Device Characterization Project #1 - February 7, 2003

PN DIODE CHARACTERIZATION

Due: February 14, 2003 at recitation
(late project reports not accepted)

Please write your recitation session time on your project report

Introduction

The goal of the device characterization projects in 6.012 is to expose students to real microelectronics devices: current-voltage characteristics, parameter extraction techniques, and models. 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. The *MIT Microelectronics WebLab* is an experimental set up designed to allow the educational use of professional microelectronics characterization equipment by a large number of users through the internet. The *MIT Microelectronics WebLab* is accessed through http://weblab.mit.edu. A manual for the use of this system can be downloaded from the weblab homepage.

In the device characterization projects of 6.012, you will carry out a fairly detailed DC characterization of several microelectronic devices using an HP4155B Semiconductor Parameter Analyzer. This professional tool is basically a fancy curve tracer that allows you to obtain current-voltage (I-V) characteristics of semiconductor devices. The first device to be characterized is a p-n junction diode.

In this assignment, you will carry out the device characterization *before* the relevant theoretical material is presented in lecture. This is due to scheduling constraints, although we hope it will give you a strong motivation to learn the theoretical material when it is discussed.

Asignment: pn diode characterization

This problem is about characterizing a pn diode that is currently connected to the MIT Microelectronics WebLab. This device is available in WebLab under the *Devices* menu. The details of the device connection are available on-line. Refer to Appendix A for basic information about the pn diode.

You have to do the following:

1) (*20 points*) Obtain I-V characteristics of the pn diode. Take measurements between -2 and 1 V. 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 of 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 of 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 HP4155B can support is 100 mA. The minimum current you should be concerned with is 100 nA.

2) (*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 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 this graph.

3) (*20 points*) Study the ideal model for the I-V characteristics of the pn diode in Appendix A. Devise a simple scheme to extract from the measured data the saturation current, I_s (in A) and the temperature of the diode, T (in K). You can find the values of the fundamental constants that you need in Howe & Sodini. Explain your extraction scheme and give the extracted values. Compare the temperature that you exact with the temperature of the lab as measured by WebLab. Comment on discrepancies.

4) (*10 points*) A more realistic model for a pn diode includes a parasitic series resistance, as discussed in Appendix A. Using the values of I_s and T derived in the previous section, devise a simple scheme to extract from the measured data the series resistance, R_s (in Ω), of the diode. Explain your extraction scheme and give the extracted value.

5) (*20 points*) Compare the experimental characteristics with those predicted by the theoretical models for the pn diode given in Appendix A. To do this, graph together the experimental measurements, the predictions of the ideal model, and the predictions of the model that includes series resistance. Plotting the I-V characteristics of the model that includes series resistance is a bit tricky because I is on both sides of the equation. A good way to do it is to solve for V, then compute V vs. I, and finally plot I vs. V.

Turn in the following graphs:

graph 5: Linear plot of I-V characteristics (V in x axis in linear scale, I in y axis in linear scale). Show experimental data points with symbols, ideal model with dashed line and second-order model with continuous line. Print out this graph.

graph 6: Semilogarithmic plot of I-V characteristics (V in x axis in linear scale, I in y axis in logarithmic scale). Show experimental data points with symbols, ideal model with dashed line and second-order model with continuous line. Print out this graph.

6) (*10 points*) *Post-morten* and evaluation. On a separate page, give us feedback on this assignment and on the use of WebLab in this device characterization project. You can be candid. This page will be separated from the rest of your work and studied by the WebLab team.

Additional information and assorted advice

- The required graphs need not be too fancy, just simply correct. They must have proper tickmarks, axis labeling and correct units. When there are several lines, each one should be properly identified (handwriting is OK).
- If you encounter problems with WebLab or the diode, please e-mail the weblab TA (Niamh Waldron), Prof. del Alamo, or the weblab system manager.
- 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 the second device 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.

Note on collaboration policy

In carrying out this exercise (as in all exercises in this class), you may collaborate with somebody else that is taking the subject. In fact, collaboration is encouraged. However, this is not a group project to be divided among several participants. Every individual must have carried out the entire exercise, that means, using the web tool, graphing the data off line, and extracting suitable parameters. Everyone of these items contains a substantial educational experience that every individual must be exposed to. If you have questions regarding this policy, please ask the instructor. Prominently shown in your solutions should be the name of the person(s) you have collaborated with in this homework.

Appendix A: DC I-V characteristics of pn diode

Ideal model

The ideal I-V characteristics of a pn diode are given by:

$$I = I_s(\exp\frac{qV}{kT} - 1)$$

where I_s is the *saturation current*.

Second-order model

"Real" diodes suffer from a number of parasitics. One of the most important ones is the presence of parasitic *series resistance*, R_s. This reduces the voltage that is available to the junction from an external one V to an internal one $V - IR_s$. Hence, the DC I-V characteristics of the diode are given by:

$$I = I_s[\exp\frac{q(V - IR_s)}{kT} - 1]$$

The I-V characteristics look as in the graphs below.

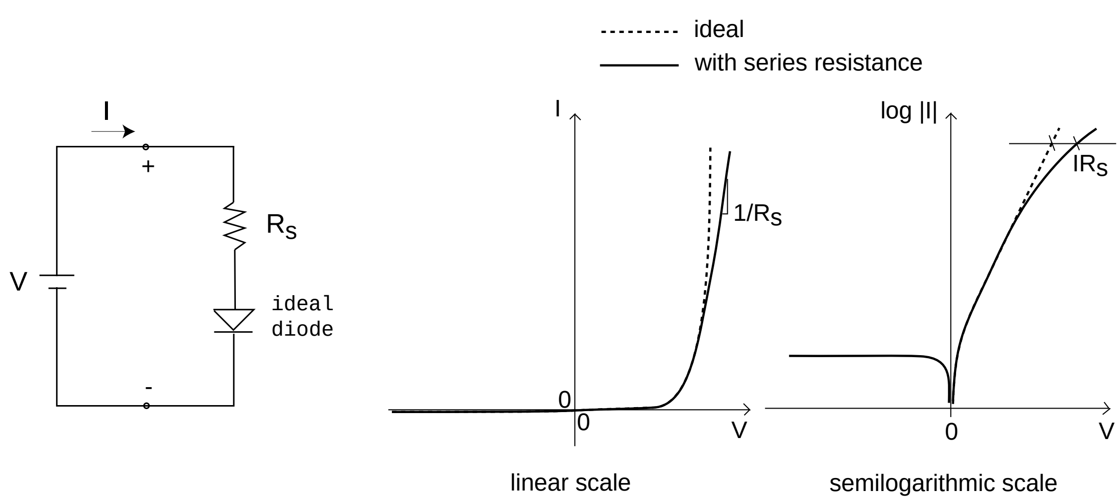

Figure 1: Sketch of I-V characteristics (ideal and with series resistance) of p-n junction in linear and semilogarithmic scales.