STUDENT ID: 40178580

ELE8084 Assignment 2

1

a)

The base transit time is given by:

$$\tau_F = \frac{W_B^2}{2D_{pB}}$$

$$\tau_F = \frac{(0.2\times10^{-4})^2}{2(6)}$$

$$\tau_F = 3.33\times10^{-11} \text{ seconds}$$

The base transport factor is given by:

$$\alpha_T = 1 - \frac{\tau_F}{\tau_{pB}}$$

$$= 1 - \frac{3.33\times10^{-11}}{0.2\times10^{-6}}$$

$$\alpha_T = 0.9998$$

The emitter efficiency is given by:

$$\gamma = \frac{I_{DB}}{I_E}$$

$$\gamma = \frac{I_{DB}}{I_{DB} + I_{DE} + I_R}$$

Ignoring I_R

$$\gamma = \frac{I_{DB}}{I_{DB} + I_{DE}}$$

$$= \frac{1}{1 + \frac{I_{DE}}{I_{DB}}}$$

$$\gamma = \frac{1}{1 + \frac{D_{nE} W_B N_{DB}}{D_{pB} W_E N_{AE}}}$$

$$= \frac{1}{1 + \frac{(10)(0.2)(4\times10^{18})}{(6)(0.4)(2\times10^{20})}}$$

$$\gamma = 0.9836$$

Finally,

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

$$\beta = \frac{0.9998 \times 0.9836}{1 - (0.9998 \times 0.9836)}$$

$$\beta = 59.24$$

(1b) Now we want $\beta = 80$

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

~~γ is derived~~

~~or in terms of W_B~~

where
$$\alpha_T = 1 - \left(\frac{W_B^2}{2D_{PB}} \Big/ 0.2\times10^{-4} \right)$$

or
$$\alpha_T = 1 - \frac{W_B^2}{2(6)(0.2\times10^{-4})}$$

$$\alpha_T = 1 - \frac{W_B^2}{2.4\times10^{-4}}$$

AND
$$\gamma = \frac{1}{1 + \frac{D_{NE} W_B N_{DB}}{D_{PB} W_E N_{AE}}}$$

$$\gamma = \frac{1}{1 + \frac{(10)(W_B)(4\times10^{18})}{(6)(0.4\times10^{-4})(2\times10^{20})}}$$

$$\gamma = \frac{1}{1 + \frac{4\times10^{19} W_B}{4.8\times10^{16}}}$$

Now that we have α_T and γ in terms of W_B, we can trial different values of W_B and see when we get $\beta = 80$.

Start with $W_B = 0.1\times10^{-4}$ cm:

$$\gamma = \cancel{9}0.99174$$

$$\alpha_T = 0.99999.$$

$$\beta = 119.92$$ => Too high so we increase W_B.

Let $W_B = 0.15\times10^{-4}$ cm

$$\gamma = 0.98765$$

$$\alpha_T = 0.99999$$

$$\beta = 79.97$$ => Almost there

Let $\cancel{W_B = 0.153\times10^{-4}\text{ cm}}$ $\cancel{W_B = 1.495}\times10^{-4}$ cm.

$$\cancel{\gamma = 0.9874}$$

$$\alpha_T = 0.999999$$

let $W_B = 0.1459 \times 10^{-4}$ cm

$\gamma = \cancel{1}\ 0.98799$

$\alpha_T = 0.99999$

$\cancel{W_B} = \beta = 82.3 \Rightarrow$ Too high

let $W_B = 0.149 \times 10^{-4}$

$\gamma = 0.9877$

$\alpha_T = 0.99999$

$\beta = 80\cancel{22}$

And so we can say that W_B lies between 0.149×10^{-4} cm and 0.15×10^{-4} cm to produce $\beta = 80$

~~Ie~~

$W_B = 0.15 \mu m$

2a $$N = 2.5\times10^{18}\left(1-\frac{x}{W_B}\right)^2$$

We know that:

$$T_F = \frac{1}{D_{pB}}\int_0^{W_B}\frac{1}{N}\left[\int_x^{W_B} N\,dx\right]dx$$

