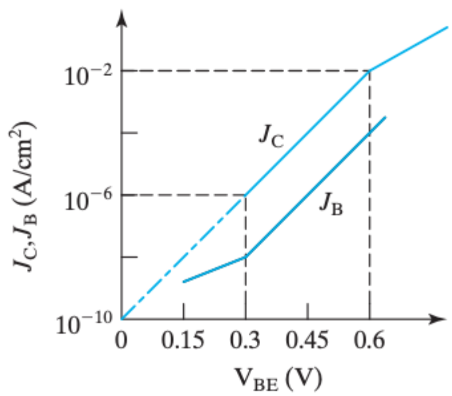
Columbia University
Department of Electrical Engineering
Solid State Devices and Materials
ELEN E3106/4106
Homework #7

Due: Friday, November 14th by 5pm
Goal: Practice solving practical problems in bipolar junction transistor (BJTs). Gain an intuitive understanding of the basic device operation and the effect of device design on key metrics of performance, like the current gain.
Instructions: Show your work and include units in answers for full credit. Unless stated otherwise, make the assumptions we have been taking in class (the sample is at 300 K in the dark) Circle or box your final answer.
Points: 110 pts for 3106. 130 pts for 4106.

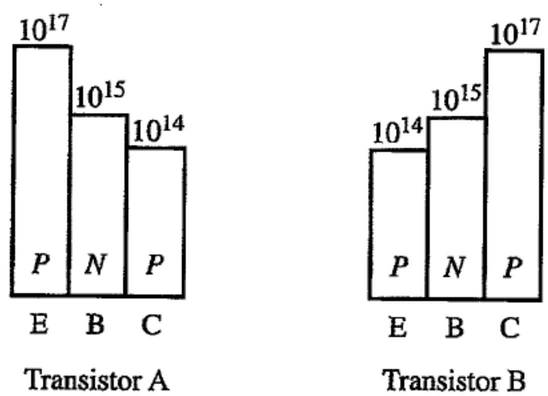
- **Problem 1 (25 pts)** Extracting key parameters from Gummel plots.

Consider an n-p-n transistor with $W_E = 0.5\ \mu m$, $W_B = 0.2\ \mu m$, $W_C = 2\ \mu m$, $D_B = 12\ cm^2/s$.



(a) Find the peak β from the figure.
(b) Estimate the base doping concentration, N_B.
(c) Find the base transit time, τ_t.
(d) Qualitatively, what effect causes β reduction at $V_{BE} < 0.3\ V$?
(e) Qualitatively, what effect causes β reduction at $V_{BE} > 0.6\ V$?

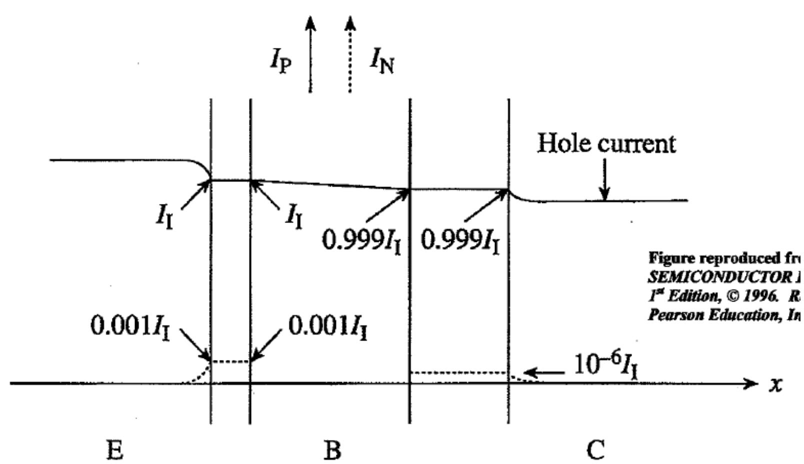
- **Problem 2 (15 pts)** Comparison between two BJTs.
Two p-n-p BJTs are identical except that the emitter and collector region doping are interchanged as illustrated in the figure below.



(a) Which transistor is expected to have the greater emitter injection efficiency, A or B? Explain.
(b) Which transistor will exhibit the greater sensitivity to base width modulation under active mode biasing, A or B? Explain.
(c) Which transistor will have a greater avalanche breakdown of the C-B junction, A or B? Explain.
(d) Which transistor will have a higher common-emitter current gain, β, when operated in active mode, A or B? Explain.
(e) If we want the transistor output characteristics to be identical, which of the following combinations of modes of operation could we use? Select one (no explanation necessary).
   1. Transistor A in cut-off and Transistor B in active.
   2. Transistor A in active and Transistor B in reverse active.
   3. Transistor A in saturation and Transistor B in cut-off.

