EE2003 – SEMICONDUCTOR FUNDAMENTALS (Part III)

Tutorial 10
Bipolar Junction Transistors

Question 1:

A bipolar transistor is biased in the forward-active region.

(a) For a base current of I_B = 4.2μA and a collector current of I_C = 0.625mA, determine (i) β, (ii) α, and (iii) I_E.

(b) For a collector current of I_C = 1.254 mA and an emitter current of I_E = 1.273 mA, determine β, α, and I_B.

Solution:

(a)

$$\beta = \frac{I_C}{I_B} = \frac{0.625}{0.0042} = 148.8$$

As $i_E = i_C + i_B$

$$\alpha = \frac{\beta}{1+\beta} = \frac{148.8}{149.8} = 0.9933$$

$$I_E = \frac{I_C}{\alpha} = \frac{0.625}{0.9933} = 0.6292mA$$

(b)

$$\alpha = \frac{I_C}{I_E} = \frac{1.254}{1.273} = 0.9851$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9851}{1-0.9851} = 66.0$$

$$I_B = \frac{I_C}{\beta} = \frac{1.254}{66} = 0.0190mA$$

Question 2:

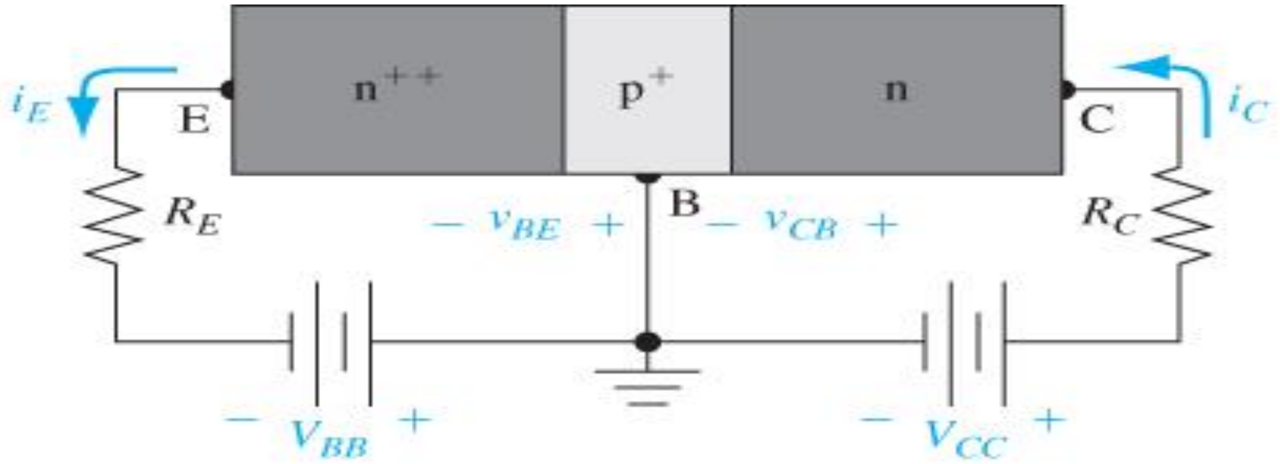
For a uniformly doped $n^{++}p^{+}n$ bipolar transistor in the forward-active region.

(a) Sketch the energy band diagram across the emitter region, the base region, and the collector region. Mark the conduction band, the valance band and the Fermi level.

(b) Sketch the minority carrier distribution across the emitter region, the base region, and the collector region. Indicate the electric field directions in the emitter-base and the base-collector space charge regions.

