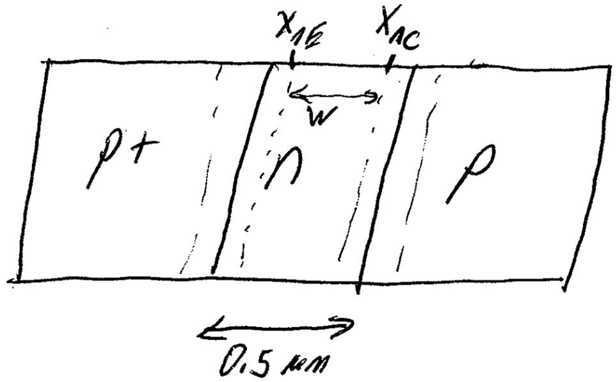
1.



p+ : $N_a = 5\times10^{17}\ cm^{-3}$

n : $N_d = 3\times10^{16}\ cm^{-3}$

p : $N_a = 6\times10^{15}\ cm^{-3}$

$\tau_B = 10^{-6}$ sec

$\tau_n = 10^{-6}$ sec

Preliminaries:

$$D_E = \frac{kT}{q}\mu_n(5\times10^{17}) = (.026)(420\ \frac{cm^2}{V\cdot s})$$ (at doping of 5×10^{17})

$$D_E = 10.9\ \frac{cm^2}{s}$$

$$D_B = \frac{kT}{q}\mu_p(3\times10^{16}) = (.026)(350)$$

$$D_B = 9.1\ \frac{cm^2}{s}$$

$$L_E = \sqrt{D_E\tau_n} = 33\ \mu m$$

at $V_{EB} = 0$

$$x_{nE} = \sqrt{\frac{2\epsilon}{q}V_{bi}\frac{N_a}{N_d(N_a+N_d)}}$$

$$V_{bi} = \frac{kT}{q}\ln\frac{N_aN_d}{n_i^2} = .84$$

$$x_{nE} = .185\ \mu m$$

at $V_{CB} = 0$

$$x_{nc} = \sqrt{\frac{2\epsilon}{q} V_{bi} \frac{N_a}{N_d(N_a + N_d)}}$$

$$V_{bi} = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

$$V_{bi} = .73$$

$$\underline{x_{nc} = .073 \ \mu m}$$

$$W = 0.5 - .185 - .073$$

$$W = W_{n\text{-}region} - x_{nE} - x_{nc}$$

$$\underline{W = .24 \ \mu m}$$

$\alpha_T \equiv$ base transport factor

α_T is ratio of:

$$\alpha_T = \frac{\text{holes from emitter to collector}}{\text{total holes from emitter}}$$

$\Longrightarrow$ it is a measure of base recombination

$$I_C \approx q n_i^2 A \left[\frac{D_B}{W N_B} - \frac{W}{2\tau_B}\frac{1}{N_B}\right]\left(e^{\frac{qV_{EB}}{kT}} - 1\right)$$

$$+ \text{ terms } \propto \left(e^{\frac{qV_{CB}}{kT}} - 1\right) \to 0$$

Now since α_T, γ, β are defined for forward active operation, $V_{CB} < 0$ and thus terms proportional to $e^{\frac{qV_{CB}}{kT}}$ can be neglected

$$I_E \approx q n_i^2 A \left[\frac{D_E}{L_E N_E} + \frac{D_B}{W N_B}\right]\left(e^{\frac{qV_{EB}}{kT}} - 1\right)$$

$$+ \text{ terms } \propto \left(e^{\frac{qV_{CB}}{kT}} - 1\right) \to 0$$

I_{Ep} = total emitter hole current $= q n_i^2 A \frac{D_B}{W N_B}\left(e^{\frac{qV_{EB}}{kT}} - 1\right)$

I_{Cp} = collector hole current from emitter $= q n_i^2 A \left(\frac{D_B}{W N_B} - \frac{W}{2\tau_B}\frac{1}{N_B}\right)\left(e^{\frac{qV_{EB}}{kT}} - 1\right)$

$$\alpha_T = \frac{I_{Cp}}{I_{Ep}} = \frac{\frac{D_B}{W N_B} - \frac{W}{2\tau_B}\frac{1}{N_B}}{\frac{D_B}{W N_B}}$$

$\alpha_T = .99997$ very high!