We plug N into equation and compute integrals:

$$\int_x^{W_B}\left(1-\frac{x}{W_B}\right)^2 \implies \text{let } u = 1-\frac{x}{W_B}$$

$$du = -\frac{1}{W_B}dx.$$

We can rewrite integral:

$$\int\left(1-\frac{x}{W_B}\right)^2 dx = \int -u^2 W_B\,du$$

$$= -W_B\int^{\cancel{W_B}} u^2\,du$$

$$= -W_B\left(\frac{u^3}{3}\right)$$

$$\therefore = -\frac{W_B\left(1-\frac{x}{W_B}\right)^3}{3}$$

Which simplifies to

$$\frac{(x-W_B)^3}{3W_B^2}$$

Now we apply the limits:

$$\left[\frac{(x-W_B)^3}{3W_B^2}\right]_x^{W_B}.$$

$$= \frac{0^3}{3W_B^2} - \frac{(x-W_B)^3}{3W_B^2}$$

$$= -\frac{(x-W_B)^3}{3W_B^2} \swarrow \text{First integral}$$

Now, we have:

$$T_F = \frac{1}{D_{pB}}\int_0^{W_B} \frac{1}{\left(1-\frac{x}{W_B}\right)^2} \cdot -\frac{(x-W_B)^3}{3W_B^2}\,dx.$$

$$T_F = \frac{1}{D_{pB}}\int_0^{W_B} -\frac{(x-W_B)^3}{3W_B^2\left(1-\frac{x}{W_B}\right)^2}\,dx.$$

Simplify integral:

$$T_F = \frac{1}{D_{pB}}\int_0^{W_B} \frac{W_B}{3} - \frac{x}{3}\,dx$$

Simplify:

$$\cancel{T_F = \frac{1}{D_{PB}} \int^{W_B}}$$

$$T_F = \frac{1}{D_{PB}} \cdot \left[\frac{x(2W_B - x)}{6} \right]_0^{W_B}$$

$$T_F = \frac{1}{D_{PB}} \left(\frac{W_B(2W_B - W_B)}{6} - 0 \right)$$

$$T_F = \frac{1}{D_{PB}} \cdot \frac{W_B^2}{6}$$

$$T_F = \frac{W_B^2}{6 D_{PB}}$$

(2b)

The Base transit time can simply be computed from the equation:

$$\tau_F = \frac{W_B^2}{6D_{pB}}$$

$$\therefore \quad \tau_F = \frac{(0.15\times10^{-4})^2}{6(8)}$$

$$\boxed{\tau_F = 4.688\times10^{-12}\,s}$$

Now, we need to compute N_B

$$N_B = \int_0^{W_B} N_{dB}(x)\,dx$$

From part (a) we know the undefinate integral is:

$$\int N_{dB}\,dx = 2.5\times10^{18}\left[\frac{(x-W_B)^3}{3W_b^2}\right]_0^{W_b}$$

Applying limits:

$$\int_0^{W_b} N_{dB}\,dx = 2.5\times10^{18}\left(0 - \frac{(-W_b^3)}{3W_b^2}\right)$$

$$\int_0^{W_b} N_{DB}\, dx = \frac{2.5\times10^{18}\, W_b^3}{3W_b^2}$$

$$= 8.333\times10^{17}\, W_b$$

Now we have $\cancel{N_B = \int_0^{W_B} N_{DB}(x)}$

$$N_B = 8.333\times10^{17}\, W_b$$

Now to get the base transport factor we use the equation:

$$f_B = \frac{1 - \exp\left(-\frac{\tau_F}{\tau_{pB}}\right)}{\tau_F/\tau_{pB}}$$

$$f_B = \frac{1 - \exp\left(-\frac{4.688\times10^{-12}}{0.2\times10^{-4}}\right)}{4.688\times10^{-12}/0.2\times10^{-4}}$$

$$f_B = 0.999 \approx 1.00$$

To get the collector current we use:

$$I_C = qA_E D_{pB} \frac{N_B}{W_B}$$

$$I_C = (1.6\times10^{-19})(30\times10^{-4})(15\times10^{-4})(8)\left(\frac{8.33\times10^{17}\times0.15\times10^{-4}}{0.15\times10^{-4}}\right.$$

$$I_C = 4.799\times10^{-6}\ A$$

$I_{C}=$

3a

We need to calculate all 4 current components

$$I_{DB} = \frac{A q D_{DB} n_i^2}{W_B N_{DB}} e^{\frac{qV_{EB}}{kT}}$$

~~I_{DB} =~~

First the Area is given by πr^2 where $r = 10\,\mu m$

$$A = (10\times10^{-4})^2 \pi$$

Now

$$I_{DB} = \frac{(10\times10^{-4})^2 \pi \times (1.6\times10^{-19})(8)(1.45\times10^{10})^2}{(0.1\times10^{-4})(2\times10^{18})}$$

