MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 MICROELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 3

Issued: September 23, 2009 **Due:** September 30, 2009

Reading Assignments:

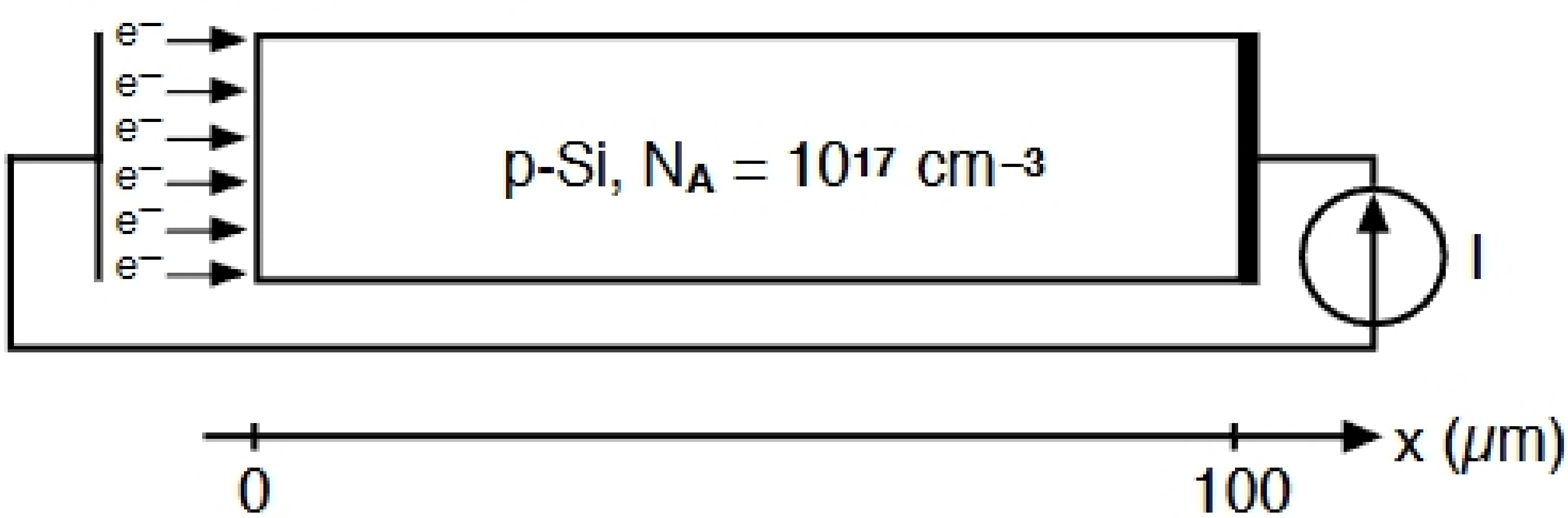
Lecture 5 (9/24/09) - Chap. 5 (5.1)
Lecture 6 (9/29/09) - Chap. 7 (7.3)
Lecture 7 (10/1/09) - Chap. 8 (8.1)

Note: The first hour exam is scheduled for Wednesday night, October 7, from 7:30 to 9:30 pm Please let me know as soon as possible (by e-mail) if you have a conflict so we can resolve it as painlessly as possible. The exam is closed book and will cover the material through 10/2/09 and Problem Set #4 (p-n junction diodes and BJT basics).

Problem 1 - Do Problem 7.3 in the course text.

Problem 2 - This problem concerns a bar of p-type silicon, $N_A = 10^{17}$ cm^{-3}, irradiated on its left end with a uniform electron beam having an electron flux of 10^{19} cm^{-2}s^{-1} as illustrated below.*

As shown, the sample is 10 μm long and has an ohmic contact on its right end; this contact is connected to the electron source to complete the circuit as indicated. In this sample the hole mobility, μ_h, is 600 cm^2/V-s; the electron mobility, μ_e, is 1600 cm^2/V-s; the electron diffusion length, L_e, is 100 μm; and the intrinsic carrier concentration at room temperature, n_i, is 10^{10} cm^{-3}.



(a) What is the electron current density just inside the bar at the left end, i.e. what is $J_e(0^+)$? Show your work and/or explain your answer.

(b) Write a formula for $n'(x)$ in terms of $n'(0)$ and then determine the value of $n'(0)$.

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* In case you are concerned: The electron beam hitting the left end of the bar behaves like an injecting contact. The injected electrons do not have sufficient energy to generate more hole-electron pairs. Also, no holes can leave the left end of the bar.

(c) Write an expression for the electron current density, $J_e(x)$, valid for $0 < x < 10$ μm.

(d) Write an expressioin for the hole current density, $J_h(x)$, valid for $0 < x < 10$ μm.

(e) Write an expression for the electric field, $E_x(x)$, valid for $0 < x < 10$ μm.

(f) What is the voltage drop from end to end in this sample? Note: this is the same as the change in electrostatic potential between $x = 0$ and 10 μm.

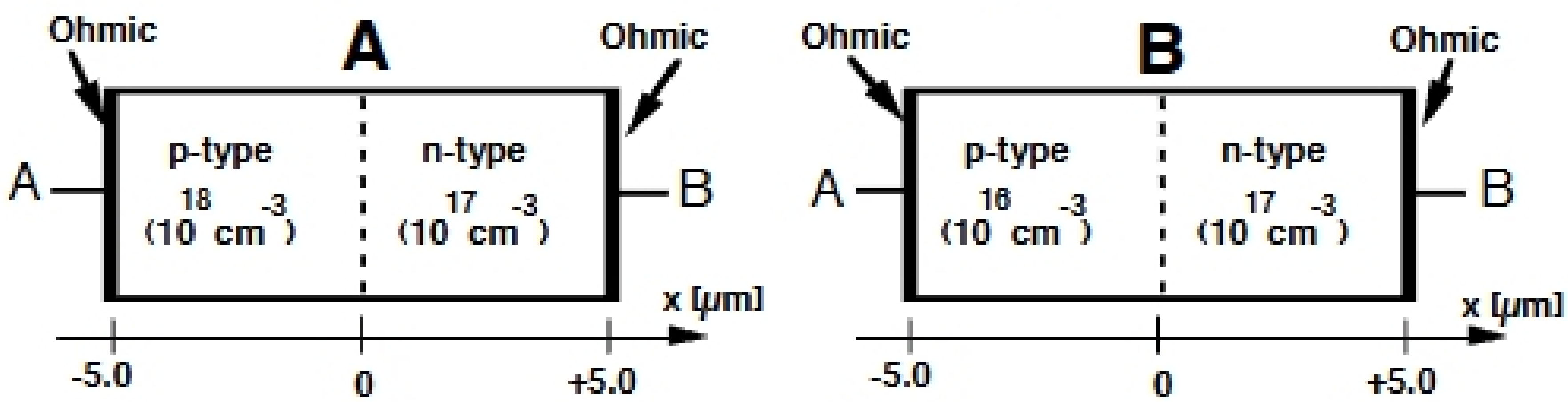
Problem 3 - Do Problem 7.5 in the course text.

Problem 4 - 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.

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?