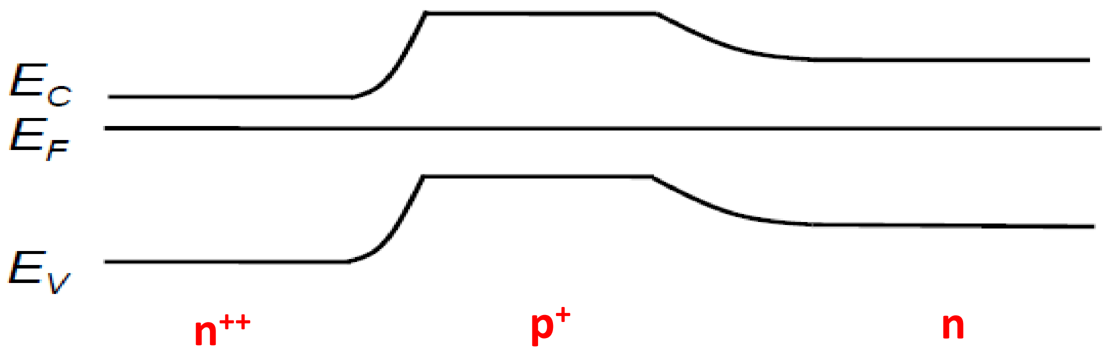
Solution:

For a $n^{++}p^{+}n$ bipolar transistor in the forward-active region, we have

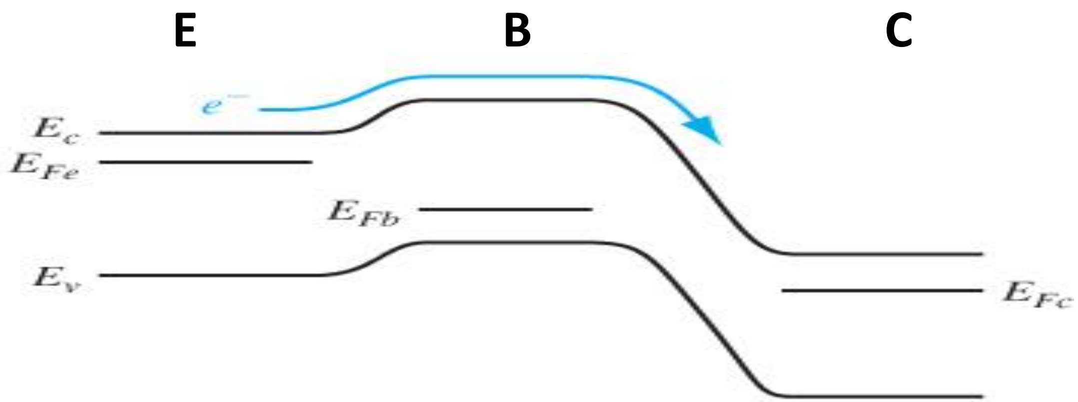


In a forward-active operating mode, the base-emitter (B-E) PN junction is forward biased; and the base-collector (B-C) PN junction is reverse biased.

