Device Characterization Project #2 - February 23, 2001

N-CHANNEL MOSFET CHARACTERIZATION

Due: March 2, 2001 at recitation
(late project reports not accepted)

Please write your recitation session time on your project report.

In this project, you will characterize the current-voltage characteristics of an n-channel MOSFET. To do this, you will use the *MIT Microelectronics WebLab*. Refer to the User Manual for instructions on how to use the system.

Several identical n-channel MOSFETs are available in locations 1, 2, 3 and 8 of weblab. The terminal connection configuration is identical for all of them and is available on line. This exercise involves three separate phases: measurement, graphing, and analysis. Take the measurements specified below. When you are happy with the results (as judged by the characteristics displayed through the web), download the data to your local machine for more graphing and further analysis. You will find useful to study the contents of *Appendix A* which describes the ideal model for the I-V characteristics of a MOSFET.

Important note: For all mesurements, hold V_{GS} between 0 and 3 V, and V_{DS} between 0 and 4 V. When relevant, examine V_{BS} between 0 and -2.5 V. As inputs to this exercise, you need the dimensions of the MOSFET: $L = 1.5$ μm and $W = 46.5$ μm.

Here is your assignment.

1. (*5 points*) Obtain the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} as parameter. Do this for $V_{BS} = 0$ V.

    graph 1: Linear plot of output characteristics (V_{DS} in x axis in linear scale, I_D in y axis in linear scale). Take a screen shot and print this graph. Download the data to your local machine.

2. (*5 points*) Obtain the *transfer characteristics* of the MOSFET. This is a plot of I_D vs. V_{GS} with V_{DS} as parameter. Do this for $V_{BS} = 0$ V.

graph 2: Linear plot of transfer characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Take a screen shot and print this graph. Download the data to your local machine.

3. (*5 points*) Obtain the *backgate characteristics* of the MOSFET in the saturation regime. This is a plot of I_D vs. V_{GS} with V_{BS} as parameter. Do this for $V_{DS} = 4$ V.

   graph 3: Linear plot of backgate characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Take a screen shot and print this graph. Download the data to your local machine.

4. (*5 points*) On your local machine, using Matlab or your favorite spreadsheet program, graph the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} as parameter. Do this for $V_{BS} = 0$ V.

   graph 4: Linear plot of output characteristics (V_{DS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

5. (*5 points*) On your local machine, graph the *transfer characteristics* of the MOSFET. This is a plot of I_D vs. V_{GS} with V_{DS} as parameter. Do this for $V_{BS} = 0$ V.

   graph 5: Linear plot of transfer characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

6. (*5 points*) On your local machine, graph the *backgate characteristics* of the MOSFET in the saturation regime. This is a plot of I_D vs. V_{GS} with V_{BS} as parameter. Do this for $V_{DS} = 4$ V.

   graph 6: Linear plot of backgate characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

7. (*15 points*) From the transfer characteristics and using the model described in Appendix A, extract $\mu_n C_{ox}$ and the threshold voltage, V_T, for this MOSFET [*Suggestions: use the transfer characteristics in saturation, say for $V_{DS} = 4$ V, to determine V_T. You can define V_T as the gate-source voltage that results in a drain current of 50 μA. Then scale the $\mu_n C_{ox}$ product to get the best possible match to the transfer characteristics. Don't be disappointed if the match is not perfect. These MOSFETs do not perfectly follow the behavior of the ideal MOSFET model*].

8. (*15 points*) From the backgate characteristics, and using the model described in Appendix A, extract the values of V_{To}, γ, and ϕ_p, for this MOSFET [*Suggestion: use the procedure mentioned above to extract V_T; the value of V_T extracted in the previous section is V_{To}; then try values of ϕ_p in the -0.3 to -0.5 V range and extract the value of γ that best matches the data.*]

9. (*30 points*) Using the parameter that you have extracted, "play back" the I-V characteristics of the transistors and compare them with the measurement data. The most effective way to do this is to program the model in matlab or your favorite spreadsheet program and construct graphs that depict the measured data as individual dots and the model as continuous lines.

   graph 7: Graph together the measured *output characteristics* of the MOSFET and those predicted from the model. Print this graph. Comment on the accuracy of the model.

   graph 8: Graph together the measured *transfer characteristics* of the MOSFET and those predicted by the model. Print this graph. Comment on the accuracy of the model.

   graph 9: Graph together the measured *backgate characteristics* of the MOSFET in the saturation regime and those predicted by the model. Print this graph. Comment on the accuracy of the model.

