MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 ELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 5

<u>Issued</u>: October 3, 2003 **<u>Due</u>:** October 10, 2003

<u>Reading Assignments:</u>

Lecture 10 (10/7/03) - Chap. 7 (7.5 to end [good quiz review])
Lecture 11 (10/9/03) - Chap. 9 (all except 9.5)
Lecture 12 (10/14/03) - Chap. 10 (10.1.1a)

The first hour exam is scheduled for Wednesday night, October 8, from 7:30 to 9:30 pm in Room 34-101. The exam is closed book and will cover the material through 9/26/03 and Problem Set #4 (through p-n diodes). Working problems 1 thru 3 and 5, parts a and b, will provide you with a good quiz review, even when they deal with BJTs.

Looking ahead, Problem Set 6 will require that you get a user account on a remote-control device measurement and characterization system called "weblab". Go to "http://weblab.mit.edu" and request a user account. In the Description field of the registration form, write "6.012 student". It will take a day to set up your account, so request your account right away to avoid the rush and the risk of future delay.

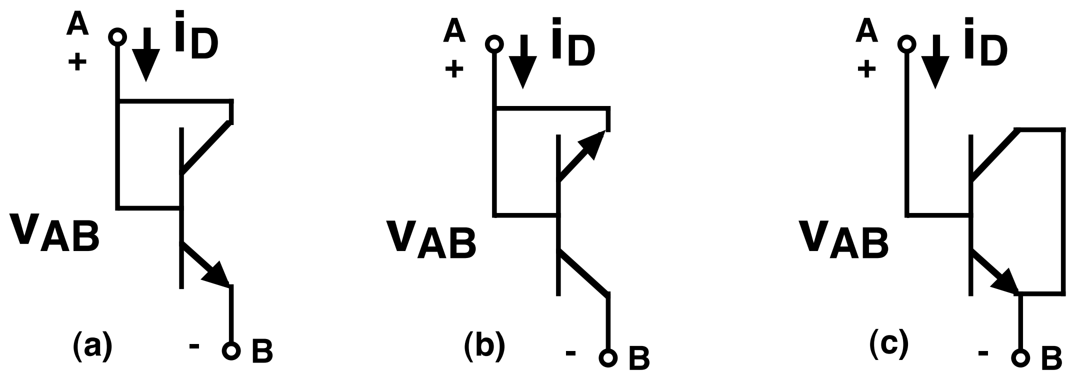
<u>Problem 1</u> - Do Problem 7.11 in the course text. Photodiodes per se will not be on the exam, but the concepts involved in their operation are basic to p-n diodes and am appear in the exam.

<u>Problem 2</u> - Do Problem 8.1 in the course text.

<u>Problem 3</u> - Do Problem 8.6 in the course text. In this problem you want to treat the horizontal and vertical junction diodes as one-dimensional diodes, and to ignor the "corner" regions. This is a good "hand calculation" approximation, and preserves the essence of the physics of the device.

<u>Problem 4</u> - This type of problem is a good review of circuit analysis and semiconductor physics, as well as addressing practical issues encountered in integrated circuit design, which is one reason it is one of my all-time favorites. This specific example is from the final exam two years ago.

In an integrated circuit, when a designer needs a diode it is easiest to use a transistor and connect it so it functions as a diode. A transistor, after all, contains two p-n junctions. There are at least five ways to connect an <u>npn transistor</u> as a diode; three of them are pictured at the top of the next page:



For purposes of this question, assume that the npn bipolar junction transistor in question has a base doping that is 4 times the collector doping and 1/4 the emitter doping, that base width is the same as the emitter width and 1/2 the collector width, and that the electron mobility is twice the hole mobility; that is:

$N_{DE} = 4\,N_{AB} = 16\,N_{DC}$, $\quad w_E = w_B$, $\quad w_C = 2w_B$, $\quad$ and $\mu_e = 2\mu_h$

a) i) Which of these diode connections will have the <u>largest</u> small signal <u>depletion capacitance</u> at a reverse bias of 1 V, and why?

ii) Which of the three diode connections will have the <u>largest</u> small signal <u>conductance</u> about the bias point I_D = 1 mA, and why?

b) i) Sketch the excess carrier populations as a function of position in the emitter and collector, respectively, of connections a, b, and c, when a forward bias, V_{AB}, of 0.6V is applied to the diode.

ii) Which one of the three diode connections a, b, or c will have the <u>smallest</u> small signal <u>diffusion</u> <u>capacitance</u> at a forward bias of 0.6 V, and why?

c) Use the Ebers-Moll Model for the large signal characteristics of a bipolar junction transistor (pictured below) to show that i_D vs v_{AB} of Connection c can be written as

$$i_D = I_{DS}\,(\exp qv_{AB}/kT - 1)$$

and find an expression for I_{DS} of Connection c in terms of the Ebers-Moll Model parameters.