8

7.20, 7.21, 7.22

A Si p-n-p transistor has the following properties at room temperature:

$\tau_n = \tau_p = 0.1\ \mu s$
$D_n = D_p = 10\ cm^2/s$
$N_E = 10^{19}\ cm^{-3}$
$N_C = N_B = 10^{16}\ cm^{-3}$
$W_E = 3\ \mu m$
$W = 1.5\ \mu m$ (metallurgical base width, distance between base-emitter junction and base-collector junction)
$A = 10^{-5}\ cm^2$

For $V_{CB} = 0$ and for each $V_{EB} = 0.2\ V$ and $0.6\ V$. Calculate:

a

The neutral base width W_b

✓ Answer

$W = \sqrt{\frac{2\epsilon(V_0 - V)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$
$V_0 = \frac{kT}{q}\ln\left(\frac{N_a N_d}{n_i^2}\right)$

$V_{0BE} = 0.8735512160281839\ V$
$V_{0CB} = 0.6946403543025464\ V$

$W_{BE} = \sqrt{(V_0 - V)1.306680375 \times 10^{-9}}$
$W_{CB} = 0.4258558799635592\ \mu m$
$x_{CB} = 0.2129279399817796\ \mu m$

For $V_{EB} = 0.2\ V, W_{BE} = 0.29666751685033083\ \mu m$
For $V_{EB} = 0.6\ V, W_{BE} = 0.18906189609263242\ \mu m$

For $V_{EB} = 0.2\ V, x_{BE} = 0.2963711457046262\ \mu m, W_b = 0.9907009143135942\ \mu m$
For $V_{EB} = 0.6\ V, x_{BE} = 0.18887302306956283\ \mu m, W_b = 1.0981990369486576\ \mu m$

b

Base transport factor

✓ **Answer**

$B = \frac{I_C}{I_{E_p}} = \text{sech}\left(\frac{W_b}{L_p}\right)$

$L = \sqrt{D\tau} = 10\ \mu m$

For $V_{EB} = 0.2\ V, B = 0.995112547857462$
For $V_{EB} = 0.6\ V, B = 0.9939999492937805$

c

Emitter injection efficiency

✓ **Answer**

$\gamma = \frac{I_{E_p}}{I_{E_n}+I_{E_p}} = \left(1 + \frac{L_p^n n_n \mu_n^p}{L_n^p p_p \mu_p^n} \tanh\left(\frac{W_b}{L_p^n}\right)\right)^{-1}$
$= \left(1 + \frac{n_n}{p_p} \tanh\left(\frac{W_b}{L_p^n}\right)\right)^{-1}$

$L = 10\ \mu m$
$n_n = 10^{16}$
$p_p = 10^{19}$
$\gamma = \left(1 + \frac{1}{1000} \times \tanh\left(\frac{W_b}{10}\right)\right)^{-1}$

For $V_{EB} = 0.2\ V, \gamma = 0.999901262511629$
For $V_{EB} = 0.6\ V, \gamma = 0.9998906314306855$

d

α

✓ **Answer**

$\alpha = B\gamma$

For $V_{EB} = 0.2\ V, \alpha = 0.99501429294384$
For $V_{EB} = 0.6\ V, \alpha = 0.9938912369414276$

e

β

✓ **Answer**

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

For $V_{EB} = 0.2\ V, \beta = 199.57335674475175$
For $V_{EB} = 0.6\ V, \beta = 162.6992612762575$

f

I_B

✓ **Answer**

$p_n = 22500$

$\Delta p_C = 0$

$$I_B = qA\frac{D_p}{L_p}\left((\Delta p_E + \Delta p_C)\tanh\frac{W_b}{2L_p}\right)$$

For $V_{EB} = 0.2\ V, \Delta p_E = 50770967.42075891, I_B = 4.020619552810045 \times 10^{-14}\ A$
For $V_{EB} = 0.6\ V, \Delta p_E = 258856185256414.6, I_B = 2.271922006217088 \times 10^{-7}\ A$

g

I_C

✓ **Answer**

$$I_C = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{csch}\frac{W_b}{L_p} - \Delta p_C \operatorname{ctnh}\frac{W_b}{L_p}\right)$$

For $V_{EB} = 0.2\ V, I_C = 8.186205921772223 \times 10^{-12}\ A$
For $V_{EB} = 0.6\ V, I_C = 3.763785457076855 \times 10^{-5}\ A$

h

I_E

✓ **Answer**

$$I_E = \frac{I_C}{\alpha}$$

For $V_{EB} = 0.2\ V, I_E = 8.227224452779055 \times 10^{-12}\ A$
For $V_{EB} = 0.6\ V, I_E = 3.7869188470354374 \times 10^{-5}\ A$