Mon $\longrightarrow$ 289

BJT

NPN

$n^+ > p^+ > n$

E　　　B　　　C

i_E

$n^+ \rightarrow N_{d_E}$　$p^+ \rightarrow N_{a_B}$　$(n) \rightarrow N_{d_C}$

i_C

$e^- \ominus$

$\ominus$ $\oplus$

$\ominus$

h^+

i_B

v_{BE}　v_{BC}

v_{BC}
B
C
E
v_{BE}

C　　P　　　E

p^+　n^+　p^+　n^+　p　n^+

n

n^+

buried layer

$p - Si$

Regions of operation:

BE	BC	
R	R	Cutoff
F	R	Forward - Active
R	F	Reverse - Active
F	F	Saturation

Cut off:

[Diagram: BJT symbol with B, C, E terminals]

$B \,\, \multimap \quad$ [open circuit] $\quad \uparrow I_C$ $\quad$ in reality $\quad$ [diagram with B, $I_{S_{CB}}$, $I_{J_{BE}}$, C, E]

$\uparrow I_E$

Forward - Active Region

E $\qquad$ B $\qquad$ C

[Diagram of BJT cross-section]

n^+ $\qquad r^+ \,\, w_B \qquad n$

I_E $\quad e^- \longrightarrow$ $\qquad$ ①

② ③ h^+

$\longleftarrow I_C$

$0 \qquad w_B$

$\uparrow I_B$

$V_{BE} \sim 0.7V \qquad V_{BC}$

$V_T = \dfrac{KT}{q}$

n^+

Minority carriers

$p_{nE}(0) = \dfrac{n_i^2}{N_{dE}} \cdot e^{\frac{V_{BE}}{V_T}}$

$n_{pB}(0) = \dfrac{n_i^2}{N_{aB}} \cdot e^{\frac{V_{BE}}{V_T}}$

$-w_E \quad (-L_p \quad 0 \qquad w_B \qquad\qquad x$
