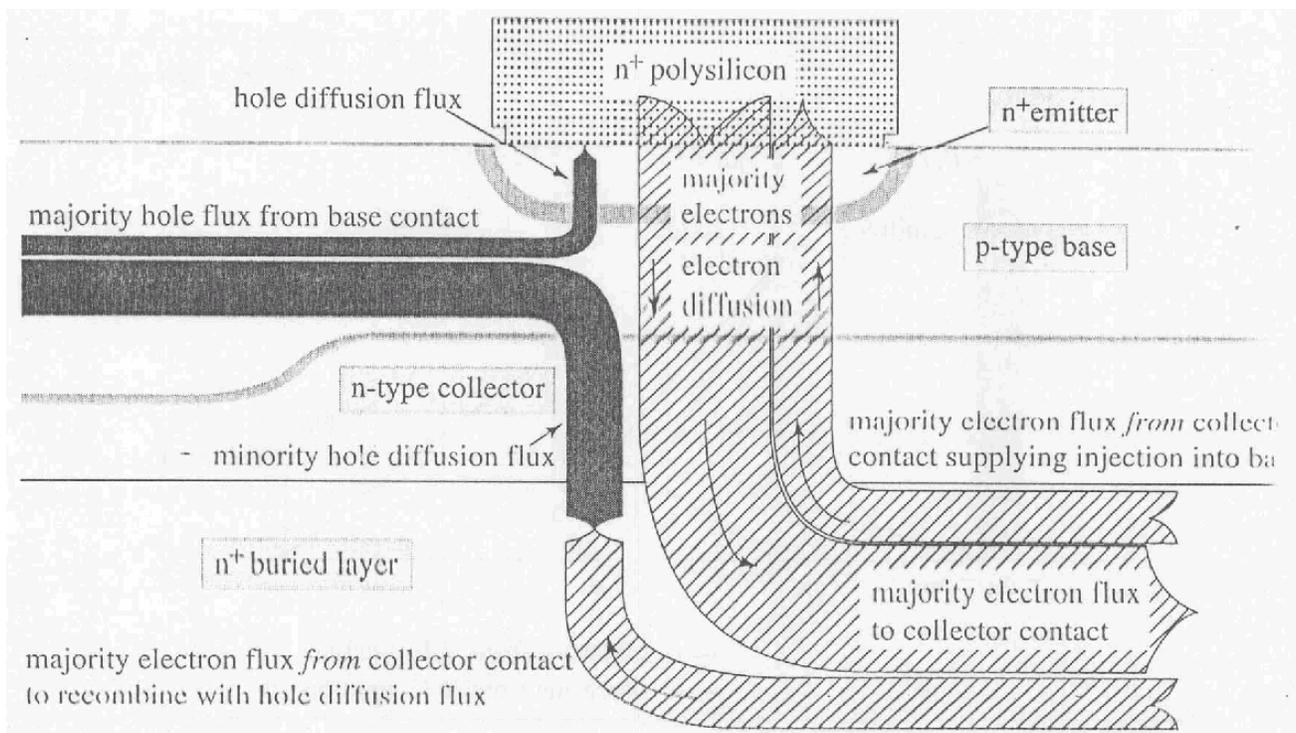
- $V_{CE(sat)} = 0.1 \text{ V}$  (approx) from the characteristics --> both the emitter-base and the base-collector junctions are forward-biased
- Law of the Junction --> find minority carrier concentrations in the emitter, base, and the collector



- Both junctions are injecting and both are also collecting ... since the electric field in the depletion region remains in the same direction under forward bias.
- Separate the electron diffusion current in the base into two components: one due to the emitter-base junction (with zero bias on the base-collector junction) and the other due to the base-collector junction:

$$J_{nB}^{diff} = -qD_n \frac{n_{pB0}(e^{V_{BE}/V_{th}} - 1)}{W_B} + qD_n \frac{n_{pB0}(e^{V_{BC}/V_{th}} - 1)}{W_B}$$

# Saturation region currents



## Ebers-Moll Model

- Electron diffusion current in the base: multiply by the emitter area

$$I_{diff} = \boxed{-I_S(e^{V_{BE}/V_{th}} - 1)} + \boxed{I_S(e^{V_{BC}/V_{th}} - 1)} = -I_1 + I_2$$

- Emitter current  $I_E$ : three components

1.  $-I_1$  due to injection of electrons from the emitter-base junction,
2.  $-I_1 / \beta_F$  due to reverse injection of holes into the emitter, and
3.  $I_2$  due to collection of electrons from the base-collector junction.

$$I_E = -I_1 + (-I_1/\beta_F) + I_2 = -\left(1 + \frac{1}{\beta_F}\right)I_1 + I_2 = -\left(\frac{1}{\alpha_F}\right)I_1 + I_2$$

- Collector current  $I_C$ : three components (by symmetry)

