

Device Characterization Project #1 - February 9, 2001

PN DIODE CHARACTERIZATION

Due: February 16, 2001 at recitation
(*late project reports not accepted*)

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*, a remote web-enabled 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 in a remote way. The *MIT Microelectronics WebLab* is accessed through <http://weblab.mit.edu>. A (slightly out-of-date) manual for the use of this system can be downloaded from the weblab homepage.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.

Assignment: pn diode characterization

This problem is about characterizing a pn diode that is currently connected to the MIT Microelectronics WebLab. Two identical devices are available in locations 6 and 7 under the *device* menu of the *channel definition* panel of weblab. The details of the device connection are available on-line (see manual). 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. 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 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. 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. Illustrate your procedure graphically. Give the extracted values.
- 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. Illustrate your procedure graphically. 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-mortem* and evaluation. Please fill the questionnaire of Appendix B and turn it in.

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 diodes, please e-mail the weblab TA, Jim Fiorenza (fiorenza@mtl.mit.edu), Prof. del Alamo (alamo@mit.edu), or the weblab system manager, Jim Hardison (hardison@mtl.mit.edu).
- 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 of the *channel definition* panel (see manual).
- 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:

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

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:

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

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

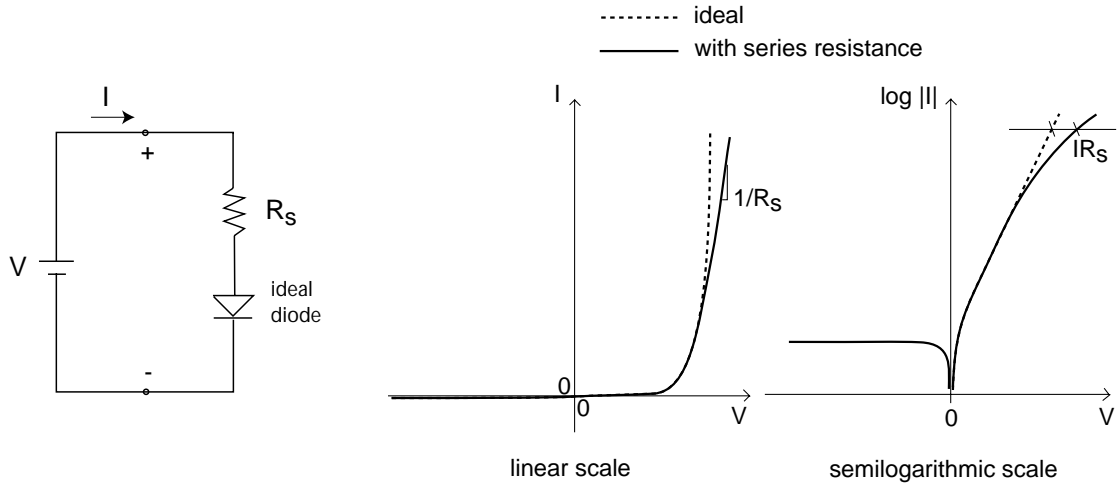


Figure 1: Sketch of I-V characteristics (ideal and with series resistance) of p-n junction in linear and semilogarithmic scales.

[This will not be examined by the 6.012 staff but by Dr. Barbara Masi who is conducting a study on the educational value of WebLab]

1. Now that you've completed project 1, did you find that you were given sufficient information in the WEBLAB tutorial on how to easily generate and download data from WEBLAB? Choose ONE response that best describes your experience:

3. Now that you've completed project 1, what questions regarding project results, pn diode models, HP4155, etc. would you like Professor del Alamo or recitation instructors to address in lecture or recitation to improve your understanding of pn diode characteristics?

☐ Yes, I was easily able to work with the data and the models in completing the assignment.
☐ No, I realized that my experience in manipulating data and models was insufficient for completing the assignment.
☐ The difficulties I had completing the assignment were not related to my experience in data and model manipulation.
 Other (please describe):

[illegible][illegible]

How many hours did it take you to complete this assignment once you had obtained useful data from the WEBLAB system?