10. (*10 points*) *Evaluation.* Please fill the questionnaire of Appendix B and turn it in. Please write your name on it. This facilitates our handling of the paperwork. Only Dr. Barbara Masi will read your responses to this questionnaire. The 6.012 staff will not look at it. Please turn the questionnaire in separately.

**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 MOSFETs, 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 these devices. Please do not apply a higher voltage than suggested. The MOSFETs are real and they can be damaged. If the characteristics look funny, try a different 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: MOSFET I-V characteristics

The conventions for terminal naming, and voltage and current notations for an n-channel MOSFET are all shown below:
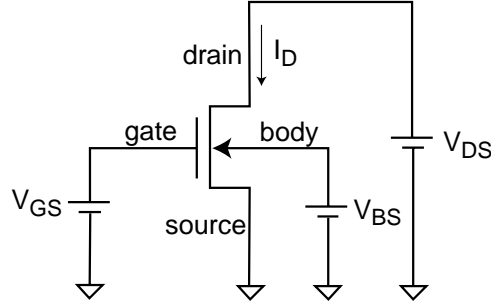
The ideal I-V characteristics of a MOSFET are given by the following set of equations:

- *Linear regime,* $V_{GS} > V_T$, $V_{DS} < V_{DSsat}$:

$$I_D = \frac{W}{L}\mu_n C_{ox}(V_{GS} - \frac{V_{DS}}{2} - V_T)V_{DS}$$

- *Saturation regime,* $V_{GS} > V_T$, $V_{DS} > V_{DSsat}$:

$$I_D = \frac{W}{2L}\mu_n C_{ox}(V_{GS} - V_T)^2$$

  In these equations, L and W are the gate dimensions, μ_n is the electron mobility, C_{ox} is the capacitance per unit area of the gate, and V_T is the threshold voltage.

  V_{DSsat} is the drain-source voltage that "saturates" the transistor. In the simplest model:

$$V_{DSsat} = V_{GS} - V_{th}$$

- The effect of applying a *back bias* is to shift the threshold voltage according to the following relation:

$$V_T = V_{To} + \gamma(\sqrt{-2\phi_p - V_{BS}} - \sqrt{-2\phi_p})$$

  where γ and ϕ_p are two parameters that describe the electrostatics of the MOSFET, as we will see in class. V_{To} is the value of threshold voltage that corresponds to $V_{BS} = 0$.

The *output characteristics* of the MOSFET refer to a graph that shows the drain current, I_D, *vs.* the drain-source voltage, V_{DS}, with the gate-source voltage V_{GS} as parameter.
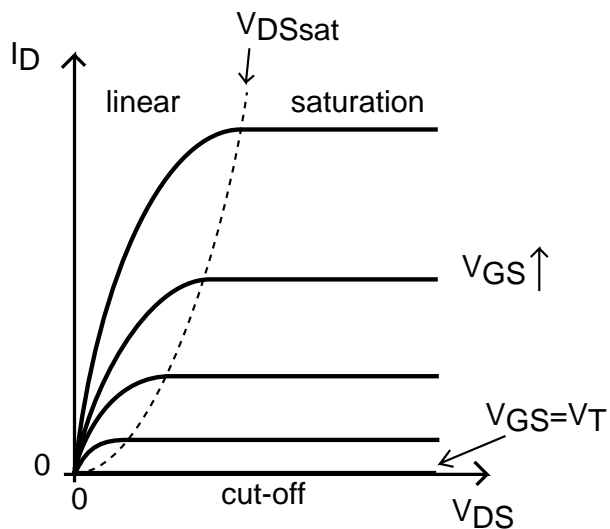

Figure 1: Sketch of ideal output characteristics of an n-channel MOSFET.