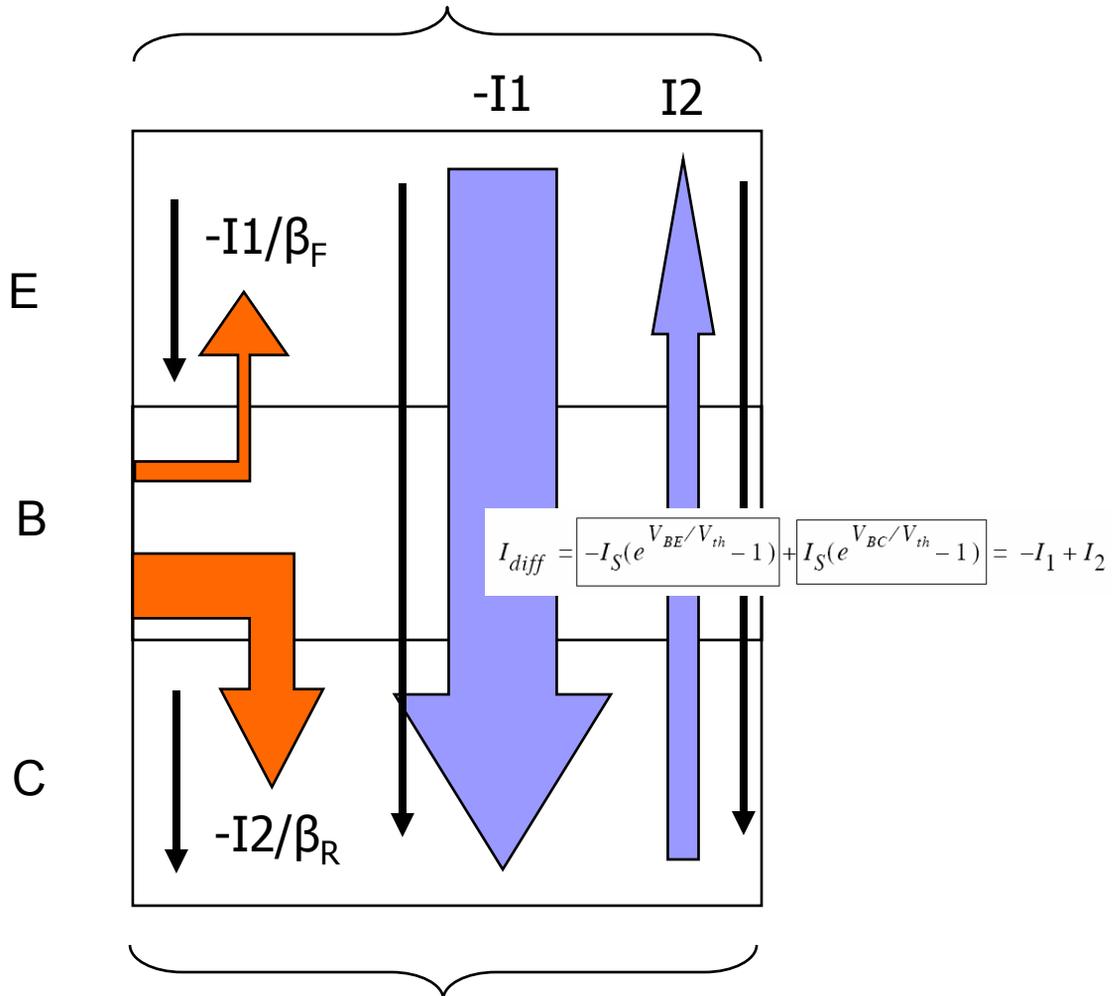
1.  $-I_2$  due to injection of electrons from the base-collector junction,
2.  $-I_2 / \beta_R$  due to reverse injection of holes into the collector, and
3.  $I_1$  due to collection of electrons from the emitter-base junction

$$I_C = I_1 - I_2 - \frac{I_2}{\beta_R} = I_1 - \left(1 + \frac{1}{\beta_R}\right)I_2 = I_1 - \left(\frac{1}{\alpha_R}\right)I_2$$

$\beta_R = \alpha_R / (1 - \alpha_R)$  is the reverse current gain

# Ebers Moll model

$$I_E = -I_1 + (-I_1/\beta_F) + I_2 = -\left(1 + \frac{1}{\beta_F}\right)I_1 + I_2 = -\left(\frac{1}{\alpha_F}\right)I_1 + I_2$$



$$I_C = I_1 - I_2 - \frac{I_2}{\beta_R} = I_1 - \left(1 + \frac{1}{\beta_R}\right)I_2 = I_1 - \left(\frac{1}{\alpha_R}\right)I_2$$

## Ebers-Moll Model (cont.)

- “Standard form” for Ebers-Moll equations: define two new constants

$$I_{ES} = I_S / \alpha_F \text{ and } I_{CS} = I_S / \alpha_R,$$

- Emitter current:

$$I_E = -I_{ES}(e^{V_{BE}/V_{th}} - 1) + \alpha_R I_{CS}(e^{V_{BC}/V_{th}} - 1)$$

- Collector current:

$$I_C = \alpha_F I_{ES}(e^{V_{BE}/V_{th}} - 1) - I_{CS}(e^{V_{BC}/V_{th}} - 1)$$

- The collector current and the emitter current represent two diodes with current-controlled current sources coupling the emitter and the collector branches

## Carrier Fluxes in Saturation

- Both junctions injecting and collecting; holes injected into collector recombine with electrons upon reaching the  $n^+$  buried layer
- For bias condition shown,  $I_C > 0$  ... injection from emitter-base junction still dominates. (could have  $I_C = 0$  or even  $I_C < 0$ )

