

1. $p_p = 100n$ $W_b = 0.1 \cdot L_p$

$$\frac{L_p^*}{L_n^*} = \frac{\sqrt{D_p \cdot \tau_p}}{\sqrt{D_n \cdot \tau_n}} = \sqrt{2}$$

$$\alpha = \beta \cdot \gamma = \frac{1}{\cosh\left(\frac{W_b}{L_p}\right) + \frac{L_p^* \rho_n \mu_{np}}{L_n^* \rho_p \mu_{pn}} \sinh\left(\frac{W_b}{L_p}\right)} = 0.988$$

$$\beta = \frac{\alpha}{1 - \alpha} = 82$$

2 a) $I_c = \frac{q \cdot A \cdot D_p \cdot p_n}{W} = \frac{q \cdot A \cdot D_p \cdot n_i^2 \cdot 2 \cdot V_{BE}}{N_A W_b \cdot e \cdot \frac{KT}{q}}$

$$I_c' = \frac{I_c}{10 \times 0.5} = \frac{I_c}{5}$$

b) $I_E \propto \frac{n_i^2}{N_E \cdot W_E} \cdot e \cdot \frac{2 \cdot V_{BE}}{KT}$

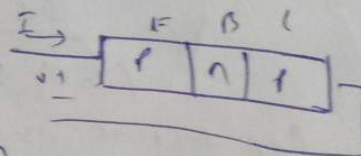
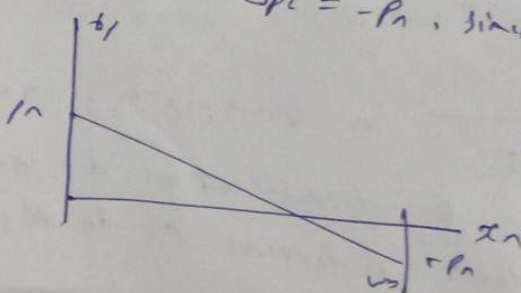
$$\gamma = \frac{I_{Ep}}{I_{Ep} + I_{En}} = \frac{1}{1 + \frac{N_B \cdot W_D}{100 \cdot N_E \cdot 0.1 \cdot W_E}} = \frac{1}{1 + 0.1} = 0.91$$

c) Bulk carrier profile for long diode exponentially decays to 0;
If $N_E = 100 \cdot N_B$, $L_n = L_p = L$ $\beta = 0$

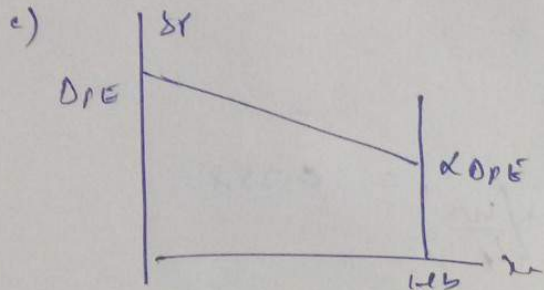
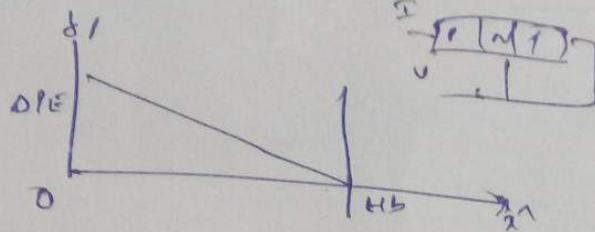
$$I_{Ep} \propto \frac{n_i^2}{N_B \cdot L} \cdot e \cdot \frac{2 \cdot V_{BE}}{KT} \quad \text{and} \quad I_{En} \propto \frac{n_i^2}{N_E \cdot L} \cdot e \cdot \frac{2 \cdot V_{BE}}{KT}$$

$$\gamma = \frac{I_{Ep}}{I_{Ep} + I_{En}} = \frac{1}{1 + \frac{N_B}{N_E}} = \frac{1}{1 + \frac{N_B}{100 \cdot N_B}} = \frac{1}{1 + 0.01} = 0.99$$