- **Problem 3 (20 pts)** BJT current in active mode.

The electron and hole currents inside of a p-n-p BJT biased in the active mode are plotted in the figure below. All the currents are referenced to I_I, the hole current injected into the base. Determine the following parameters.



(a) The emitter injection efficiency, γ.
(b) The base transport factor, B.

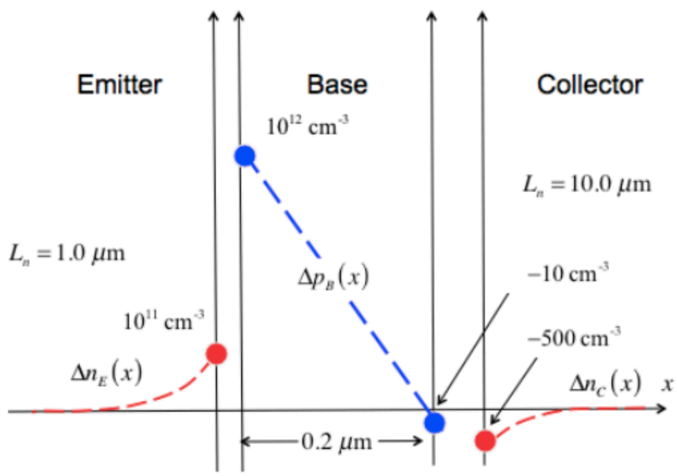
(c) The common emitter gain, β.(Note: This particular device has a higher gain than the typical range we discussed in class.)

(d) The base current, I_B. (Hint: Recall $I_E = I_B + I_C$.)

(e) For the given transistor, is the recombination-generation current arising from the depletion regions negligible as assumed in the ideal transistor analysis, yes or no? Explain.

- **Problem 4 (30 pts)** Excess minority carrier concentrations in a BJT.

The excess minority carrier concentrations for a specific bias are shown in the figure below for a BJT. The scale is linear (note: concentrations near the CH junction are exaggerated and not to scale). Assume the E/B/C regions are all composed of the same semiconductor material (with different doping type/density), and the the base is doped at $N_B = 10^{17}\ cm^{-3}$. The diffusion coefficients are $D_n = 25\ cm^2/s$ and $D_p = 12\ cm^2/s$ for electrons and holes, respectively.



(a) Is than an n-p-n or p-n-p transistor?

(b) What mode of operation is illustrated in the figure? Explain. (Hint: consider when minority carrier injection and extraction occur in p-n diodes)

(c) What is the doping density in the emitter, N_E? (Hint: N_B is given. Consider the ratio between Δn_E, Δp_B at the edge of the EB junction – which gives the ratio between the doping densities.)

(d) Which of the following best describes the base region? (no explanation necessary)
1. The base width is much larger than the minority carrier diffusion length
2. Recombination is the dominant process for minority carrier flow through the base
3. Both (a) and (b)
4. Neither (a) nor (b)

(e) What is the emitter injection efficiency, γ? (Hint: Consider the form of the equation for injection efficiency in terms of Gummel numbers and you can easily solve. Assume $n_{iE}^2 = n_{iB}^2$.

(f) What is the common emitter gain, β, for this transistor, assuming there is no recombination in the base (e.g. base transport factor is 1)?

- **Problem 5 (20 pts)** Short answer questions.
  (a) Why should the emitter be more heavily doped than the base? Explain.
  (b) The base width is "small" or "narrow" is often stated in our analysis. What is it being compared with?
  (c) What is a common way to mitigate the Early effect in BJTs?
  (d) For an n-p-n device, indicate the voltage polarity (+ or -) in the table below:

Region/Mode of Operation	V_{BE}	V_{BC}
Active		
Saturation		
Cut-off		
Reverse active		

- **Problem 6 (20 pts)** **(Required for 4106 students ONLY):** Schottky emitter and collector.

The emitter of a high-β BJT should be heavily doped.
  (a) Is it desirable to replace the emitter in BJT with a metal (e.g. the emitter is Schottky)? Explain.
  (b) If the collector of a BJT is replaced with a metal, would is still function as a BJT? (Hint: It may be helpful to compare the energy band diagrams of the two cases). Explain.