The *transfer characteristics* refer to a graph of I_D vs. V_{GS} with V_{DS} as parameter.
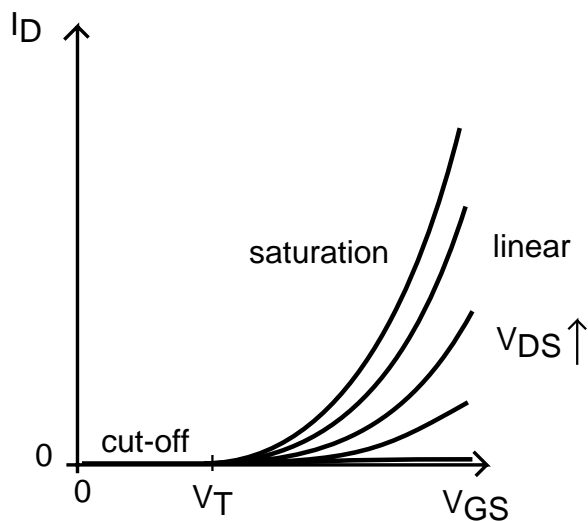

Figure 2: Sketch of ideal transfer characteristics of an n-channel MOSFET.

The *backgate characteristics* refer to a graph that plots the drain current in saturation as a function of V_{GS} for several values of V_{BS}.
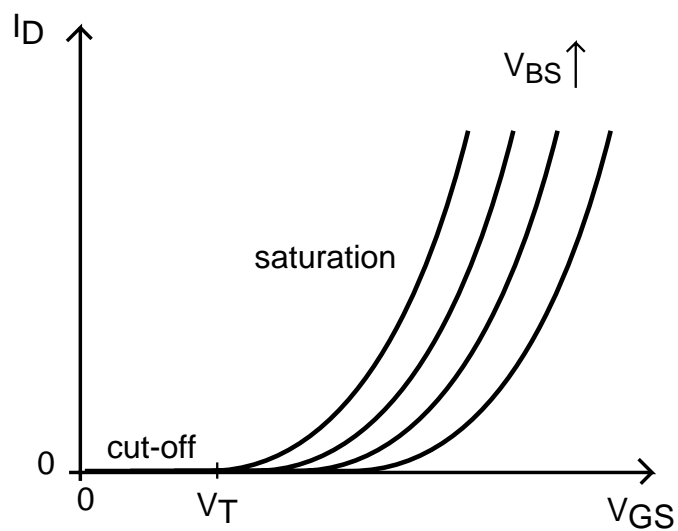

Figure 3: Sketch of ideal backgate characteristics of an n-channel MOSFET in saturation.

Your name (for getting project points only!): _____

Dear student: Once again, Dr. Barbara Masi is hoping for your feedback on the WEBLAB experience. Your responses will NOT be examined by the 6.012 staff. So feel free to provide candid feedback!

CIRCLE OR CHECK THE RESPONSE THAT DESCRIBES YOUR IMPRESSIONS:

How might you rate your knowledge of output, transfer, and backgate characteristics of MOSFET?	__I knew nothing about output, transfer, and backgate characteristics of MOSFET prior to taking 6.012 __I had a vague idea about these concepts since they were introduced in other classes __ I know these concepts well.
Did manipulating and analyzing the data improve your understanding of the difference between output, transfer, and backgate characteristics of MOSFETs?	1----------2----------3----------4----------5----------6----------7 did somewhat greatly not improved improved improve understanding understanding
Did extracting values for threshold voltage, & the mobility-capacitance product help you understand the role of these parameters in MOSFET equations?	1----------2----------3----------4----------5----------6----------7 did somewhat greatly not helped helped help understanding understanding
Did working on this project improve your comprehension of "saturation regime" for a MOSFET?	1----------2----------3----------4----------5----------6----------7 did somewhat greatly not improved improved improve understanding understanding

In completing this project, what sources did you use? Check all that apply.
__TA or professor answered my questions   __I didn't use any other sources.
__Friends/ peers answered my questions   __Other (please describe):_____
__I used a textbook I found.

How might the 6.012 staff improve the on-line WEBLAB experience? Check all that apply.
___ provide better introduction to MOSFET theory and equations.
___ provide information on downloading WEBLAB data into MATLAB or EXCEL.
___ provide information on how to use MATLAB or EXCEL to analyze and graph data.
___ TA help available on-line while I am completing the project.
___Other (please describe):_____

How might you rate WEBLAB as a means of providing you with a microelectronics lab experience as part of 6.012? Check all that apply.
__I don't think any lab as part of 6.012 helps me understand 6.012 material.
__Having a 6.012 lab is great, but make it a real lab.
__WEBLAB was better than a real lab since I could complete it whenever I wanted to.
__WEBLAB was great, but I just would have liked more help using it and completing the project.
__WEBLAB was great just the way it stands.
__Other (please describe): _____

Now that you've completed the project, what questions would you like Professor del Alamo to answer about MOSFETs and the project in class?