EE216 Winter 2009

Homework 2

Due in lecture Thursday, January 22, 2009, or before 5:00 PM, in CISX-329.

1. *Velocity Limits and Ohm's Law*. In some precision analog-IC technologies, it's important to have as close to a truly linear resistor as possible, so that $V = I{\cdot}R$. *Given*: the n-type resistor's doping is 4 x 10^{16} cm^{-3} and p-type resistor's doping is 8 x 10^{16} cm^{-3}. The resistor length and width should be selected so that the resistance is 1 kΩ; the thickness of the resistor is 200 nm and its minimum width is 500 nm. The resistor needs to operate over a range $|V| < 5$ V.

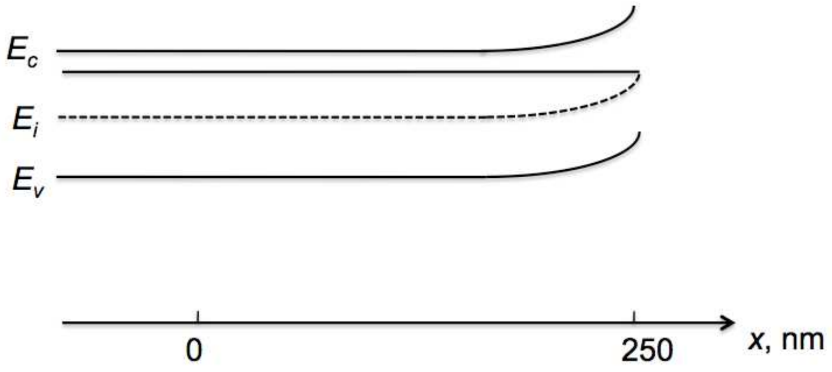
   a) In order to use the least area, what is the resistor doping type and what are the resistor's dimensions?
   b) For this minimum-area resistor, what is the deviation (in %) from the low-field, linear I-V curve for $V = 5$ V? You should use Eq. (1.2.12) and Table 1.2.
   c) How can the resistor be redesigned to reduce this non-linearity to less than 0.1%, while maintaining the low-field resistance at 1 kΩ?
   d) A 1 kΩ resistor is fabricated with the same doping concentration, opposite doping type, and same width as in part c). What must the length be? What is the non-linearity at $V = 5$ V in %?

2. *Drift-diffusion transport*. Find the built-in electric field (with direction) at $x = 0.5$ µm for a boron doping profile that varies linearly from 1 x 10^{17} cm^{-3} at $x = 0$ to 5 x 10^{16} cm^{-3} at $x = 1$ µm under the following conditions:

   a) Only this doping profile present.
   b) This doping profile with a uniform additional 10^{18} cm^{-3} boron doping.
   c) The profile in (a) with a uniform additional 10^{18} cm^{-3} phosphorus doping.
   d) Describe using a qualitative sketch how the built-in electric field arises.
   e) At $x = 0.5$ µm, estimate the percentage difference between the hole concentration and the doping concentration for each of the cases in (a) – (c). Does quasi-neutrality apply in each of the cases?

3. This problem investigates the problems with using compensation as a technique for controlling resistivity.
   a) We start with p-type silicon, with a doping concentration $N_a = 2 \times 10^{18}$ cm^{-3}. What is the resistivity at room temperature?
   b) Since the resistivity is much too low, we compensate the sample by adding arsenic with a concentration $N_d = 1.8 \times 10^{18}$ cm^{-3}. What is the resistivity?
   c) What is the resistivity of silicon doped with boron at $N_a = 2 \times 10^{17}$ cm^{-3}?
   d) Why are you answers from parts (b) and (c) different?
   e) If we heat the silicon, will the answers in parts (b) and (c) get closer or farther apart?
   f) If each step in the doping process has an uncertainty of + or - 5%, what is the range of resistivity values in parts (b) and (c)?

4. The band diagram of a region of silicon is illustrated below. The unlabeled line is the Fermi energy, E_F.



a) Sketch the electrostatic potential from x = 0 to 250 nm.
b) Sketch the electric field from x = 0 to 250 nm.
c) Sketch the electron concentration x = 0 to 250 nm using a log scale.
d) Finally, sketch the drift and diffusion current densities in this region.