(a) Sketch the energy band diagram



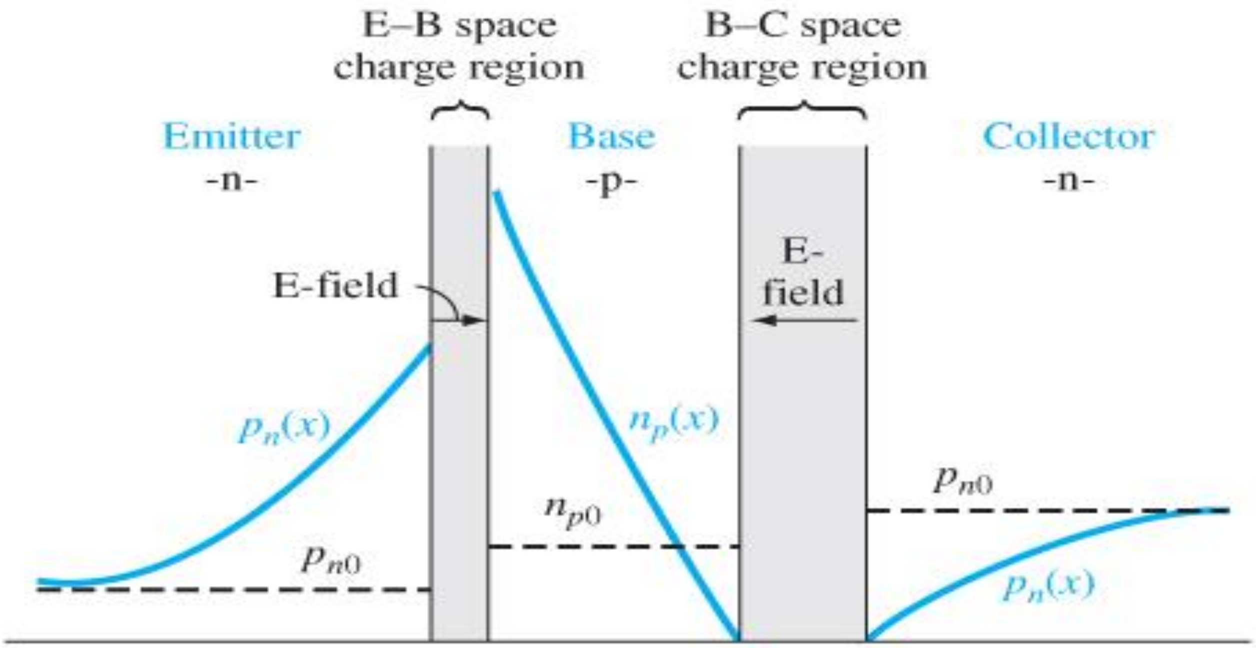
Under zero bias



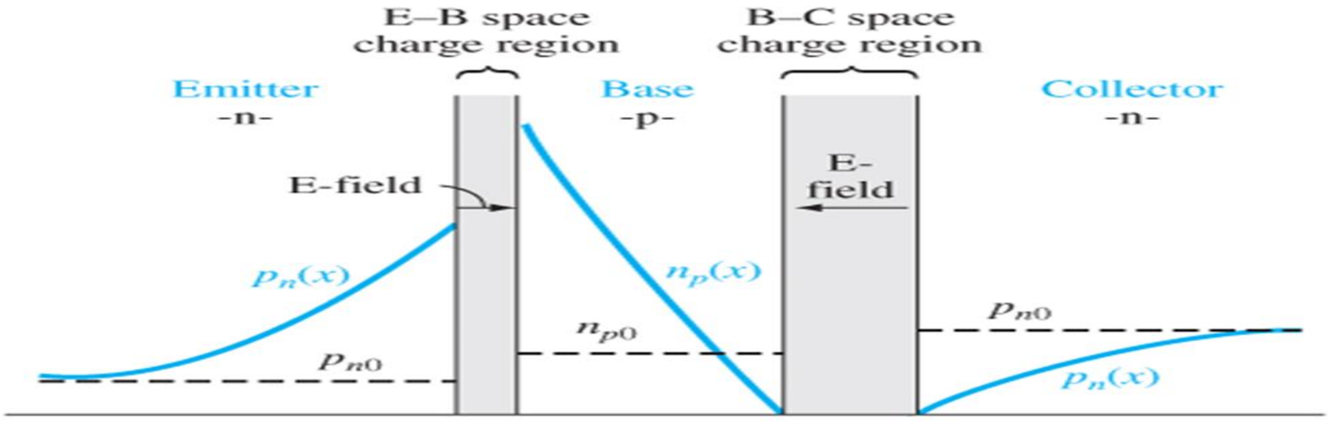
Forward active

- Note the position of the conduction band edge with respect to the Fermi level considering the n-doping levels in the emitter and in the collector.
- In the base, note the Fermi level is closer to the valence band because of the p-doping there.
- Also, note the band bending at the depletion regions.

(b) Sketch the minority carrier distribution and Indicate the electric field directions



- This is a n^{++}p^{+}n transistor. The emitter is n-type highly doped, the base is p-type moderately doped, and the collector is n-type lightly doped. Thus, the **minority carrier in the emitter region is hole; that in the base region is electron, and that in the collector region is hole**.