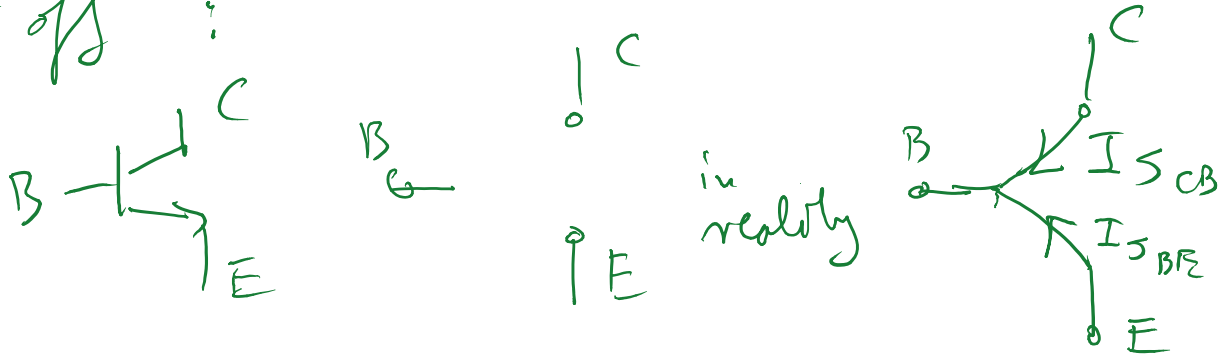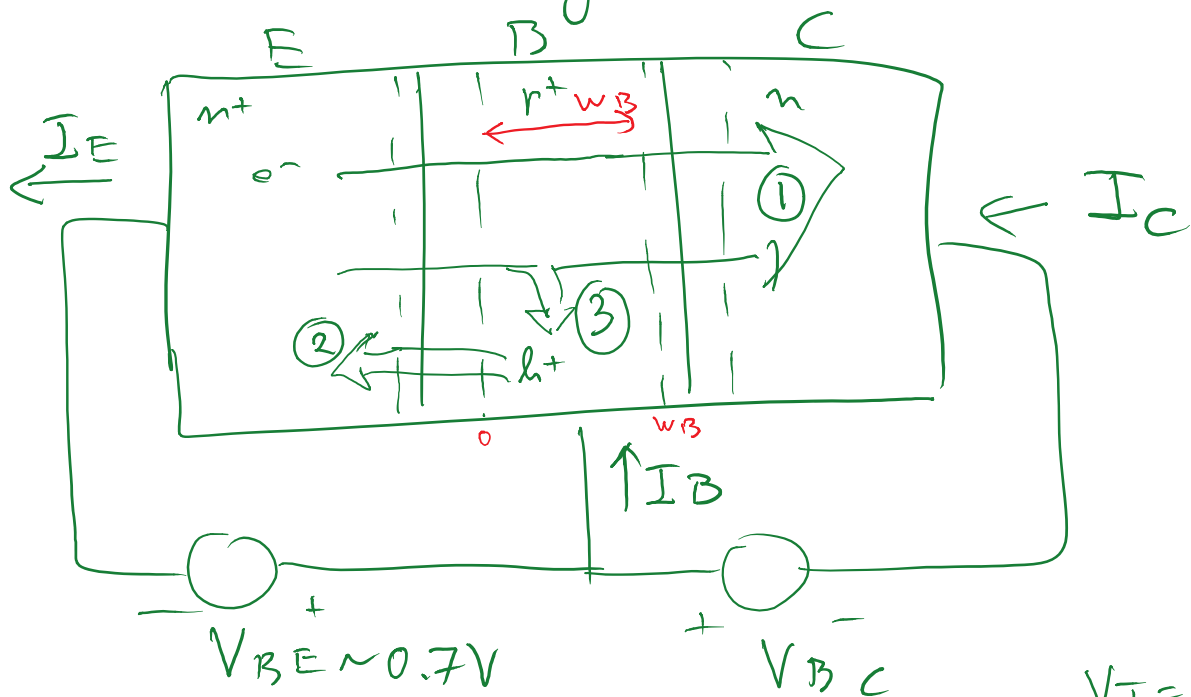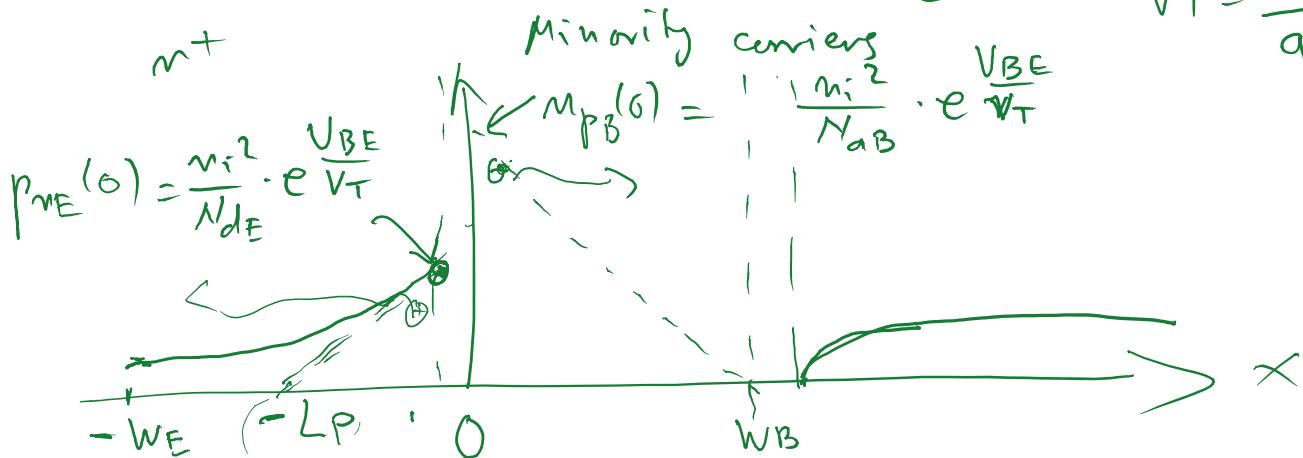
that did not recombine

① e^- injected from E to B $\overset{v}{:}$ $I_{nB} = -A \cdot J_{nB}^{diff}$

② h^+ injected from B to E : $I_{pE} = A \cdot J_{pE}^{diff}$

③ recombination current in B : I_{rB}

$$I_C = I_{nB}$$

$$I_B = I_{rB} + I_{pE} \quad , \quad I_{pE} \gg I_{rB}$$

$$I_E = I_c + I_B$$

Collector current :

$$I_C = I_{nB} = -A \cdot J_{nB}^{diff} = -Aq\,D_{nB} \cdot \frac{d\, n_{pB}(x)}{dx} =$$

diffusion coeff

$$= q\,A\,D_{nB}\, \frac{n_{pB}(0)}{W_B} = q\,A\,D_{nB}\, \frac{n_i^2}{N_{aB} \cdot W_B} \cdot e^{\frac{V_{BE}}{V_T}} \quad \text{slope in base}$$

$$I_C = I_{nB} = I_S \cdot e^{\frac{V_{BE}}{V_T}}$$

Base current: in base I_{B2}, I_{B1}

I_{pE}, I_{rB}

$$I_{pE} = A J_{pE}^{diff} = A q D_{pE} \cdot \frac{d p_{nE}(x)}{dx} =$$

$p_{nE}(0)$

$-W_E \quad -L_P$

$$I_{pE} = A q D_{pE} \cdot \frac{p_{nE}(0)}{L_P} = \boxed{A q D_{pE} \frac{n_i^2}{N_{dE} \cdot L_P} \cdot e^{\frac{U_{BE}}{V_T}}}$$

$$I_{rB} = \frac{Q_e}{\tau_B} = \frac{1}{\tau_B} \cdot \left(\frac{1}{2} \boxed{n_{rE}(0)} \cdot W_B q A \right)$$