γ = emitter injection efficiency $= \dfrac{I_{Ep}}{I_{En} + I_{Ep}}$

$$\gamma = \frac{\dfrac{D_B}{W N_B}}{\dfrac{D_E}{L_E N_E} + \dfrac{D_B}{W N_B}} = .9995$$

$$\beta = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{\alpha_T \gamma}{1-\alpha_T \gamma}$$

$$\boxed{\beta = 1885}$$

Punchthrough (PT)

$(X_{nC}(V=0) + W)$

PT occurs when $X_{nC} = .313\,\mu m$

$$X_{nC} = \sqrt{\frac{2\epsilon}{q}(V_{bi} - V_A)\frac{N_C}{N_B(N_C+N_B)}}$$

$$(.40\,\mu m)^2 = \frac{2\epsilon}{q}(V_{bi} - V_A)\frac{N_C}{N_B(N_C+N_B)}$$

$$V_{bi} - V_A = \frac{q}{2\epsilon}(.313\,\mu m)^2\frac{N_B(N_C+N_B)}{N_C}$$

$\boxed{V_A \simeq 13.6\ V \text{ at punchthrough}}$

Avalanche BD of BC junction

$$\mathcal{E}_{cr} = \mathcal{E}(0) = \frac{qN_d x_n}{\epsilon}$$

$$\frac{\epsilon^2}{q^2 N_B^2}\mathcal{E}_{cr}^2 = \frac{2\epsilon}{q}(V_{bi} - V_{BD})\frac{N_C}{N_B(N_B + N_C)}$$

$$V_{bi} - V_{BD} = \frac{\epsilon}{2q}\frac{N_B + N_C}{N_B N_C}\mathcal{E}_{cr}^2$$

for silicon $\mathcal{E}_{cr} = 4 \times 10^5 \frac{V}{cm}$

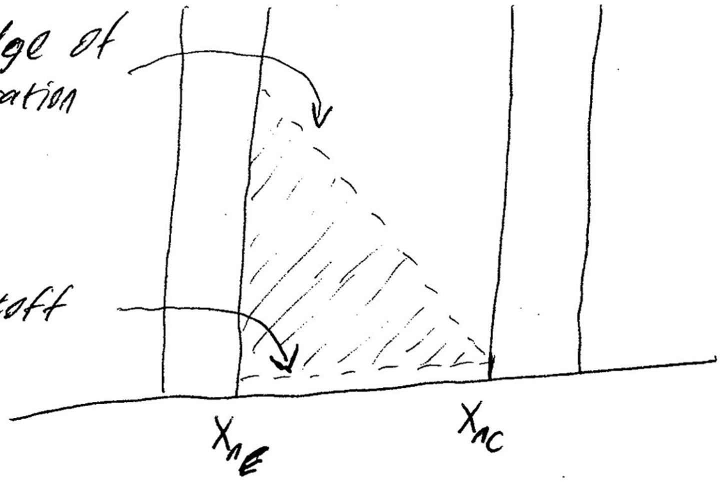
$$V_{BD} \approx 103V$$

$$V_{CEO} = \frac{V_{CBO}}{(\beta + 1)^{1/m}}$$

$$= \frac{103}{(1886)^{1/4}}$$

$$\boxed{V_{CEO} = 15.6V}$$

②



$\tau_B = .1\mu s$

$\tau_t = 1ns$

$I_{csat} = 10mA$

$I_{Bon} = 1mA$

$$t_{rise} = \tau_B \ln\left(\frac{1}{1 - \frac{I_{csat}\,\tau_t}{I_{Bon}\,\tau_B}}\right)$$

$t_{rise} = .01\,\mu s$

Note: At edge of saturation (edge of forward active) $I_{csat} = \beta I_{Bsat}$ where I_{Bsat} is the minimum base current necessary to bring the transistor to the edge of saturation. Therefore, if $I_{Bon} < I_{Bsat}$ then t_{rise} is undefined. Thus I_{Bon} must be $> I_{Bsat}$ i.e. $I_{Bon} > \frac{I_{csat}}{\beta} \left(= \frac{I_{csat}}{\tau_B / \tau_t} \right)$

Switch ON to OFF by removing I_B

$I_B = 0$

$$t_{sd} = \tau_B \ln\left[\frac{I_B\,\tau_B}{I_{csat}\,\tau_t}\right]$$

$t_{sd} = .23\,\mu s$ very long!

t_{sd} is delay before switching can occur switch by setting $I_B = -I_{Bon}$

$$t_{sd} = \tau_B \ln \frac{I_B \tau_B}{I_{Csat} \tau_t \left[\frac{1}{2} + \frac{1}{2} \frac{I_B \tau_B}{I_{Csat} \tau_t}\right]}$$

$t_{sd} = .06\ \mu s$