Device Characterization Project 2: MOSFET TRANSISTOR

Summary: In this project, you will be characterizing the current voltage characteristics of an n-channel MOSFET. The provided data were collected by measuring IV characteristics of a real device (2N7000). The experiments was performed using a set-up in ICDT Research Lab. (FAB 60-23).

Background:

- ICDT Research Lab is Prof. Pejcinovic's research measurement facility and we used B1500 Device analyzer to obtain the I-V characteristics of semiconductor devices.
- We used a 2N7000 n-channel MOSFET, for the experiment. Please refer to the 2N7000 MOSFET data sheet for maximum voltages, currents, and any other parameters you might need.

Assignment[1]: This problem is about characterizing an n-channel MOSFET. . This exercise involves two separate phases: graphing, and analysis (with emphasis on the latter).

Important note: For all measurements, V_{GS} was held between 0 and 4 V, and V_{DS} between 0 and 4 V. As inputs to this exercise, you need the dimensions of the MOSFET: $L = 1.5\ \mu m$ and $W = 46.5\ \mu m$. Note that the required SMU compliance is 100 mA, which isn't that high for this device. Make sure you don't include any data, which is "railed" (maxed out at the compliance value) when you do curve fitting.

Description:

- The purpose of this lab is to graph and analyze the MOSFET output and transfer characteristics.
- B1500 Device analyzer in ICDT LAB was used to measure characteristics.

PART I: MOSFET CHARACTERISTICS

1. Use the data given in "Id-Vd" file to graph the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} a as parameter, like Figure 6-9/10 in Streetman[3].
    a. (10 pts) The data include I_D vs. V_{DS} values for nine values of V_{GS} parameter. Please use at least five of them to draw nice curves. (Please notice that I_D do not exceed 100mA and try to include one curve with very low currents.) Plot the characteristics using your favorite tool (Excel, Matlab, …)
    b. (10 pts) Obtain a rough estimate of V_T from this graph using two different techniques. This means using visual observation and a ruler, rather than fitting a curve. Explain your techniques in one or two sentences.

2. Obtain the *transfer characteristics* of the MOSFET for two different drain voltages. This is a plot of I_D vs. V_{GS} with V_{DS} as a parameter, like, Figure 6.28 in Streetman[2]
    a. (10 pts) Using the output characteristics above choose two different values of V_{DS} so that you obtain one measurement plot in saturation and one plot in the linear region. Explain those choices.
    b. (5 pts) Plot the characteristics. Note that in saturation you will want to plot the square root of I_D. Explain why this is a good choice.

c. (5 pts) Obtain estimates of the threshold voltage, V_T, in the linear and the saturation regions. Do they agree? (You can do this manually using the graph and using a ruler, or by using some functions in your favorite software.)

3. (10 pts) From the <u>transfer characteristics</u> in the linear and saturation regions, <u>extract</u> ($\mu_n C_{ox}$) and the threshold voltage, V_T, for this MOSFET. "Extract" means to use your knowledge of the model Equations 6-49/54 from Streetman[3] (Equations 10-62/67 from Neamen[2]) to fit a line to one of your transfer curves. The modeled slope should allow you to calculate μ_nCox. Note that we cannot separate the mobility from the oxide capacitance using this data. Are your extracted values of V_T close to your previous estimates? Summarize your results in a table.

4. First some context for this assignment: in an ideal case, we would have one model and one set of parameter values that would describe our transistor across all biases and modes of operation. However, that is not the case and we often have to use models that are accurate only within some range of values or certain region so that parameters for the linear region will differ from the ones for saturation. So, which one should we use? That depends on the application – suppose you are trying to design a class A amplifier. Which region would you try to model with the greatest accuracy? Keeping this in mind, here is the actual assignment. Use the parameters that you would use for Class A amplifier design in an I-V model and compare graphically with the output and both transfer curves.
   a) (10 pts) Use equation 6-49 from Streetman[3] as your starting point for the model. Then put your calculated numbers from above into this model and plot it on the same graphs (output and both transfer) with the measured data. Use only the one set of parameter values from Part 3 you chose for the Class A amplifier.
   b) (5 pts) If the model fits the output characteristics data (Part 1) well with parameters based on the transfer data (Part 3) we have good confirmation of the validity of the model. Discuss your results in several sentences. Does the model fit the data well? If not, why not? Do you have possible explanations?