$n_{rE}(0)$ $\quad \uparrow$ lifetime $\qquad$ average # elechs

$\xleftrightarrow[W_B]{} \circ$

$$= \frac{1}{2} \frac{n_i^2 \cdot W_B}{N_{aB} \tau_B} \cdot q A e^{\frac{U_{BE}}{V_T}}$$

$$I_B = I_{pE} + I_{rB} = q A n_i^2 \left[\frac{D_{pE}}{N_{dE} \cdot L_P} + \frac{W_B}{2 N_{aB} \tau_B} \right] \cdot e^{\frac{U_{BE}}{V_T}}$$

Forward - current gain:

$$\beta_F = \frac{I_C}{I_B} = \frac{\frac{D_{nB}}{N_{aB} \cdot W_B}}{\frac{D_{pE}}{N_{dE} L_P} + \frac{W_B}{N_{aB} \cdot \tau_B}}$$

$$= \frac{1}{\frac{D_{pE}}{D_{nB}} \cdot \frac{W_B}{L_P} \cdot \boxed{\frac{N_{aB}}{N_{dE}}} + \frac{W_B^2}{2 \tau_B \cdot D_{nB}}}$$

N_{aB}, N_{dE} W_B

To maximize β_F:

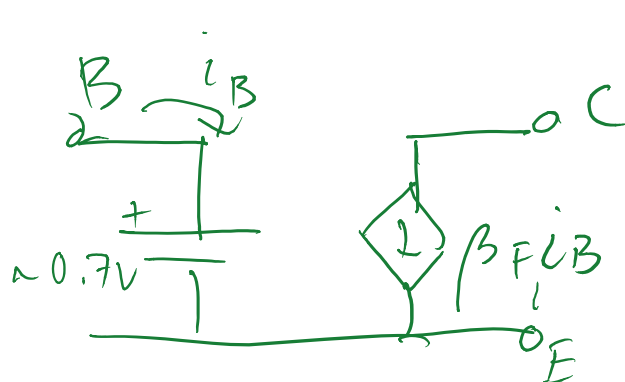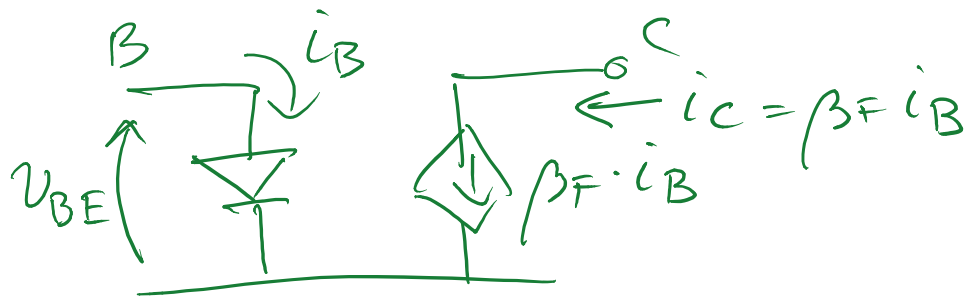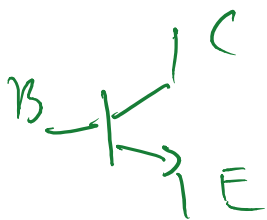- $W_B \downarrow$
- $N_{aB} \ll N_{dE}$

$NPN: \beta_F \sim 50\text{-}500$

$PNP: \beta_F \sim 5\text{-}100$

Emitter current

$$I_E = I_B + I_C = I_C + \frac{I_C}{\beta_F} = \frac{I_C}{\alpha_F}$$

$$\alpha_F = \frac{\beta_F}{1 + \beta_F} \cong 0.99$$

F.A. Region model - Large Signal

$$i_C = \beta_F i_B$$

$$\beta_F \cdot i_B$$

$$\sim 0.7V$$

$$\beta_F i_B$$

$$i_B = \frac{I_S}{\beta_F} e^{\frac{V_{BE}}{V_T}}$$