ECSE-2210 Microelectronics Technology
Class Activity 20 – Solution

1. In a BJT, indicate what happens (**increase, decrease or no-effect**: **choose one and understand "why"**):

   a. to γ if we increase the emitter doping?
   Increases. It is the fraction of emitter current carried by the emitter majority carriers. If we increase the majority carriers in the emitters, this fraction increases. In a pnp transistor, $\gamma = \dfrac{I_{EP}}{I_{EP} + I_{EN}}$. By increasing the emitter doping, I_{EP} increases and as a result the fraction increases.

   b. to γ if we increase the base doping?
   Since the reverse injection of carriers from the base increases, the emitter-injection efficiency (γ) decreases. In a pnp transistor, $\gamma = \dfrac{I_{EP}}{I_{EP} + I_{EN}}$. By increasing the base doping, I_{EN} increases and this reduces the fraction. As a result, the emitter-injection efficiency (γ) decreases.

   c. to γ if we increase the collector doping?
   No direct effect (to a first order).

   d. to α_T if we increase the base width?
   Decreases since the distance the minority carriers have to travel increases. With the increase in the base width more carriers recombine and the base transport factor reduces.

   e. to α_T if we increase the lifetime in the base?
   Increases since the minority carriers can be collected by the collector with negligible recombination. The carriers spend more time in the base before they recombine, increasing the probability of being collected by the base.

   f. to α_T if we increase the C-B reverse voltage?
   Increases since increasing the reverse bias of the C-B junction effectively reduce the base width. With a reduction of the base width the α_T increases.

2. The base transport factor, α_T, is I_C/I_{EP}. Using the equations derived in class for I_C and I_{EP}, show that the base transport factor is given by (see equation 11.42 in the textbook)

$$\alpha_T = \frac{1}{1 + \dfrac{W_B^2}{2L_B^2}}$$

$I_{EP} = q\,A\,(D_B / W_B)\,p$B0 [exp $(q\,V_{EB} / kT)] + q\,A\,[W_B/(2\,\tau_B)]\,p_{B0}$ [exp $(q\,V_{EB} / kT)]$
$Ic = q\,A\,(D_B / W_B)\,p_{B0}.$ exp $(q\,V_{EB} / kT)$

We know that, $\alpha_T = I_C / I_{EP}$

$$\alpha_T = \frac{qA(D_B/W_B)\,p_{B0}.\exp(qV_{EB}/kT)}{qA(D_B/W_B)\,p_{B0}\,[\exp(qV_{EB}/kT)] + qA[W_B/(2\tau_B)]\;p_{B0}\,[\exp(qV_{EB}/kT)]}$$

with $\alpha_T = \dfrac{1}{1+\dfrac{W_B}{2\tau_B}\dfrac{W_B}{D_B}}$

We also know that, $L_B = \sqrt{D_B\tau_B}$

So, $\alpha_T = \dfrac{1}{1+\dfrac{W_B^2}{2L_B^2}}$

Straightforward manipulation of the equations for I_C and I_{EP} results in the above equation. Note that $D_B\tau_B = L_B^2$.

3. (Derivation of equation 11.41 in the textbook): Show that the emitter injection efficiency is given by:

$$\gamma = \frac{1}{1+\dfrac{D_E N_B W_B}{D_B N_E L_E}}$$

Use: $\gamma = I_{EP} / (I_{EP} + I_{EN})$ $\qquad\qquad$ $\gamma = 1 / (1 + I_{EN}/I_{EP})$

$\gamma = 1 / [1 + (C) / (B)]$

$$\gamma = \frac{1}{1+\dfrac{\left(D_E/L_E\right)n_{EO}}{\left(D_B/W_B\right)p_{B0}}}$$

$$\gamma = \frac{1}{1+\dfrac{D_E W_B n_{E0}}{D_B L_E p_{B0}}}$$

$$\gamma = \frac{1}{1+\dfrac{D_E N_B W_B}{D_B N_E L_E}}$$

In the equation for I_{EP}, you can neglect the recombination part of the emitter hole current since it is small in comparison to the emitter current. This will simplify the equation.

4. A sample set of assumed and measured material parameters for a pnp BJT is given in the table below. Calculate base transport factor, emitter injection efficiency, common base current gain (also called collector-to-emitter current gain) and common emitter current gain (also called collector-to-base current gain).

Emitter	**Base**	**Collector**
$N_E = 10^{18}$ cm^{-3}	$N_B = 10^{16}$ cm^{-3}	$N_C = 10^{15}$ cm^{-3}
$\mu_E = 263$ cm^2/Vs	$\mu_B = 437$ cm^2/Vs	$\mu_C = 1345$ cm^2/Vs
$D_E = 6.81$ cm^2/s	$D_B = 11.3$ cm^2/s	$D_C = 34.8$ cm^2/s
$\tau_E = 10^{-7}$ s	$\tau_B = 10^{-6}$ s	$\tau_C = 10^{-6}$ s
$L_E = 8.25 \times 10^{-4}$ cm	$L_B = 3.36 \times 10^{-3}$ cm	$L_C = 5.90 \times 10^{-3}$ cm
	$W_B = 2 \times 10^{-4}$ cm	

This is a plug-in type question to get an idea of the parameter values.

Answers: $\gamma = 0.9985$

$\alpha_T = 0.9982$

$\alpha_{dc} = 0.9968$

$\beta_{dc} = 310$