Device Characterization Project 1 - February 7, 2007

MOSFET source-body pn diode characterization

Due: February 14 at lecture (10 AM)

The main goal of the device characterization projects in 6.720 is to expose students to "real" microelectronic devices: current-voltage characteristics, parameter extraction techniques, and models. These projects use an online microelectronics device characterization laboratory that Prof. del Alamo and his team have been developing for a while at MIT. This is an experimental set up designed to allow the educational use of professional microelectronics characterization equipment by a large number of users through the web. The latest version of the system (v. 6.1) is accessed at http://ilab.mit.edu. A manual for the system can be browsed and downloaded from the iLab homepage. At the heart of this lab is an HP4155B Semiconductor Parameter Analyzer. This tool is basically a fancy curve tracer that allows one to obtain I-V characteristics of semiconductor devices.

In this first device characterization project, your assignment is to characterize the source-body pn junction of an integrated n-channel MOSFET. In a second asignment, to follow later in the semester, you will characterize the MOSFET itself. In both cases, you will perform the device characterization *before* the relevant theoretical material is presented in lecture. This is to alleviate scheduling problems, but also to see to what extent these device characterization projects serve as an effective motivational tool for key material in this subject. The instructor is much interested in your feedback on this matter.

Assignment: characterization of source-body pn junction of a MOSFET

This assignment is about characterizing the source-body pn diode of a MOSFET, labeled "6.720 MOSFET". The details of the device connection are available on-line (see manual). For this measurement, the source, drain and gate of the MOSFET should be shorted together. Refer to Appendix A at the end of this handout for basic information about the pn diode.

You have to do the following:

1) (*30 points*) Obtain I-V characteristics of the source-body pn diode of the MOSFET. Take measurements between -1.5 and 1.5 V. 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 0.1 pA.

When you are happy with the result (as judged by the characteristics displayed through the web interface), download the data to your local machine and port them into your favorite data analysis program for graphing and analysis. In this environment, do the following:

Graph 1: 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 2: Semilogarithmic plot of I-V characteristics (V in x axis in linear scale, I in y axis in logarithmic scale). Note: in your data analysis program, you will have to compute the absolute of the current before you can graph it in a logarithmic scale. Print out this graph.

2) (*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). You can find the values of the fundamental constants that you need in the 6.720 notes. A real-time measurement of the ambient temperature in the lab is printed right above the graphics canvas of weblab. Explain your extraction scheme and give the extracted value of I_s.

3) (*20 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 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 of R_s.

4) (*30 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 3: 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 4: 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.

Comment on the importance of R_s in obtaining a good quality fit to the measured characteristics. Comment on the remaining shortcomings of the models. Can you speculate what is missing in the model that might be responsible for the residual discrepancies?

Additional information and assorted advice

- The system supports 8 devices at any one time. The device under test is selected through the *Devices* menu. Use any one of the devices labeled "6.720 MOSFET". The device location might change as weblab will be used in other subjects this semester.

- It takes a bit of thinking and trial and error to configure the HP4155B to acquire the required source-body diode measurements. You might want to practice simple pn diode measurements in the device labeled "pn Diode" that are available simultaneously. These are simple two-terminal pn diodes.

- The required graphs need not be too fancy, just simply correct. They must have proper tickmarks, axis labeling and correct units. If there are several lines, each one should be properly identified (handwriting is OK).

- If you encounter problems with the system, please e-mail the TA, Jungwoo Joh (jungwoo@), Prof. del Alamo (alamo@), or the weblab system manager, Jim Hardison (hardison@).

- You have to exercise care with these devices. Please do not apply a higher voltage than suggested. The MOSFET 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* and *User-defined* functions that the lab provides (see manual).

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

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 assignment.

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*, q is the electron charge, k is Boltzmann constant, and T is temperature.

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 the external value V to an internal one $V - IR_s$. Hence, the DC I-V characteristics of the diode are given by:

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

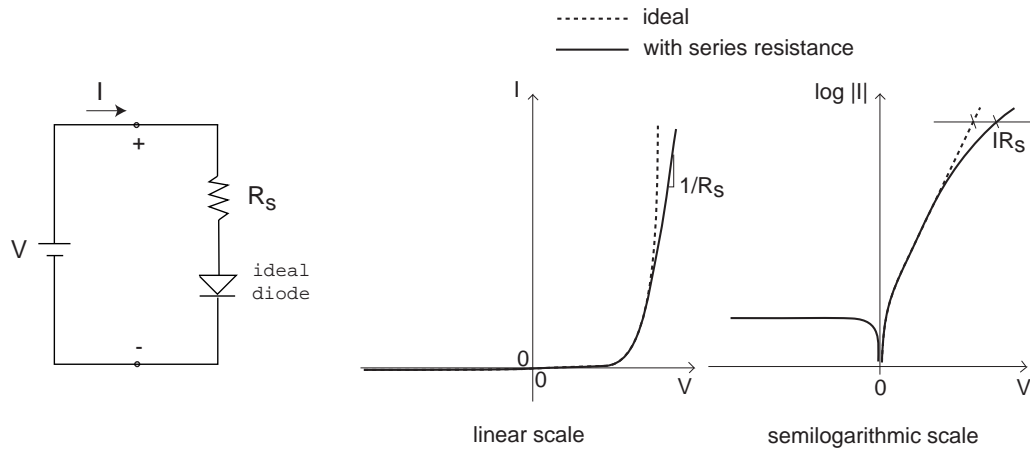The I-V characteristics look as in the graphs below.

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