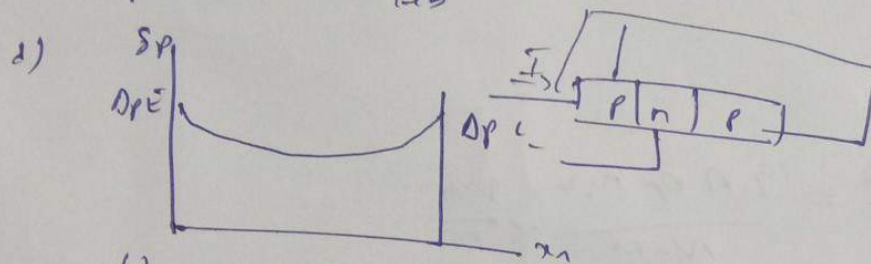
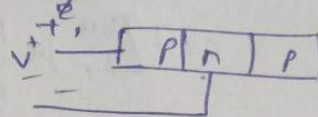
3) a) $I_E = I_c$, $I_B = 0$, since V_{is} large (the collector is strongly reverse biased). $\Delta p_c = -p_n$, since $I_E = I_c$, $\Delta p_E = -\Delta p_c = p_n$



b) $V_{CB} = 0$, thus $\Delta p_E = 0$. Notice that this is the narrow-base diode distribution



since $I_C = 0$, $\Delta p_C = \alpha \Delta p_E$



1) $V_{CB} = V_{CB} = V$ Thus $\Delta p_C = \Delta p_E$

connection (b) gives best diode since stored charge is least and current is good. (a) not good diode since current is small (c) and (d) are not good.

4) current transfer ratio $= \beta = \frac{I_{CB}}{I_{EP}} = \frac{9.8 \text{ mA}}{10 \text{ mA}} = 0.98$

emitter efficiency

$$\gamma = \frac{I_{EP}}{I_{EP} + I_{EB}} = 0.9961$$

current gain $= \alpha = \beta \cdot \gamma = 0.97$

common emitter gain $= \beta = \frac{\alpha}{1 - \alpha} = 32.7$

$I_{CB} = 1 \text{ mA}$

$\tau_1 = 5 \cdot 10^{-9} \text{ s} = 5 \text{ ns}$

$\tau_f = \frac{Q_0}{(1 - \beta) I_{EP}}$

$= 2.45 \cdot 10^{-8} \text{ s} = 24.5 \text{ ns}$

I_{EP} decreases then β decreases as α decreases
 I_{EP} decreases then β decreases as α decreases

5)

total delay time for primitive given as

$$\tau_d = 10 \text{ ps} + \frac{10^{-9} \text{ s} \cdot 10^{12} \text{ ps}}{10^9} + 80 \text{ ps} + 10 \Omega \cdot 0.1 \text{ pF} = 141 \text{ ps}$$

$$f_T = \frac{1}{2\pi\tau_d} = 1.1 \text{ GHz}$$

c) $\Delta n_E = n_p \cdot e^{\frac{qV_{BE}}{kT}} = N_A n_i \rightarrow V_{BE} = \frac{kT}{q} \cdot \ln \frac{N_A n_i}{n_i} = 0.195 \text{ V}$

$$\frac{N_E}{N_B} = 100, \text{ high level injection.}$$

~~until~~ until emitter junction is biased to nearly 0.2 V,

contact potential $V_0 = 0.81 \text{ V}$, this is very high bias.

7)

a) $V_{biBE} = 0.55 + \frac{kT}{q} \ln \frac{N_B}{n_i} = 0.878 \text{ V}$

→ built-in potential at base-emitter junction can be given

→ collector-base junction given by,

$$V_{biC} = \frac{kT}{q} \left[\ln \frac{N_B}{n_i} + \ln \frac{N_C}{n_i} \right]$$

$$= 0.0257 \text{ V} \left[\ln \frac{10^{14}}{1.5 \times 10^{10}} + \ln \frac{10^{16}}{1.5 \times 10^{10}} \right] = 0.676 \text{ V}$$

$$W_{EB} = \sqrt{\frac{2\epsilon_B}{qN_B} (V_{biBE} - V_{EB})}$$

Since $N_E \gg N_B$ and B-E junction is forward

$$W_{EB} = \sqrt{\frac{2 \cdot 11.8 \times 8.8 \times 85 \times 10^{-14}}{1.6 \times 10^{-19} \cdot 1 \times 10^{-16}}}$$

