MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 ELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 4

Issued: September 26, 2003 **Due**: October 3, 2003

Reading Assignments:

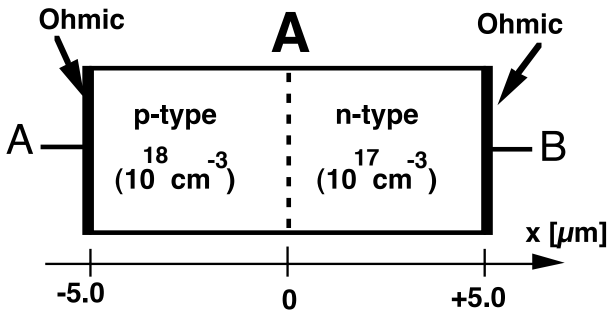
Lecture 8 (9/30/03) - Chap. 8 (8.1)
Lecture 9 (10/2/03) - Chap. 8 (8.2.1a)
Lecture 10 (10/7/03) - Chap. 7 (7.5 to end [good quiz review])

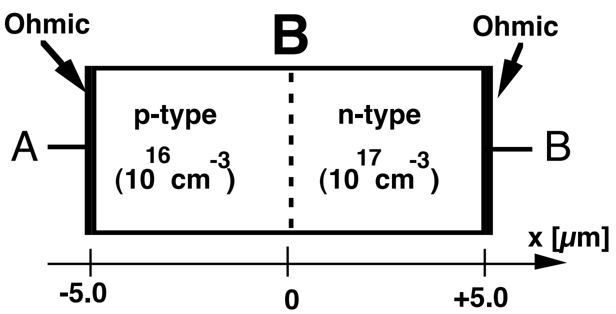
The first hour exam is scheduled for Wednesday night, October 8, from 7:30 to 9:30 pm in Room 34-101. The exam is closed book and will cover the material through 9/26/01 and Problem Set #4 (through p-n diodes).

Several of the problems on this set are from old exams; in many cases the answers won't require alot of calculation and you can give approximate answers.

Problem 1 - This problem concerns the two abrupt p-n diodes pictured below. These two diodes have identical dimensions and differ only in the doping levels on the p-sides. In both diodes the n-side is doped with 10^{17} cm^{-3} donors. In Diode A the p-side is doped with 10^{18} cm^{-3} acceptors and in Diode B it is doped with 10^{16} cm^{-3} acceptors. You may assume for purposes of this problem that:

(1) the widths of the depletion regions on either side of the junctions in these diodes are all negligible relative to 5 μm when they are forward biased,
(2) the hole mobility is 600 cm^2/V-s and the electron mobility is 1600 cm^2/V-s in all regions, and
(3) the minority carrier diffusion lengths are much larger than 10 μm.





a) Which diode has the wider zero-bias depletion region? Explain your answer.

b) With zero applied bias, in which diode is the magnitude of the peak electric field in the depletion region largest? Explain your answer.

c) For which diode will the magnitude of the reverse breakdown voltage be largest? Explain your answer.

d) A reverse bias is applied to both diodes so that the depletion region on the n-side in each diode is 0.2 μm wide.

- i) What is the width of the depletion region on the p-side in each diode?
- ii) On which diode is the magnitude of the reverse bias larger? Explain your answer.

e) A forward bias is applied to each diode so that the excess hole population on the n-side at x_n, $p'(x_n)$, is 10^{12} cm^{-3} in both diodes.

- i) What are the excess electron populations at the edge of the depletion region on the p-side, i.e., $n'(-x_p)$, in each diode?
- ii) What is the ratio of the total hole current to the total electron current through each diode at x = 0?
- iii) What is the total excess minority carrier charge per unit area in each diode at this bias level? Note: Consider the entire device, i.e., from - 5μm to + 5 μm.
- iv) What is the applied bias on each diode?

Problem 2 - Do Problem 7.4 in the course text.

Problem 4 - Consider an abrupt, asymmetrically-doped p-n diode in which the p-side and the n-side are 20 microns wide. The p-side is doped to a level of 10^{18} cm^{-3}, and the n-side is doped to a level of 10^{16} cm^{-3}. The hole mobility is 600 cm^2/V-s, the electron mobility is 1600 cm^2/V-s, and the minority carrier diffusion length is 5 microns, so you can assume the diode is a long-base device.

(a) Derive an expression for the excess minority carrier populations throughout this device with an applied forward bias voltage of V_{AB}. Plot your expressions for V_{AB} = 0.5 V. Justify the argument that you can neglect injection into the p-side because it is so much more heavily doped than the n-side.

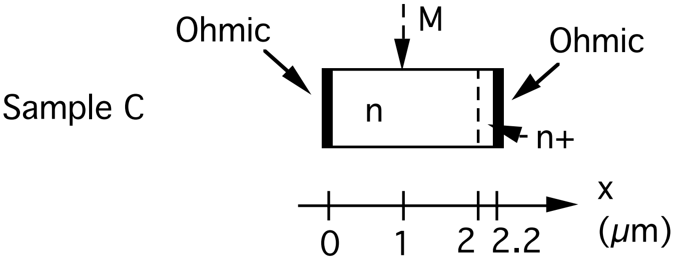
(b) Derive an expression for the total current density through this device as a function of the applied voltage, V_{AB}. Again argue that one of the components of the current is negligible and right your expression to reflect this fact. (Assume you can neglect the width of the depletion region on the n-side relative to 20 microns.)

(c) Derive an expression for the total amount of excess charge on the n-side of the junction as a function of V_{AB}, i.e., integrate $p'(x)$ from 0 to 20 microns. (Assume you can neglect the width of the depletion region on the n-side relative to 20 microns.)

(d) The excess charge that you calculated in Part (c) represents stored charge that must be supplied from the terminals when the voltage is changed. Thus it looks like a capacitance. It is called the "diffusion capacitance" and is discussed in Section 7.3.4 in the course text for short-base diodes. Using the expressions you have derived above, calculate the equivalent of Equation 7.44') in the course text for the present long-base diode.

(e) What is the equivalent of the transit time in a long-base diode?

Problem 5 - Look back at Problem 5 on Problem Set No. 2. Now consider a third sample, Sample C, which, as pictured below, has a heavily doped n-region 0.2 μm thick starting at 2 μm. The doping in this region is 10^{18} cm^{-3}.



a) What is the electrostatic potential, □, in the n and n$^+$ regions of Sample C?

b) The change of potential, $\square_{n+}$ - $\square_n$, at x = 2μm between the n and the n$^+$ regions represents a potential energy barrier for holes so the excess hole concentration to the right of the step, p'(2$^+$) is much smaller than that to left, p'(2$^-$). [Given time and under less pressure, you should be able to find that it is actually 100 times smaller, which is exp -q($\square_{n+}$ - $\square_n$)/kT, and which is also the ratio of the doping levels on either side of the n-n$^+$ interface.]

This question concerns the slope of the excess hole concentration crossing the interface at x = 2 μm. How is the slope in the excess population at x = 2$^+$ μm related to that at x = 2$^-$ μm? Write an expression for $dp'/dx\,|_{x=2^+}$ in terms of $dp'/dx\,|_{x=2^-}$.

c) Use the information in Part (b) and your answer in that part to sketch the excess minority carrier profile in Sample C when it is illuminated with light which generates qM hole-electron pairs cm^{-3}-s^{-1} uniformly across the plane at x = 1μm. Assume L_h >> 2.2 μm. You need not calculate p'(1 μm).