6.012 Microelectronic Devices and Circuits Fall 2008

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Problem Set #2

Assigned: September 10, 2008
Due: September 17, 2008 at recitation

Reading Assignments:	09/09/04	Sections 2.4-2.6 of Howe & Sodini
	09/11/04	Sections 3.1-3.3 of Howe & Sodini
	09/16/04	Sections 3.3-3.6 of Howe & Sodini

PLEASE WRITE YOUR RECITATION SESSION TIME ON YOUR PROBLEM SET SOLUTION

Problem 1. [20 points]
Consider a sample shown in Figure P2.1 of n-type Si with a resistivity of 10 Ω-cm at room temperature.

(a) Estimate at room temperature (i) the equilibrium electron concentration n_o, (ii) the equilibrium hole concentration p_o, (iii) the electron mobility μ_n and (iv) the hole mobility μ_p. {***Hint:*** *Use Figure 2.8 from Howe & Sodini and Pages 7 & 10 of Lecture 2 Notes*}

At a location in the middle of the sample, a current density $J = 10^3$ A/cm^2 was measured.

(b) Estimate the magnitude of the electric field at this location. [***State any assumptions***]?
(c) Estimate the relative contributions of the electron and hole drift to the total current?
(d) Estimate the hole drift velocity?
(e) Estimate the electron drift velocity?

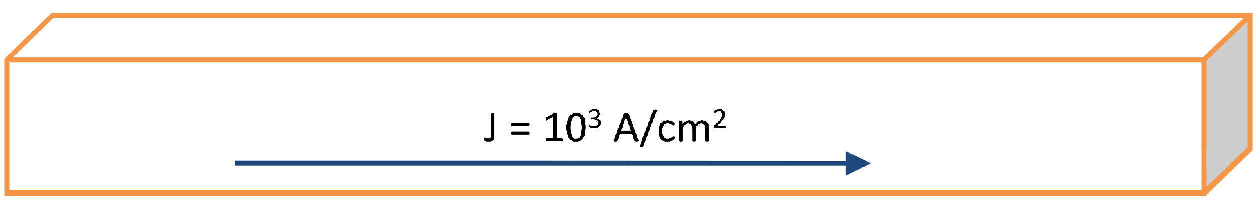

Figure P2.1

Problem 2. [20 points] *Adapted from Problem 3.4 of Fonstad*

(a) Consider a sample of n-type silicon L cm long, W cm wide, and T cm thick that is nonuniformly doped in such a manner that the equilibrium majority carrier population varies throughout its thickness as $n_o(x)$ (see Figure P2-2a). Show that if the mobility μ_N is constant, independent of the doping level, then the end-to-end resistance of this sample depends only on the integral of $n_o(x)$ over the thickness of the sample (i.e. , from x=0 at the top surface to x=T at the bottom surface) and not on the actual shape of $n_o(x)$. (Hints: Assume that current conduction is lateral, i.e. parallel to the surface. Mentally divide the sample into thin slabs of material dx wide, and add the conductances of these slabs connected in parallel.)

(b) In an integrated circuit, dopants are introduced to the top surface of a silicon wafer (slab) to produce non-uniformly doped regions like the sample described in (a) and resistors are formed by putting contacts at the ends of rectangularly shaped regions doped in this manner. Suppose that the doping profile of such a resistive region is such that

$$n_o(x) = 1\times10^{18}\exp\left[-\left(\frac{x-x_p}{L_x}\right)^2\right]\text{cm}^{-3}$$

where L_x is 0.25 μm and x_p is 5 μm. (Note: 1 μm $=10^{-4}$ cm). What is the sheet resistance R_{sh} of the region if T=10 μm? [***Use the electron mobility from Figure 2.8 of Howe and Sodini corresponding to the highest doping in the resistor; For all practical purposes, the integrals you require are very well approximated by setting the limits to -∞ to ∞***]. From the Table of Integrals,

$$\int_0^\infty e^{-a^2y^2}dy = \frac{\sqrt{\pi}}{2a} \qquad [a>0]$$

(c) The dopant profile in part (b) is introduced in a pattern like that illustrated in Figure P2-2b. What is the approximate resistance between contact pads A and B of this resistor?

