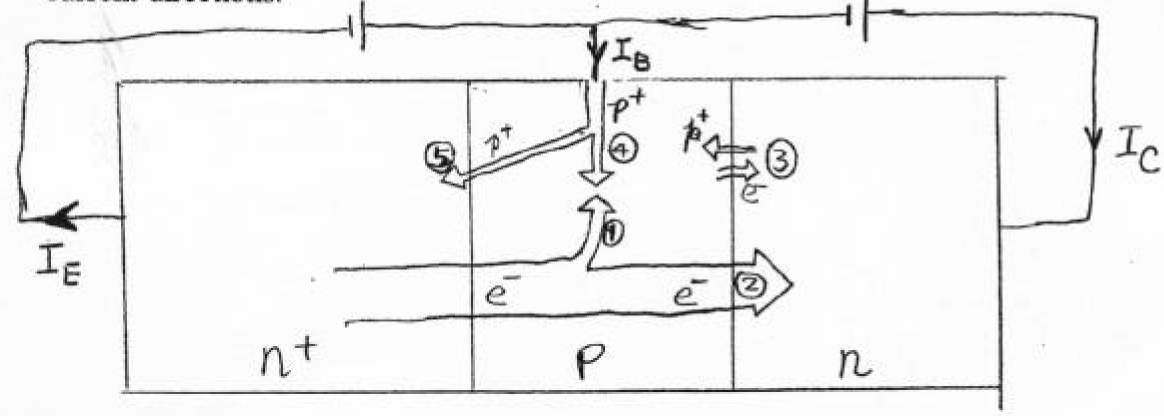
ECE 340 Homework XII Spring 2003

Due: Wednesday, April 09, 2003

1. Redraw Fig. 7-3 for an n^+-p-n transistor, and explain the various components of carrier flow and current directions.

current directions.

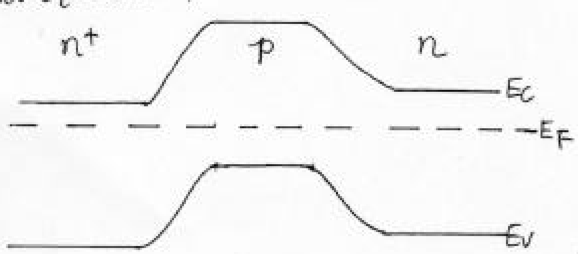


1. Electrons injected from emitter, but lost to recombination with holes in base region.
2. Electrons injected from emitter, reaching collector through diffusion process.
3. Thermally generated electrons and holes in the base-collector junction that form the reverse saturation current.
4. Holes supplied by base current to recombine with electrons (process 1).
5. Holes injected from base to emitter, acrossing the forward-biased emitter-base juction.

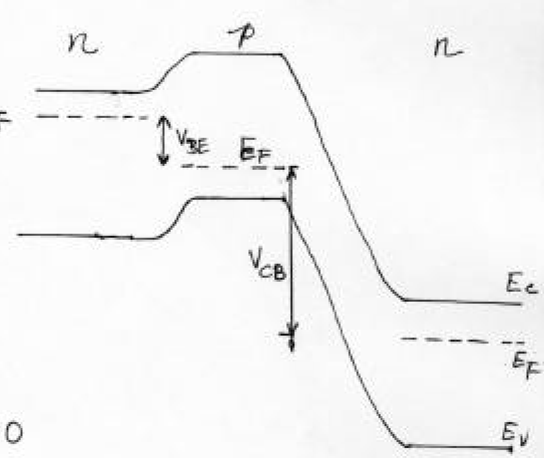
2. Sketch the energy band diagram for an n-p-n transistor in equilibrium (all terminals grounded) and also under normal active bias (emitter junction forward biased, collector junction reverse biased). With the emitter terminal grounded, determine the signs (positive or negative) of the collector voltage V_{CE} and base voltage V_{BE}, relative to the emitter, that correspond to normal bias.

Solutions:

at Equlibrium,



under normal active bias



Emitter junction forward biased $\Rightarrow V_{BE} > 0$

Collecter junction reverse biased $\Rightarrow V_{CB} > 0$

$\therefore \quad V_{CE} = V_{CB} + V_{BE} > 0$

3. A symmetrical p$^+$-n-p$^+$ Si bipolar transistor has the following properties:

Emitter/Collector	Base	$A = 10^{-4} cm^2$
$N_a = 10^{18}/cm^3$	$N_d = 10^{16}/cm^3$	$W_b = 1\ \mu m$
$\tau_n = 0.1\ \mu s$	$\tau_p = 10\ \mu s$	
$\mu_p = 100\ cm^2/V\text{-}s$	$\mu_n = 1060\ cm^2/V\text{-}s$	
$\mu_n = 350\ cm^2/V\text{-}s$	$\mu_p = 380\ cm^2/V\text{-}s$	

(a) Determine if the straight-line approximation can be applied to evaluate the excess carriers in the base region.

