Device Characterization Project 1: PN JUNCTION
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Updated 5/8/2023 (Step 2 and 8 removed)

Summary

In this project you will be characterizing a p-n junction (a diode) using data from measured real devices. In the second, following project you will be characterizing a MOSFET.

Total number of point is 100.

90 points as distributed through steps that need to be completed, and additional 10 points for the overall report quality.

Background on how the data was collected:

- ICDT Research Lab is Prof. Pejcinovic's research measurement facility and B1500 Device analyzer was used to obtain the I-V characteristics of semiconductor devices.
- 1N4148 diode was used for the experiment.

Getting Started

- Files with the measured data will be posted on Canvas. You will need to download the files and do the project.
- PN junction diode – there will be four files with measured data for IV characteristics. Two files for forward IV characteristics, FWR and FWR-Heat, and two files for reverse IV characteristics; RV and RV-Heat. "-Heat" indicates that characteristics were measured at elevated temperature.
- We used heat gun set 350 F to increase the ambient temperature, and we were not able to measure what temperature the test diode was in. So we will assume the base set of data was measured at 25 C and the "-Heat" at elevated temperature larger than 25 C.
- 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.

Learning Goals:

- Become familiar with the current-voltage characteristics.
- Compare theoretical models with experimental data.
- Compare experimental characteristics at different temperatures
- 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).

ASSIGNMENT [1]

[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

This problem is about characterizing a p-n junction diode 1N4148. 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 of explanation. Every graph must have a figure caption.

I-V characteristics of the p-n diode were measured using B1500. Measurements were taken between -10 and 1.5 V. The measurement set-up is shown in the files.
Diode characteristics at higher than room temperature taken by using a heat gun. Steps 7 and 8 of the experiment deal with characteristics taken at higher temperature.

Perform steps 1 through 6 using characteristics measured at room temperature.

1. Graph your measured results in the following way:
   a. (5 points) Graph 1: Linear plot of I-V characteristics (V in x axis in linear scale, I in y axis in linear scale).
   b. (5 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 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.
   c. Include both plots in your report.

2. Disregard Part 2
   When you are satisfied with the results (i.e. they look like you would expect them to), download the data to TA USB memory stick. TA will send the data to you via email and you will need to transfer the data to your computer 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 Streetman equation 5.74.)
   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 Streetman 5.6 and Neamen 8.2 & 8.3.3 carefully. (Neamen 8.2 and 8.3.3 chapters are posted on D2L) 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?

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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 & M. Chrzanowska-Jeske.

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 Streetman, 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 Streetman. 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. Discuss the graph.
   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. Discuss the graph.

To complete step 7 using characteristics measured at higher temperature.

7. Transfer the posted measured data to your computer and port them into MATLAB or your favorite spreadsheet program for graphing and analysis. Then do the following:
   a. (5 points) Graph 9: 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 10: 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.
   c. (10 points) Graph 11: Plot I-V diode characteristics for room and higher temperatures on the same semi-logarithmic plot (V in x axis in linear scale, I in y axis in logarithmic scale) and describe differences you notice. Explain these differences based on real diode behavior.

Additional 10 points for the overall report quality.

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 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 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.