MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 MICROELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 1

Issued: September 11, 2009 **Due**: September 16, 2009

Reading Assignments:

Lecture 1 (9/10/09) - Chap. 1 (all), Chap. 2 (all), Chap.3 (3.1)
Lecture 2 (9/15/09) - Chap. 3 (all), Chap. 4 (4.1)
Lecture 3 (9/17/09) - Chap. 4 (4.2, 4.3), Chap. 6 (all)

Problem 1 - This problem concerns the following three samples of silicon, each of which has a different doping level:

Sample a: 10^{17} cm^{-3} arsenic

Sample b: 10^{16} cm^{-3} boron, 5 x 10^{15} cm^{-3} phosphorous

Sample c: intrinsic (no dopants)

Complete a table like that shown below for these three samples. Assume that at room temperature the electron mobility, μ_e, is 1600 cm^2/V-s, the hole mobility, μ_h, is 600 cm^2/V-s, and the intrinsic carrier concentration, n_i, is 10^{10} cm^{-3}.

Sample	Type (n or p)	n_o [cm^{-3}]	p_o [cm^{-3}]	Resistivity, ρ_o [Ω-cm]
a				
b				
c				

Problem 2 [A one-dimensional electrostatics problem] - Consider a situation in which there is a net charge density profile, ρ(x,y,z), that varies in the x-direction only, i.e. ρ(x,y,z) = ρ(x). There is a negative sheet charge density, –Q coul/cm^2, at x = -50 nm, and a uniform positive charge density of 1.6 x 10^{-2} coul/cm^3 between 0 and 300 nm. The dielectric constant is 3.5 x 10^{-9} coul/V-cm for x ≤ 0, and it is 10^{-10} coul/V-cm for x > 0.

a) Sketch and label ρ(x). The sheet charge density should be represented as an impulse at x = -10 nm with an intensity –Q. Assuming the electric field is zero for x < -50 nm, and x > 300 nm, what is the strength, Q, of the negative sheet charge at x = -50 nm?

b) Sketch and label the electric field, E(x), for -100 nm ≤ x ≤ 500 nm. Where does the electric field have its maximum intensity, $|E(x)|_{max}$, and what is $|E(x)|_{max}$?

c) Sketch and label the electrostatic potential, ϕ(x), for -100 nm ≤ x ≤ 500 nm, and give an algebraic expression for ϕ(x) valid in the region 0 ≤ x ≤ 500 nm. Assume ϕ = 0.5 V at x = 500 nm. What is the change in potential, $\Delta\phi$, between x = -100 nm and x = 500 nm?

d) Finally consider how $\rho(x)$, $E(x)$, and $\phi(x)$ change if the extent of the uniform charge density is reduced and it now only extends from x = 0 to x = 200 nm.

i) Is Q larger or smaller, and by how much?

ii) Is $|E(x)|_{max}$ larger or smaller, and by how much?

iii) Is $\Delta\phi$ larger or smaller?

Problem 3 - A p-type sample of silicon has a resistivity of 5 Ω-cm. In this sample, the hole mobility, μ_h, is 600 cm^2/V-s and the electron mobility, μ_e, is 1600 cm^2/V-s. Ohmic contacts are formed on the ends of the sample and a uniform electric field is imposed which results in a drift current density in the sample is 2×10^3 A/cm^2.

a) What are the hole and electron concentrations in this sample?

b) What are the hole and electron drift velocities under these conditions?

c) What is the magnitude of the electric field?

Problem 4 - This problem concerns a sample of Semiconductor X. At room temperature in Semiconductor X, the intrinsic carrier concentration, n_i, is 10^7 cm^{-3}, the hole mobility, μ_h, is 300 cm^2/V-s, and the electron mobility, μ_e, is 4000 cm^2/V-s. The minority carrier lifetime, τ_{min}, is 10^{-9} s.

This sample is known to have 2×10^{16} cm^{-3} donors and an unknown number of acceptors. A measurement is made on the sample and it is found to be p-type with an equilibrium hole concentration, p_o, of 5×10^{17} cm^{-3}.

a) What is the net acceptor concentration, N_A (= N_a - N_d), in this sample, and what is the total acceptor concentration, N_a?

b) What is the equilibrium electron concentration, n_o, in this sample at room temperature?

c) What is the electrical conductivity, σ_o, of this sample in thermal equilibrium at room temperature?

d) This sample is illuminated by a steady state light which generates hole-electron pairs uniformly throughout its bulk, and the conductivity of the sample is found to increase by 1% (that is, to 1.01 σ_o). What are the excess hole and electron concentrations, p' and n', in the illuminated sample, assuming that the illumination has been on for a long time?

f) What is the optical generation rate, G_L, in Part d?

g) If the illumination in Part d is extinguished at t = 0, write an expression for the sample conductivity as a function of time for t > 0. Express your answer in terms of σ_o, rather than the numerical value.