PART II: MOSFET IN SUBTRESHOLD REGION

5. Use the data given in "Id-Vg" file to graph the subthreshold characteristics, that is I_D vs V_{GS} for V_{DS}=2V. Focus in on V_{GS} values that are near the threshold voltage (above & below.)
   a. (10 pts) Plot these characteristics as $\log_{10} I_D$ vs V_{GS} (like Streetman Fig 6-38[3].)
   b. (5 pts) For the full equation and explanation see (Streetman[2] Section 6.5.7, Eqn 6-65.). Equations are also given below. All of the constants can be lumped into one constant I_{OFF}.

$$I_D(sub) = \mu(C_d + C_i)\frac{Z}{L}\left(\frac{kT}{q}\right)^2\left(1-\exp\left(\frac{-qV_D}{kT}\right)\right)\exp\left(\frac{q(V_G-V_T)}{c_r kT}\right)$$

where Z is the channel width

$I_D = I_{OFF}\exp\left(\frac{qV_G}{c_r kT}\right)$ where $c_r = \left[1+\frac{C_d + C_{it}}{C_i}\right]$, C_i is the gate capacitance,

C_d is the (sub-threshold) depletion capacitance in the channel, and

C_{it} is the "fast interface state" capacitance[3].

Subthreshold "Slope" S is defined by $S = 2.3\frac{kT}{q}c_r$

simplified version of the equation 6-65 is given in Neaman[3] Section 11.1.1 and Eqn 11.1.

$$I_D(sub) \sim \left(1-\exp\left(\frac{-qV_D}{kT}\right)\right)\exp\left(\frac{q(V_G)}{kT}\right)$$

What will happen to the exp(V_D) term for our choice of V_D =2V? Explain.

c. (10 pts) Calling S a "slope" is a misnomer; its proper name is "inverse slope" of $\log_{10}I_D$ vs V_G but it is commonly labeled as "subthreshold slope" in the literature. S is measured in V/decade, and it tells us how much increase in voltage is needed to increase current by one decade. Using your data and the equation above, fit a curve which will allow you to calculate your subthreshold slope, S, and hence c_r. Explain your procedure.

d. (5 pts) Comment on the effect of oxide thickness on subthreshold slope. How would you improve S? (Hint: "improving" means decreasing S in value.)

6. (5 pts) Feedback: Please give feedback on the project. Was this project instructive? Did you experience major problems or frustrations with measurements, understanding the instructions, or completing the assignment? Any suggestions for improving the instructions, or the project itself?

Additional information and assorted advice

- The required graphs need not be too fancy but they must follow the guidelines discussed in class. For example, they must have proper axis labeling and correct units. All figures must have figure captions and be explained in the text. When there are several lines on a plot, each one should be properly identified (handwriting is NOT OK). Please spend some time making your plots look "nice". Once you have a setup that looks good then it will be easy to do it for the rest.

Note on collaboration: You are encouraged to work in groups to aid in your understanding. It is appropriate to ask questions of another student and check your work against each other as you proceed. This is NOT a group project, though. Each person must create his/her own graphs, and write up his/her interpretations individually. Any sharing of plots will result in a zero points for the entire assignment for all involved. Bottom line – don't share your plots and report with anyone.

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 and modified by B. Natter, B. Pejcinovic, J. Morris & M. Chrzanowska-Jeske for ECE 415/515.
The project was update in 2021 for remote measurements by M. Chrzanowska-Jeske, and in 2023 updated to analyze given data of previously measured I-V Characteristics.

2 Streetman, B.G., & Banerjee, S.K., *Solid State Electronic Devices*, Prentice Hall, Sixth Edition, 2006.
3 Neamen, D.A., *Semiconductor Physics & Devices*, McGraw-Hill, Fourth Edition, 2012.