Device Characterization Project 1: PN junction

Summary
In this project you will be characterizing the source-body pn junction of an integrated n-channel MOSFET using real devices which are accessible through the web on MIT's WebLab. In the following project you will be characterizing the MOSFET itself.

Background
- *MIT Microelectronics WebLab* is a remote web-enabled test station that Prof. del Alamo and his students have been developing in his lab at MIT for characterizing microelectronic devices. The experimental set up is designed to allow the educational use of professional microelectronics characterization equipment by a large number of users through the web. WebLab uses an HP4155B Semiconductor Parameter Analyzer to obtain the I-V characteristics of semiconductor devices.

Getting Started
- You will need to request an account on MIT's Weblab version 6.0. Go to ilab.mit.edu.
- Request an account. It may take a couple days to get the account, so please start well before the project is due.
- The client requires Java Plugin 1.4.2 in order to run. This can be downloaded from http://java.sun.com/j2se/1.4.2/download.html. (this may no longer be true)
- A manual for the system can be browsed and downloaded from http://weblab2.mit.edu/
- You can also find the manual and client information in WebCT under the content module (backpack) named Characterization Projects.
- You will need to use something to analyze the data such as Excel or MATLAB. MATLAB is vastly superior for curve fitting and most other things.
- Mozilla Firefox users must disable popup blocking for this site in order to view lab documentation.

Learning Goals:
- Become familiar with the current-voltage characteristics of real devices under almost real testing conditions.
- Enhance intuition by playing with the devices and varying the input parameters.
- Compare theoretical models with experimental data.
- Reinforce learning from class and homework.
- Use graphical analysis for parameter extraction.

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 (clear handwriting is OK).
- 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.

Assignment[1]

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 Streetman for basic information about the pn diode.

Do not apply higher voltage than suggested. The device can be damaged.

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) (10 points) When you are happy with the results, download the data to your local machine and port them into MATLAB or your favorite spreadsheet program 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) Fit the data to an ideal diode, except use the ideality factor "n". I~exp(qV/nkT) (See Streetman, e.g. 5-36) Devise a simple scheme to extract from the measured data the saturation current, *I*s (in *A*). (Hint: It is easier to fit lines than curves.) Explain your extraction scheme and give the extracted values.

4)a (10 points) A more realistic model for a pn diode includes a parasitic series resistance, effects of contact potential, and recombination/generation in the space charge region as discussed in Streetman and in Lecture 7. Examine the slope (on the semi-log plot) of the I-V curve. Does it appear that these factors may be significant? Comment on low voltage, medium voltage, high voltage, and reverse bias regions. Use your judgment to adjust the ideality factor "n" and consider if a piecewise linear (semi-log) approximation will give you better results (i.e. adjusting "n" for different ranges of voltage to cover recombination in the neutral region or high level injection)

4b) (10 points) Using the optimum parameters from section 4a devise a simple scheme to extract from the measured data the series resistance, *R*s (in), of the diode. Explain your extraction scheme and give the extracted value. (Hint: it is easier to fit lines than curves.)

5) (20 points) Compare the experimental characteristics with those predicted by the theoretical models for the pn diode given in Streetman. 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 2 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**. On a separate page, give feedback on this assignment and on the use of WebLab in this device characterization project. You can be candid, as the goal is to improve the project and the lab set-up. You will receive full credit if you have a couple sentences, even if you hated the project. This page will be separated from the rest of your work and studied by me, summarized, and passed on to the WebLab team at MIT.

<u>Note on collaboration policy</u>

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.

1 This material was created by or adapted from material created by MIT faculty members, Jesús del Alamo, Dimitri Antoniadis, Judy Hoyt, Charles Sodini, Pablo Acosta, Susan Luschas, Jorg Scholvin, Niamh Waldron, 6.012 Microelectronic Devices and Circuits, (2003).

This particular project was written by Professor Jesus del Alamo for his class at MIT. I modified it only slightly for ECE 415/515.