Device Characterization Project 1: PN JUNCTION

Summary

In this project you will be characterizing a p-n junction (a diode) using real devices which are accessible through the web on MIT's WebLab. In the following project you will be characterizing a MOSFET.

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. WebLab uses an HP4155B Semiconductor Parameter Analyzer to obtain the I-V characteristics of semiconductor devices.

Getting Started

- Make sure that you have Java installed! This won't work without it.
- You will need to request an account on MIT's WebLab version 7.0. Go to ilab.mit.edu. (Note: there is an older interface/client available, v6.0. Feel free to use it. There may be some relatively small differences).
- Request an account. You do not have to select any group; you will be given a "guest account" automatically. It may take a couple days to get the account, so start well before the project is due.
- A manual for the system can be browsed and downloaded from http://weblab2.mit.edu/docs/weblab/v6.1/manual/index.htm (it appears that they did not upgrade their documentation to v7 but I did not look up the details)
- You will need to use something to analyze the measured data, such as Excel or MATLAB. In general, MATLAB is superior for good statistics, but in this case Excel is recommended for interactivity.
- 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 real testing conditions.
- Compare theoretical models with experimental data.
- Use graphical analysis for parameter extraction.
- Reinforce learning from class and homework.

Additional information and assorted advice

- The required graphs need not be too fancy, just simply correct. They must have proper tick-marks, axis labeling and correct units. When there are several lines, each one should be properly identified (handwriting is NOT 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 Setup menu. For example, you may want to store all your settings so the next time you can just load the whole setup.

ASSIGNMENT [1]

This problem is about characterizing a p-n junction diode 1N914. This device is available in WebLab under the Devices menu. The details of how to connect the device are available on-line. Please do try to experiment a little bit with different settings until you find "just the right" one. Refer to the ECE415/515 textbook and reference texts for basic information about the p-n diode. For every graph that is required below you must provide at least one or two sentences explaining what's going on. Every graph must have a figure caption.

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

Obtain I-V characteristics of the p-n diode on ILab. Take measurements between -2 and 1.1 V. You may 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. **Do not set your voltage step** to less than 15-20 mV or so.

1. Graph your results on ILab in the following way:
   a. (10 points) 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 plot.
   b. (10 points) Graph 2: Semi-logarithmic 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. Include both plots in your report.
2. When you are satisfied with the results (i.e. they look like you would expect them to), 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:
   a. (5 points) Graph 3: Linear plot of I-V characteristics (V in x axis in linear scale, I in y axis in linear scale). Incorporate this plot into your report.
   b. (5 points) Graph 4: Semi-logarithmic 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. Fit the data to an ideal diode, except use the ideality factor "n" in

   $I= I_0$ [exp(qV/nkT)-1]; (see Neamen equation 8.59.)

   a. (10 points) Devise a simple scheme to extract the saturation current, I_0 (in *A*), from the measured data, and give the extracted values for I_0 and n. (Hint: It is easier to fit straight lines than curves. Read Neamen 8.2 & 8.3.3 carefully.) You may have to limit your range of voltages for this simple model to give acceptable results.
   b. (5 points) Explain your extraction scheme. What should the current value be for voltage V = 0V? What do you do if it that is not what you measure? Is it necessary for your data?

[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). Copyright © 2003, Massachusetts Institute of Technology. This particular project was written by Professor Jesus del Alamo for his class at MIT. It was modified for ECE 415/515 by B. Natter, B. Pejcinovic, & J. Morris.

4. A more realistic model for a pn diode includes a parasitic series resistance, and recombination/generation in the space charge region as discussed in Neamen and in lectures.
   a. (5 points) 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.
   b. (10 points) Use your judgment to adjust the ideality factor "n" for each region, i.e. use a piecewise linear (semi-log) approximation – that will give you better results (i.e. adjust "n" for different ranges of voltage to cover recombination in the neutral region or high level injection)
5. (10 points) Using the optimum parameters from Section 4 above, devise a simple scheme to extract the series resistance, r_s (in **Ω**), of the diode from the measured data. Explain your extraction scheme and give the extracted value. (Hint: it is easier to fit straight lines than curves.)
6. Compare the experimental characteristics with those predicted by the theoretical models for the p-n diode given in Neamen. To do this, graph together on the same plot: (i) the experimental measurements, (ii) the predictions of the ideal model, (using the results of 4(b)) and (iii) 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:
   a. (10 points) 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. Include this graph in your report.
   b. (10 points) Graph 6: Semi-logarithmic 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. Include this graph in your report.
7. (10 points) **Post-mortem and evaluation**: 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. You will receive full credit for this section for just a couple of sentences, whether positive or negative.

Notes on lab write ups: Don't display pages of tables or lists of numbers. Nobody is interested. Do show all graphs and all calculations.

Note on collaboration policy

In carrying out this assignment (as in all assignments in this class), you may collaborate by discussion with somebody else that is taking the class. In fact, such 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 on their own, which specifically includes using the web tool for data acquisition, graphing the data off line, extracting suitable parameters, and analysis. Every one 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. Include the name(s) of the person(s) you have collaborated with, and how, in your report.

Excel hints:

- Plotting in Excel is straightforward. If you select the proper data, in the proper order, with the proper headings, you'll get a nice graph automatically. (What constitutes a "nice" graph can be discussed in class).
- Don't confuse plotting things on a logarithmic scale with taking the logarithm of something. They aren't the same thing.
- You can fit lines on the graph. If you are doing a piecewise linear fit, however, you'll need to make each piece its own data set and curve; otherwise, Excel will fit the entire data set, so you have to restrict it somehow.
    - Under Chart, choose Add Trendline
    - This is the best because you can combine your visual representation with the numbers. You can check to see that R^2 is close to 1 and that it looks right.
    - You can also easily adjust the data range if you see that it isn't linear.
- If you want to just pick values off, you can use
    - Slope=SLOPE(known_y's,known_x's)
    - Intercept=INTERCEPT(known_y's,known_x's)
    - This can be helpful if you are making a table.