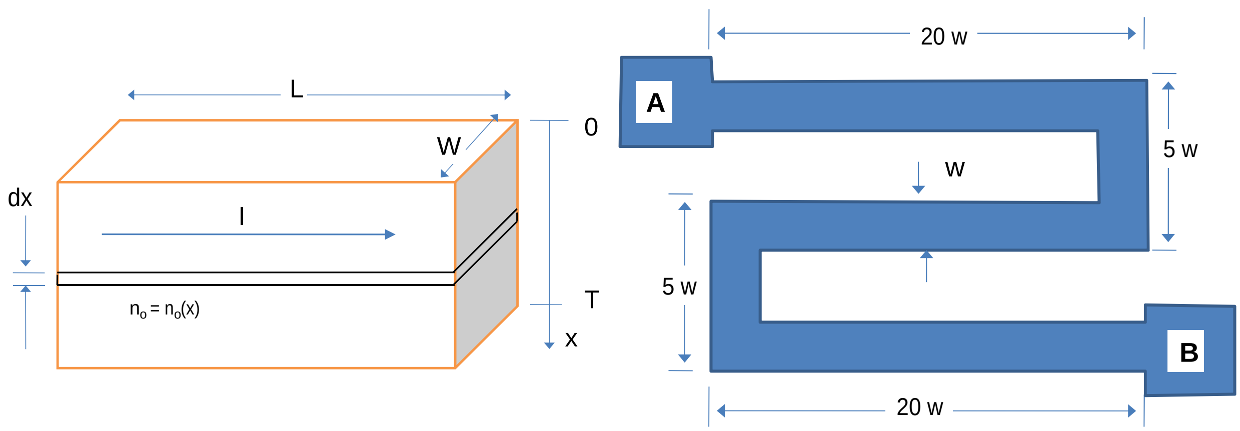

Figure P2-2a & b

Problem 3. [20 points] *Adapted from Problem P2.14 of Howe and Sodini*

Consider a sample of n-type silicon that is 1 μm long. Shining at one end (x=0) only leads to electron and hole generation at x=0 resulting in a gradient of minority carriers shown in Figure P2.3b. When a gradient in minority carrier concentration is set up in a semiconductor region, an identical majority carrier concentration is quickly established to maintain charge neutrality as shown in Figure P2.3b.

a) Estimate the minority hole diffusion current density.
b) Estimate the majority electron diffusion current density

c) Given that the total current density is zero because the sample is open-circuited, determine the drift current density.

d) By assuming that the contribution of the minority carriers to the drift current is negligible, what is the electric field required in the sample to obtain the drift current density you determined above.

