MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 MICROELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 2

Issued: September 16, 2009 **Due**: September 23, 2009

Reading Assignments:

Lecture 3 (9/17/09) - Chap. 4 (4.2, 4.3), Chap. 6 (begin)
Lecture 4 (9/22/09) - Chap. 6 (all), Chap. 7 (7.1, 7.2)
Lecture 5 (9/24/09) - Chap. 5 (5.1)

Problem 1 - We say that we can approximate the minority carrier lifetime in Si as being infinite even though it is really several hundred milliseconds, because this is a long time compared to the time it takes a hole or an electron to drift or diffuse across a device to a contact or junction. To verify this statement consider the following two questions:

a) With drift, the time it takes a carrier to go (transit) a distance d is: $\tau_{tr,Drift} = d/\mu E$.

i) How long does it take an electron ($\mu_e = 1600\ cm^2/V\text{-}s$) to drift 10 μm in a field of 10 V/cm?

ii) Repeat a) i) for a hole ($\mu_h = 600\ cm^2/V\text{-}s$).

iii) Compare your answers in a) i) and a) ii) to a lifetime of 100 ms. Is approximating this lifetime as "infinite" in this situation reasonable?

b) With diffusion, the time it takes a carrier to transit a distance d is: $\tau_{tr,Diff} = d^2/2D$.

i) How long does it take an electron ($D_e = 40\ cm^2/s$) to diffuse 10 μm in a concentration gradient of $10^{15}\ cm^{-3}$ per micron?

ii) Repeat b) i) for a hole ($D_h = 15\ cm^2/s$).

iii) Compare your answers in a) i) and a) ii) to a lifetime of 100 ms. Is approximating this lifetime as "infinite" in this situation reasonable?

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Problem 2 - Do Problem 3.9, Parts a thru d, in the course textbook.

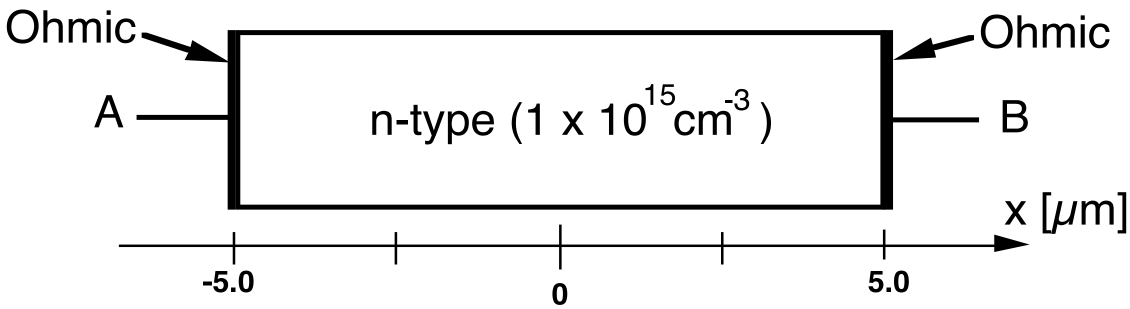
Problem 3 - Two short problems:

i) Do Problem 4.3 in the course textbook.

ii) Do Problem 4.2 in the course textbook.

Problem 4 - The n-type silicon sample illustrated on the top of the next page is 10 microns (μm) long and has metal ohmic contacts, A and B, on either end. The net donor concentration is $1 \times 10^{15}\ cm^{-3}$; the electron mobility, μ_e, is 1600 $cm^2/V\text{-}s$; and the hole mobility, μ_h, is 600 $cm^2/V\text{-}s$. The electrostatic potential of the metal relative to intrinsic silicon is 0.2V, and the intrinsic carrier concentration at room temperature is $10^{10}\ cm^{-3}$.

Use the 60 mV rule to calculate the electrostatic potential, i.e. use $(kT/q) \ln 10 = 0.06$ V.



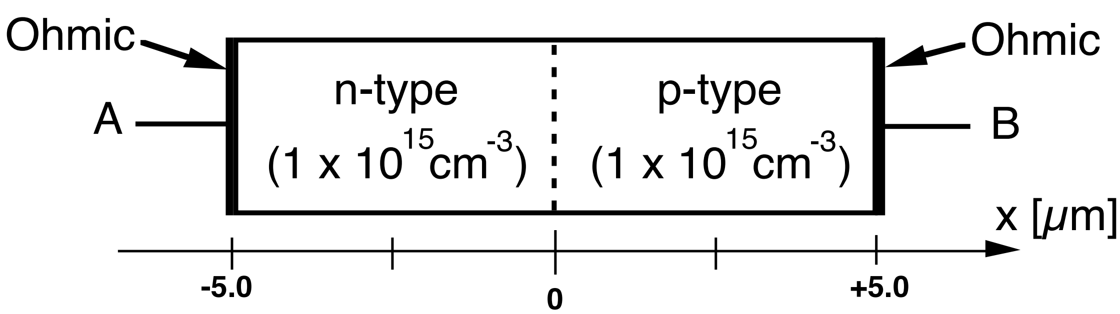
a) What are the thermal equilibrium (i.e., no light, v_{AB} = 0 V) hole and electron concentrations and electrostatic potential, ϕ_n, in this silicon?

b) Sketch the electrostatic potential, $\phi(x)$, with v_{AB} = 0 V, going from the metal on the left, through the silicon, and into the metal on the right. Dimension your sketch; label any significant features.

c) Assume now that v_{AB} = 0.5 V. Sketch the electrostatic potential, $\phi(x)$, with v_{AB} = 0.5 V, going from the metal on the left, through the silicon, and into the metal on the right (where you should assume the value of ø is unchanged, i.e. 0.2 V). Dimension your sketch and label any significant features, including $\phi(0)$.

e) When v_{AB} = 0.5 V, what are the electron and hole <u>drift</u> current densities, J_e^{dr} and J_h^{dr}, respectively, at x = 0 μm

Next consider a sample similar to our original sample, except that it is doped p-type with a net acceptor concentration of 1 x 10^{15} cm^{-3} in the region from x = 0 μm to x = +5 μm as shown below. **Note**: This is a diode with the p-side to the right.



f) Sketch the electrostatic potential, $\phi(x)$, going from the metal on the left, through the silicon, and into the metal on the right, with v_{AB} = 0 V. Dimension your sketch and label any significant features, including the value of $\phi(0)$.

g) The diode is now <u>reverse biased</u> by v_{AB} = 0.5 V. Sketch the electrostatic potential, $\phi(x)$, now, going from the metal on the left, through the silicon, and into the metal on the right. Keep ϕ in the metal to the right of x = 5 μm at the value it had in Part f. Dimension your sketch and label any significant features, including the value of $\phi(0)$.