- The B-E junction is forward biased so **electrons are injected** into base (p-type) from the emitter (n++-type), as excess minority concentration.
- The B-C junction is reverse biased, so the electrons at the edge of the B-C junction is zero. The electrons will diffuse across the base region (large gradient), and then into the B-C space charge region.
- In the emitter-base space charge region, the electric field direction is from the emitter (n-type) to the base (p-type) .And as the emitter-base region is a forward-biased PN junction, the magnitude of this electric field is relatively small, with a smaller space charge region.
- In the base-collector space charge region, the electric field direction is from the collector (n-type) to the base (p-type). And as the base-collector region is a reverse-biased PN junction, the magnitude of this electric field is relatively large, with a larger space charge region.

Question 3:

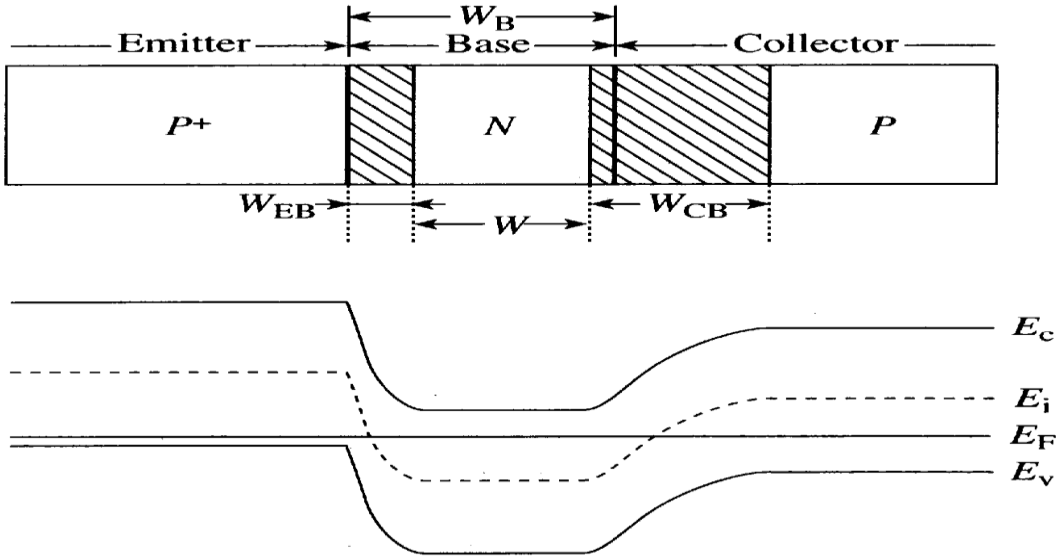
Consider a bipolar junction transistor (BJT) made of ***p^+np*** junctions (emitter-base-collector), with the emitter region having the largest doping and the collector the lowest. Hint: Answer the following questions considering two back-to-back junctions in reverse orientation and use your background on the junction theory.

a) Sketch the energy band diagram across the emitter region, the base region, and the collector region (under ZERO bias). Make sure to mark the conduction band, the valance band and the Fermi level.

b) Plot the electric field in the emitter-base and the base-collector space charge regions and show the levels of space charge densities in these regions. Be careful about the charge density levels, the peak electric fields and the extent of depletion regions.