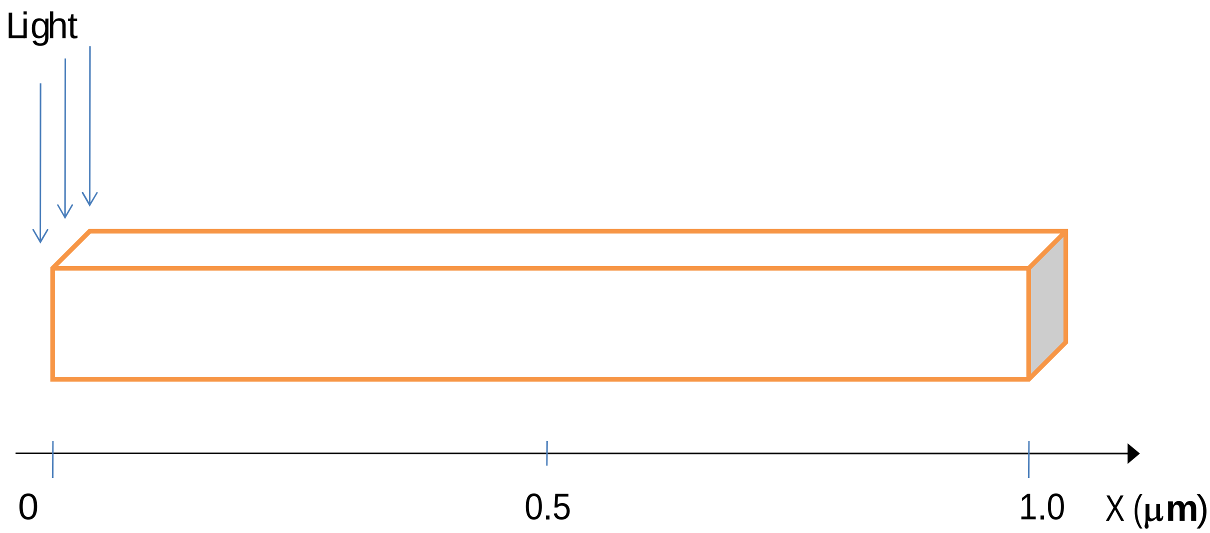

Figure 2.3a

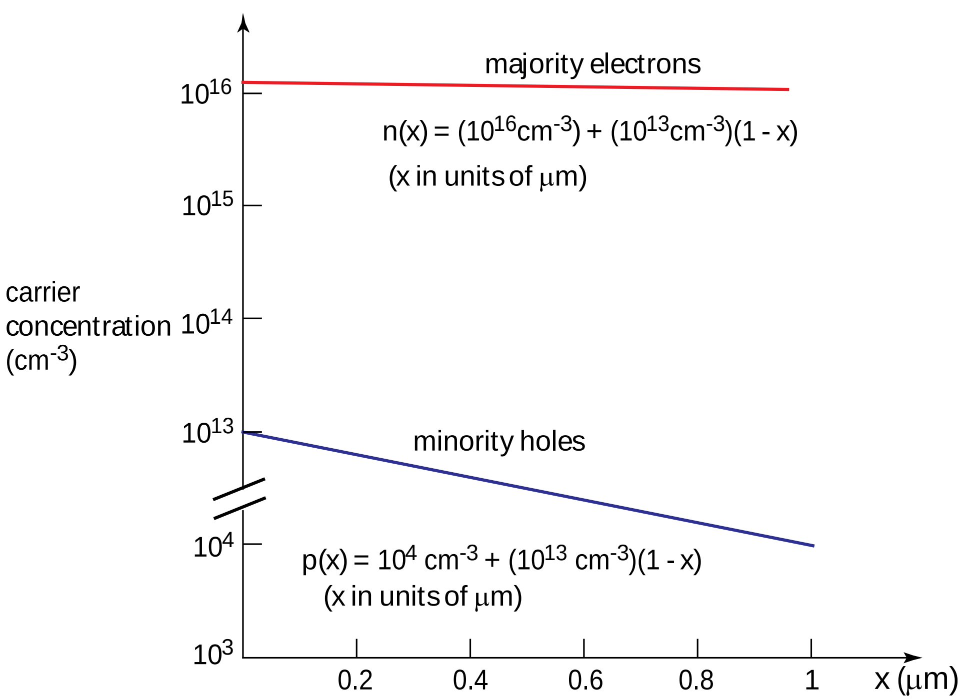

Figure P2.3b

Problem 4. [20 points]
In an integrated circuit, dopants are introduced to the top surface of a silicon wafer (slab) to produce non-uniformly doped regions. Suppose that the doping profile of such a resistive region is such that

$$p_o(x) = 10^{19} \times 10^{-\left[\frac{x}{L_x}\right]} \text{ cm}^{-3}$$

where L_x is 10 μm and the wafer thickness is 50 μm. The resulting hole concentration as a function of depth in silicon is shown in Figure P2.4 below. *It was assumed that the wafer had no background doping before dopants were introduced.*

(a) Derive an analytical expression for the electrostatic potential as a function of depth in the silicon, x, and quantitatively sketch the result in a suitable diagram.
(b) Derive an analytical expression for the electrostatic field as a function of depth in the silicon, x, and quantitatively sketch the result in a suitable diagram.
(c) Derive an analytical expression for the space charge distribution that supports this electric field as a function of depth in the silicon, x, and quantitatively sketch the result in a suitable diagram.
(d) Derive an analytical expression for the minority carrier concentration as a function of depth in the silicon, x, and quantitatively sketch the result in a suitable diagram.