$$\cdot\, e^{\frac{(1.6\times10^{-19})(0.65)}{(1.38\times10^{-23}\times300)}}$$

$$I_{DB} = 4.222\times10^{-17} \cdot 8.125\times10^{10}$$

$$I_{DB} = 3.43\times10^{-6}\ A$$

Now,

$$I_{DE} = \frac{A q D_{NE} n_i^2}{W_E N_{AE}} e^{\frac{qV_{EB}}{kT}}$$

$$I_{DE} = \frac{(10\times10^{-4})^2 \pi \times (1.6\times10^{-19})(12)(1.45\times10^{10})^2}{(\cancel{0.3})(0.3\times10^{-4})(1\times10^{20})} \cdot e^{\frac{(1.6\times10^{-19})(0.65)}{1.38\times10^{-23}\times300}}$$

$$I_{DE} = 4.227\times10^{-19} \times 8.125\times10^{10}$$

$$I_{DE} = 3.43\times10^{-8}\ A$$

Now, $I_{RB} = \frac{W_B^2}{2L_{PB}^2} I_{DB}$

$$I_{RB} = \frac{(0.1\times10^{-4})^2}{2(\cancel{1.2045\times10^{-4}})} \cdot 3.43\times10^{-}$$

$$(8)(0.15\times10^{-4}) \pi = \sqrt{D_{PB} \tau_{PB}}$$

$$I_{RB} = 1.43\times10^{-12}$$

$$I_R = \frac{1}{2} A_J q n_i R e^{\frac{qV_{EB}}{2kT}}$$

$$R = W_{EB}\left(\frac{1}{\tau_0} + \frac{P}{A_J} S_0\right)$$

Firstly,

$$V_0 = \frac{kT}{q} \ln . \frac{N_{AE} N_{DB}}{n_i^2}$$

$$V_0 = \frac{(1.38\times10^{-23})(300)}{1.6\times10^{-19}} \ln\left(\frac{(1\times10^{20})(2\times10^{18})}{(1.45\times10^{10})^2}\right)$$

$$V_0 = 0.025875 \times 41.397$$

$$V_0 = 1.07V$$

Now, $W_{EB} = \sqrt{\frac{2\varepsilon_0\varepsilon_{Si}(V_0 - V_{EB})}{q N_{DB}}}$

as $N_{AE} \gg N$

$$W_{EB} = \sqrt{\frac{2(8.85\times10^{-14})(11.7)(1.07 - 0.65)}{1.6\times10^{-19} \times 2\times10^{18}}}$$

$$W_{EB} = 1.649\times10^{-6}\ cm$$

$$R = 1.649\times10^{-6}\left[\frac{1}{(0.1\times10^{-4})} + \frac{(200\times10^{-4})(80)}{(10\times10^{-4})^2\pi}\right]$$

$$R = 1.005 \text{ cm/s}$$

Now we find I_R

$$I_R = \frac{1}{2}(10\times10^{-4})^2\pi\times(1.6\times10^{-19})(1.45\times10^{10})(1.005)\cancel{6}$$

$$e^{\frac{(1.6\times10^{-19})(0.65)}{2(1.38\times10^{-23})(300)}}$$

$$I_R = 4.102\times10^{-15}\times \overset{285040.47}{\cancel{12.801}}$$

$$I_R = 1.169\times10^{-9} A$$

Now $\qquad \gamma = \frac{I_{DB}}{I_{DB}+I_{DE}+I_R}$

$$\gamma = \frac{3.43\times10^{-6}}{(3.43\times10^{-6})+(3.43\times10^{-8})+1.169\times10^{-9}}$$

$$\gamma = 0.9898$$

Finally, $$\beta = \frac{I_{DB} - I_{RB}}{I_{DE} + I_{RB} + I_R}$$

$$\beta = \frac{3.43 \times 10^{-6} - 1.43 \times 10^{-12}}{3.43 \times 10^{-6} + 1.43 \times 10^{-12} + 1.169 \times 10^{-9}}$$

$$\beta = 0.9997$$