$$\text{for } V_{EB} = 0.2 \text{ V}$$

$$V_{EB} = 0.6 \text{ V}$$

$$W_{EB} = 3.02 \times 10^{-5} \text{ cm}$$

$$W_{EB} = 1.97 \times 10^{-5} \text{ cm}$$

$$W_{EB} = \sqrt{\frac{2q N_A + N_B}{q N_A N_B}} \phi_p$$

$$N_B = N_A$$

$$W_{EB} = 0.426 \times 10^{-4} \text{ cm}$$

L = metallurgical base width = 1.5 microns

$$W_B = L - W_{EB} - \frac{N_A}{N_B + N_A} \times W_{EB}$$

$$V_{EB} = 0.2 \text{ V}$$

$$W_B = 1.5 - 0.302 - \frac{0.426}{2} = 0.98 \text{ microns}$$

$$V_{EB} = 0.6 \text{ V}$$

$$W_B = 1.09 \text{ microns}$$

$$b) \quad D_n = D_p = 10 \frac{\text{cm}^2}{\text{s}}$$

$$\tau_n = \tau_p = \tau_0 = 10^{-7} \text{ s}$$

$$L_n = \sqrt{D_n \tau_n} = 10^{-3} \text{ cm}$$

$$L_p = 10 \mu\text{m}$$

$$B = \frac{1}{\cosh\left(\frac{W_B}{L_p}\right)} \approx 1 - \frac{1}{2} \times \left(\frac{W_B}{L_p}\right)^2$$

$$\text{For } V_{EB} = 0.2 \text{ V} \rightarrow B = 1 - \frac{1}{2} \times \left(\frac{0.78 \mu\text{m}}{10 \mu\text{m}}\right)^2 = 0.975$$

$$V_{EB} = 0.6 \text{ V} \rightarrow B = 1 - \frac{1}{2} \times \left(\frac{1.07 \mu\text{m}}{10 \mu\text{m}}\right)^2 = 0.974$$

calculated I_{EP} and I_{EO} as function of V_{EB} .

$$I_{EP} = A \cdot q \cdot \frac{D_n n_i^2}{N_B W_B} \times e^{\frac{q V_{EB}}{kT}}$$

$$I_{EO} = A \cdot q \cdot \frac{D_p n_i^2}{N_A W_E} \cdot e^{\frac{q V_{EB}}{kT}} \quad (\text{hole current})$$

$$I_{EP} = 8.251 \times 10^{-12} \text{ A}$$

$$I_{EO} = 2.709 \times 10^{-11} \text{ A}$$

$$\therefore V_{EB} = 0.6 \text{ V}$$

$$I_{EP} = 3.8 \times 10^{-5} \text{ A}$$

$$I_{EO} = 1.38 \times 10^{-8} \text{ A}$$

$$\gamma = \frac{I_{E1}}{I_{E1} + I_{E2}}$$

$$V_{EB} = 0.2V \quad \gamma = 0.9997$$

$$V_{EB} = 0.6V \quad \gamma = 0.9996$$

c)

$$\alpha = \beta \gamma$$

$$V_{EB} = 0.2V \rightarrow \alpha = 0.995 \times 0.9997 = 0.9972$$

$$V_{EB} = 0.6V \rightarrow \alpha = 0.994 \times 0.9996 = 0.9976$$

To calculate β butz,

$$\beta = \frac{\alpha}{1 - \alpha}$$

$$V_{EB} = 0.2 \rightarrow \beta = 187.7$$

$$V_{EB} = 0.6 \rightarrow \beta = 155.3$$

calculate currents I_E , I_B and I_C for $V_{EB} = 0.2$ and $0.6V$

$$I_E = I_{E1} + I_{E2}$$

$$\text{For } V_{EB} = 0.2V \rightarrow I_E = 8.251 \cdot 10^{-12} A + 2.409 \times 10^{-14} A = 8.25 \mu A$$

$$V_{EB} = 0.6V \rightarrow I_E = 3.8 \times 10^{-5} A = 38 \mu A$$

collector and base current can be determined,

$$I_C = \beta A \times q \times \frac{D_1 \times n_i^2}{N_B \times W_B} \times e^{\frac{q \cdot V_{EB}}{kT}}$$

$$I_B = I_E - I_C$$

$$V_{EB} = 0.2V \rightarrow \alpha = 0.9972 \quad I_E = 8.254 \mu A$$

$$I_C = 8.21 \mu A$$

$$I_B = 0.044 \mu A$$

$$V_{EB} = 0.6V \rightarrow \alpha = 0.9976$$

$$I_C = 37.8 \mu A$$

$$I_B = 0.2 \mu A$$

$$V_{EB} = 0.2V$$

$$V_{EB} = 0.6V \quad \text{Gummel} = 10^{16} \frac{1}{cm^3} \times 1.09 \times 10^7 cm = 1.09 \times 10^{23} \frac{1}{cm^3}$$

$$V_{EB} = 0.6V \quad \text{Gummel} = 10^{16} \frac{1}{cm^3} \times 0.985 \times 10^7 cm = 9.85 \times 10^{22} \frac{1}{cm^3}$$