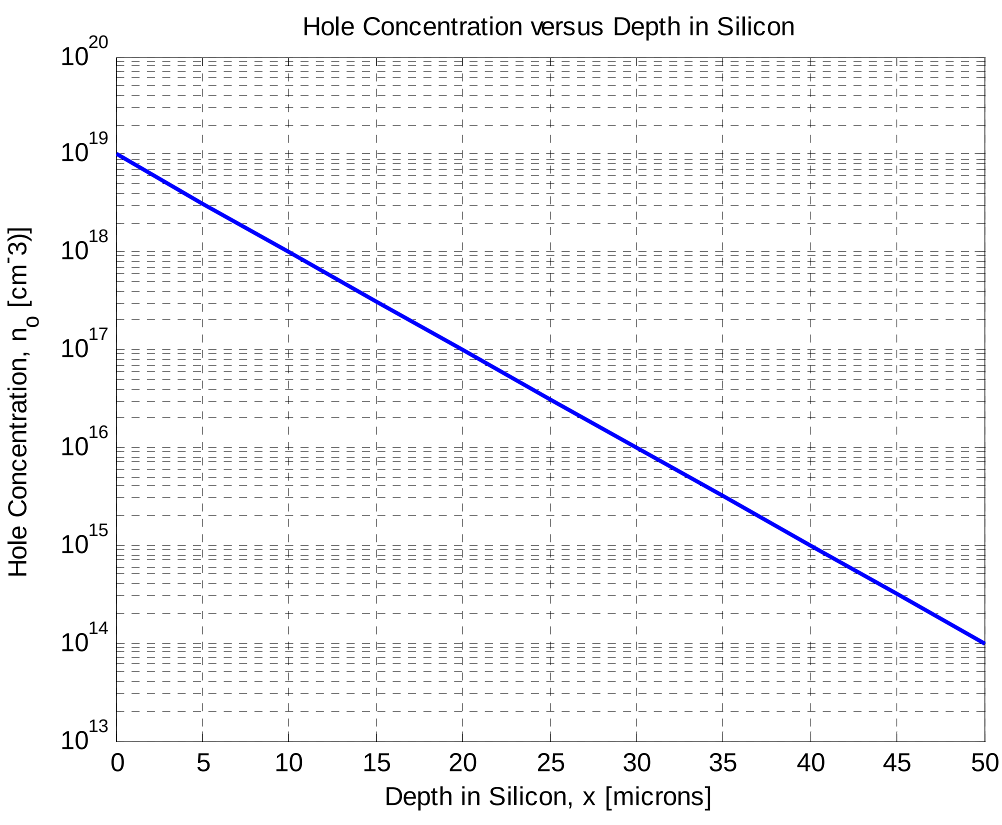

Figure P2.4

Problem 5. [20 points] **WebLab:** I-V Characteristics of the pn diode

You will be using an Agilent 4155B semiconductor Parameter Analyzer for the device characterization assignments of 6.012. The tool allows you to obtain the current – voltage characteristics of semiconductor devices. In this assignment you will take an IV characteristics of a pn junction diode, a device, whose basic behavior you studied in 6.002. One or more identical devices (*labeled pn Diode*) are available on WebLab under the devices menu. Details of the connection are given on-line.

Obtain an I-V characteristics of the pn diode. Take measurements between -2 and 1 V in steps of 10 mV (*The maximum number of data points is 500*). In the measurement panel of WebLab, plot your results as follows

Graph 1: Linear plot of the I-V characteristics (*V on the x –axis on a linear scale, I on the y –axis on a linear scale*). Take a screen shot and print this graph.

Graph 2: Semilogarithmic plot of the I-V characteristics (*V on the x –axis on a linear scale, I on the y – axis on a logarithmic scale*). Take a screen shot and print this graph.

You might need to go back and forth a few times trying different measurement point distributions so that sufficient data is taken in all regions of interest. Think about issues involved in sweeping voltage vs. sweeping current. The maximum current the Agilent 4155B can support is 100 mA so for high voltages, the diode current will be clamped to 100 mA. The minimum current you should be concerned with is 1 pA.

When you are appy with the results, download the data to your local computer and port the data into your favorite spreadsheet program or MATLAB for further plotting and analysis.

Graph 3: Linear plot of the I-V characteristics (*V on the x –axis on a linear scale, I on the y –axis on a linear scale*). Print this graph.

Graph 4: Semilogarithmic plot of the I-V characteristics (*V on the x –axis on a linear scale, I on the y – axis on a logarithmic scale*). Print this graph. *Please note that in your spread sheet program, you will need to compute the absolute number of the current before you can plot the data on a logarithmic scale.*

Device Characterization using iLab (WebLab)

It is assumed that most of the students in 6.012 used iLab (WebLab) in 6.002. If you have not used iLab (WebLab) before or you will like to have another iLab(WebLab) introduction, you are advised to take one of three actions:

1. Attend tutorials on Monday and Tuesday which will have 10 minute demonstration sessions.
2. Attend Office Hours of Instructors or a set up a time to meet with them (and they will conduct demonstrations)
3. Read the on-line manual and ask for help if you get stuck.