(b) With $V_{EB} = 0.5$ V and $V_{CB} = -3$ V, calculate the base current I_B, assuming perfect emitter injection efficiency.

(c) Assuming the emitter region is long compared to L_n, find an expression for injected electrons in the emitter. Determine the injected electron current at the emitter/base junction.

(d) Calculate the emitter injection efficiency γ and the amplification factor β for part (c).

Solutions:

(a), At base, $D_p = \dfrac{kT}{q} m_p = 0.0259 \times 380 = 9.842 cm^2 / vs$

$L_p = \sqrt{D_p t_p} = \sqrt{9.842 \times 10 \times 10^{-6}} = 0.00992 cm = 99.2 mm$

therefore, $L_p \gg W_b$, straight line approximation can be applied.

(b), Since $g = \dfrac{i_{Ep}}{i_{Ep} + i_{En}}$, $g = 1 \Rightarrow i_{En} = 0$,

Using straight-line approximation,

$$I_{B,perfect\_g} = \frac{Q_p}{t_p} = \frac{qA\Delta p_E W_b}{2t_p},\ \Delta p_E = p_n e^{qV_{EB/kT}} = \frac{n_i^2}{N_d} e^{qV_{EB/kT}} = \frac{2.25 \times 10^{20}}{10^{16}} e^{0.5/0.0259} = 5.448 \times 10^{12} cm^{-3},$$

Therefore, $I_B = \dfrac{qA\Delta p_E W_b}{2t_p} = \dfrac{1.6 \times 10^{-19} \times 10^{-4} \times 5.448 \times 10^{12} \times 10^{-4}}{2 \times 10^{-5}} = 4.358 \times 10^{-10} A$,

If we assume perfect injection efficiency, the base current is purely due to recombination in base region, we called it $I_{Brecombination}$ in later parts.

(c), In the emitter region,

$$\Delta n_{B0} = n_p e^{qV_{EB/kT}} = \frac{n_i^2}{N_a} e^{qV_{EB/kT}} = \frac{2.25 \times 10^{20}}{10^{18}} e^{0.5/0.0259} = 5.448 \times 10^{10} cm^{-3}$$

In emitter, $D_n = \dfrac{kT}{q} m_n = 0.0259 \times 350 = 9.065 cm^2 / vs$, $L_n = \sqrt{D_n t_n} = \sqrt{9.065 \times 10^{-7}} = 9.52 mm$

For emitter region much longer than L_n, we have met this kind of steady-state minority carrier distribution problem many times before (so often that you probably already memorized the results). The solution for the configuration where the injected carrier diminishes at $x = \infty$ is:

$$d\,n(x) = \Delta n_B e^{-x/L_n} = 5.448\times 10^{10} \times e^{-x(mm)/9.52}$$

$$I_{En}(x=0) = qA\Delta n_B D_n / L_n = 1.6\times 10^{-19} \times 10^{-4} \times 5.448\times 10^{10} \times 9.065/9.52\times 10^{-4} = 8.30\times 10^{-9} A$$

(d), $I_{Ep} = qAD_p \dfrac{\Delta p_E}{W_B} = 1.6\times 10^{-19} \times 10^{-4} \times 9.842 \times 5.448\times 10^{12} / 10^{-4} = 8.579\times 10^{-6} A$

$$g = \frac{I_{Ep}}{I_{En} + I_{Ep}} = \frac{8.579\times 10^{-6}}{8.3\times 10^{-9} + 8.579\times 10^{-6}} = 0.9990335,$$

$$I_B = I_{Brecombination} + I_{En} = 4.358\times 10^{-10} + 8.3\times 10^{-9} = 8.736\times 10^{-9} A$$

$$I_E = I_{Ep} + I_{En} = 8.579\times 10^{-6} + 8.3\times 10^{-9} = 8.587\times 10^{-6} A$$

$$b = \frac{I_C}{I_B} = \frac{I_E - I_B}{I_B} = \frac{8.587\times 10^{-6} + 8.736\times 10^{-9}}{8.736\times 10^{-9}} = 982$$

Comment: it may be difficult to get all the concepts right at the first time. One way is to look at Figure 7-3, trying to match I_E, I_{Ep}… etc. to the currents in the figure, then do KCL on the E, B and C nodes to get a complete idea of the current relations in the BJT. One mistake students often make is copying some “formula” from the book or notes, and applying it whenever they found the left side of the formula appears to be what they want. Without understanding how the formula was derived, this approach is often an easy way to get a “typical” wrong answer because the problem may ask for a different configuration.