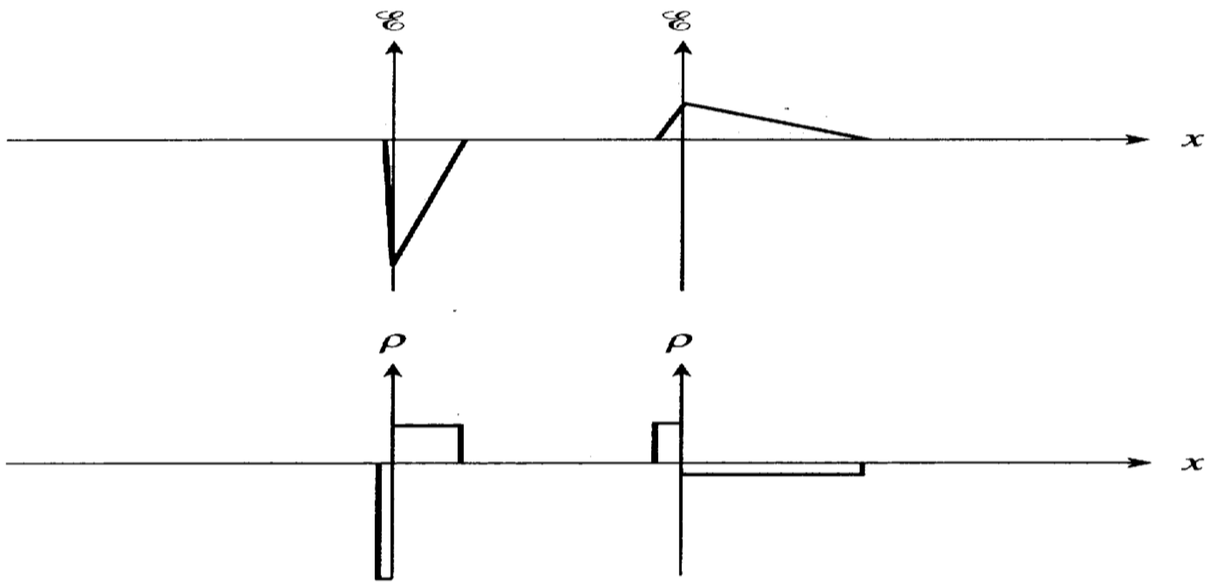
Solution:

(a) Sketch the energy band diagram



- The Fermi level is flat across the structure (i.e., EF is constant).
- Note the position of the valance band edge with respect to the Fermi level considering the p-doping levels in the emitter and in the collector.
- In the base, note the Fermi level is closer to the conduction band because of the n-doping there.
- Also, note the band bending at the depletion regions between the emitter and the base and that between the base and the collector.

(b) Plot the electric field in the emitter-base and the base-collector space charge regions and show the levels of space charge densities in these regions



- The electric field and the space charges in the depletion regions can be plotted simply considering two back-to-back junctions: first the emitter-base made of p+n junction and then the base-collector of np junction.
- The p+n junction will give the highest electric field peak because of the doping.
- Also note that the base is the same in both junctions, so be careful about having the same space charge level in the base for both of the junctions. The base doping level is between those of the emitter (the highest) and the collector (the lowest).
- Also, make sure to carefully consider the extent of the depletion regions on the two sides of each junction, inversely depending on the level of doping.

Question 4:

The parameters of the base region in a silicon npn bipolar transistor are: D_n = 18 cm^2/s, x_B = 0.8 μm, cross-sectional area A_{BE} = 5x10^{-5} cm^2, and n_{B0} = 4x10^3 cm^{-3}.

a) Calculate the collector current for v_{BE} = 0.58 V.

b) For a common-base current gain α = 0.9850, determine the common-emitter current gain β, and the emitter and base currents.

Solution:

(a) From the notes we have

$$\left|i_C\right| = \frac{eD_n A_{BE}}{x_B} \cdot n_{B0} \cdot \exp\left(\frac{V_{BE}}{kT/e}\right)$$

$$i_C = \frac{\left(1.6\times10^{-19}\right)\left(18\right)\times5\times10^{-5}}{0.80\times10^{-4}}\times\left(4\times10^{3}\right)\exp\left(\frac{0.58}{0.0259}\right)$$

$$\Rightarrow i_C = 3.827\times10^{-5}\,A$$

(b) $$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9850}{1-0.9850} = 65.7$$

$$for \quad i_C = 3.827 \times 10^{-5} A$$

$$I_E = \frac{I_C}{\alpha} = \frac{38.27}{0.9850} = 38.85\,\mu A$$

$$I_B = \frac{I_C}{\beta} = \frac{38.27}{65.67} = 0.5828\,\mu A$$

Thank you