6.012   Microelectronic Devices and Circuits   Fall 2007

Problem Set #1
Assigned: September 5, 2007
Due: Wednesday, September 12, 2007 at recitation

Reading: Thursday, September 6   Chapter 2, Section 2.1-2.3 of Howe & Sodini
               Tuesday, September 11   Chapter 2, Section 2.4-2.6 of Howe & Sodini

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PLEASE WRITE YOUR RECITATION SESSION TIME ON YOUR PROBLEM SET SOLUTION

Problem 1 [10 points]   Adapted from Problem 2.1 of Fonstad
A sample of silicon is uniformly doped with 5×10^{16} Sb atoms per cm^3 and 5×10^{17} B atoms per cm^3. Assuming that the intrinsic carrier concentration for Si is 10^{10} cm^{-3} at 300K, determine the following for this sample:
   (a) The type (n or p)
   (b) The majority carrier concentration
   (c) The minority carrier concentration

Problem 2 [20 points]
A germanium sample ($n_i = 2.5^{13}$ cm^{-3} at 300K) is doped with 10^{15} cm^{-3} As atoms, 10^{16} cm^{-3} Sb atoms and 10^{17} cm^{-3} B atoms
   (a) What are n_o and p_o for this sample?
   (b) What is the conductivity type?

An additional 10^{18} cm^{-3} P atoms are added to this sample.
   (c) What are the new n_o and p_o for this sample?
   (d) What is the conductivity type?

Problem 3 [30 points]
The intrinsic carrier concentration n_i varies with temperature as

$$n_i(T) = AT^{3/2} \exp\left[-\frac{E_G}{2kT}\right]$$

where $k = 8.62 \times 10^{-5} \, eV/K$, T is the temperature in K and E_G is the bandgap in eV and for SiGe E_G=1.0 eV. Assume that E_G does not change with temperature and n_i=1x10^{11} cm^{-3} at 300K.

   (a) Plot the electron concentration for a SiGe sample doped with 5 x10^{16} cm^{-3} of B on an Arrhenius scale (Log of electron concentration vs 1000/T). *Temperature Range:* 150K < T < 1300 K.
   (b) Over what temperature range would a SiGe sample doped 5 x 10^{16} cm^{-3} B be considered "extrinsic"?

(c) Over what temperature range would a SiGe sample doped 5 x 10^{16} cm^{-3} B be considered "intrinsic"?

(d) Which of the factors in the expression for n_i dominates its temperature dependence?

(e) If you are looking for a semiconductor doped with 1 x10^{16} cm^{-3} of As and also extrinsic at 1000 °C, what is the minimum bandgap of the material you would use? [Assume that the value of A remains the same].

Problem 4 [40 points]

I-V characteristics of pn diode

Most of the homeworks in 6.012 this semester will include a small device characterization project. The goal of these projects is to expose students to real microelectronics devices: current-voltage characteristics, parameter extraction techniques, and model construction. These projects use the MIT Microelectronics WebLab, an online microelectronics device characterization test station that Prof. del Alamo and his students have been developing for a while in his lab at MIT.WebLab allows the educational use of professional microelectronics instrumentation by a large number of users through the internet.

Access to WebLab is provided through the MIT iLab Service Broker available at http://ilab.mit.edu. Your first step is to register by clicking on the "register here" tab. Then select admission in the "Fall 2005 6.012 Students" group. Registration is not automatic but actually must be approved by the system manager. This typically takes less than a day but could take a few hours. You should therefore register early. Your one-stop shopping location for help, of any kind, regarding this assignment is through the "Help" tab in the iLab website. The WebLab team welcomes your feedback at <ilab-debug@mit.edu>. A manual for the use of this system is accessible from this site after logging in.

Engineers working at the cutting edge often use state-of-the-art design and simulation tools in their work. This is worthwhile even if it means dealing with a few bugs, small annoyances, and less than optimal documentation. WebLab 6.1 and the MIT iLab Service Broker are the latest generation in online microelectronic device characterization. In spite of extensive development and testing, it is possible that a few bugs remain. As engineers working at the state-of-the-art, you should approach this project in a conservative way and carry out your assignment as early as possible. You should also seek help if you find any difficulties.

In the device characterization assignments of 6.012, you will use an Agilent 4155B Semiconductor Parameter Analyzer. This professional tool allows you to obtain the current-voltage (I-V) characteristics of semiconductor devices.

In this first assignment, your task is to obtain, download and graph the I-V characteristics of a pn diode. In a follow-on assignment, you will attempt to fit a simple model to the measured characteristics. The pn diode is a device which basic behavior you have already studied in 6.002. One or more identical devices (labeled pn Diode) are available in WebLab under the Devices menu. The details of the device connection are available on-line. Do the following:

a) (20 points) Obtain I-V characteristics of the pn diode. Take measurements between -2 and 1 V. In the measurement results panel of WebLab, graph your results in the following way:

> **graph 1:** Linear plot of I-V characteristics (*V* in *x* axis in linear scale, *I* in *y* axis in linear scale). Take a screen shot and print this graph. Turn in this graph.

> **graph 2:** Semilogarithmic plot of I-V characteristics (*V* in *x* axis in linear scale, *I* in *y* axis in logarithmic scale). Note: in a logarithmic scale, weblab graphs the absolute of negative currents. Take a screen shot and print this graph. Turn in 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 also 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.

b) (20 points) When you are happy with the results, download the data to your local machine and port them into your favorite spreadsheet program or MATLAB for graphing and analysis. Then do the following:

> **graph 3:** Linear plot of I-V characteristics (*V* in *x* axis in linear scale, *I* in *y* axis in linear scale). Print out and turn in this graph.
> **graph 4:** Semilogarithmic plot of I-V characteristics (*V* in *x* axis in linear scale, *I* in *y* axis in logarithmic scale). Note: in your spreadsheet program, you will have to compute the absolute of the current before you can graph it in a logarithmic scale. Print out and turn in this graph.

Turn in these four graphs and comment on how the measured I-V characteristics of the diode compare with those of the ideal-diode that you studied in 6.002.

Keep all the data handy, as you will need them in a follow-on assignment in the next homework.

Additional information and assorted advice

- The required graphs 3 and 4 need not be too fancy, just simply correct and unambiguous.
- They must have proper tickmarks, axis labeling and correct units.

- You have to exercise care with this device. Please do not apply a higher voltage than suggested. The pn diode is real and it can be damaged. If the characteristics look funny, try one of the other devices and let us know.

- It will be to your advantage to make good use of the Set-up management functions that are built into the tool under the File menu.

- For research purposes, the system keeps a record of all logins and all scripts that each user executes.