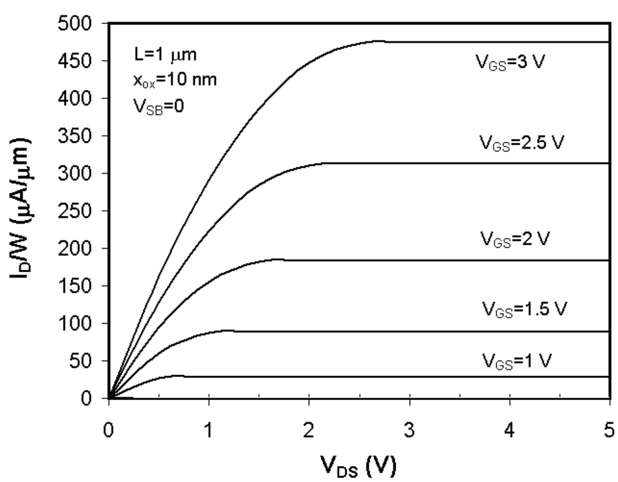
Homework #5 - October 14, 2005

Due: October 21, 2005 at recitation (2 PM latest)
(late homework will not be accepted)

Please write your recitation session time on your problem set solution.

1. *[20 points]* Consider the output I-V characteristics of an n-MOSFET for $V_{SB} = 0$ below. The device has a gate length $L_g = 1\ \mu m$ and a gate oxide thickness $x_{ox} = 10\ nm$. The output characteristics have been normalized for a unity width device.



a) Estimate the threshold voltage of the device.

b) Estimate the mobility of the electron inversion layer.

c) Estimate the transconductance g_m at a bias of $V_{GS} = 3\ V$, and $V_{DS} = 3\ V$ for $W_g = 10\ \mu m$.

d) At a bias of $V_{GS} = 3\ V$, and $V_{DS} = 3\ V$, estimate the gate-source capacitance C_{gs} of a $W_g = 10\ \mu m$ device.

2. *[20 points]* Consider an n-MOSFET with an n$^+$-polySi gate characterized by the following parameters: $L = 1\ \mu m$, $W = 5\ \mu m$, $x_{ox} = 20\ nm$, $N_a = 10^{17}\ cm^{-3}$. The device is biased with $V_{GS} = 3\ V$, $V_{DS} = 4\ V$ and $V_{BS} = 0\ V$. Assume $\mu_n = 400\ cm^2/V \cdot s$ for electrons in the inversion layer.

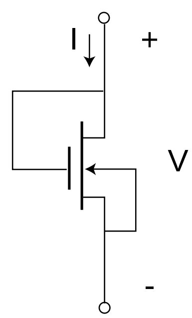
a) In what regime is the MOSFET biased? Justify your answer with suitable calculations.

b) Calculate the electron concentration per unit area at the source-end of the channel.

c) Calculate the extent of the depletion region underneath the inversion layer at the source-end of the channel.

d) What is the value of V_{BS} that would drive this transistor to cut-off (V_{GS} and V_{DS} don't change).

3. *[10 points]* Analog designers often need to shift DC bias levels in circuits. This is best accomplished using p-n diodes. In standard CMOS, floating p-n diodes (that is, diodes not in direct contact with the power rails) are not readily available. A common way to "synthesize" a diode is to tie up an enhancement-mode MOSFET ($V_T > 0$) with the gate and drain shorted as sketched below.



Derive suitable equations for the I-V characteristics of the "diode", I *vs.* V for $V < V_T$, and $V > V_T$. Sketch the I-V characteristics in a linear scale.

4. *[50 points]* **MOSFET characterization**

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 3 μm long n-channel MOSFETs are available through WebLab. The terminal connection for these devices (labeled "3 um NMOSFET") is identical for all of them and is available on line. This exercise involves three separate phases: measurement, graphing, and analysis. The exercise will continue in the next homework. 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.

Important note: For all measurements, hold V_{GS} between 0 and 2 V, and V_{DS} between 0 and 4 V. Unless specified, use $V_{BS} = 0\ V$. When relevant, examine V_{BS} between 0 and $-3\ V$. As inputs to this exercise, you need the dimensions of the MOSFET: $L = 3\ \mu m$ and $W = 20\ \mu m$.

Here is your assignment.

1. Obtain the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} as parameter. Use $\Delta V_{GS} = 0.25\ V$ and $V_{BS} = 0\ V$. Take a screen shot of these characteristics. Turn in this graph. Download the data to your local machine for later use in the next problem set.

2. Obtain the *transfer characteristics* of the MOSFET. This is a plot of I_D vs. V_{GS} with V_{DS} as parameter. Use $\Delta V_{DS} = 1\ V$ and $V_{BS} = 0\ V$. Take a screen shot of these characteristics. Turn in this graph. Download the data to your local machine.

3. 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. Use $\Delta V_{BS} = -0.5\ V$ and $V_{DS} = 4\ V$. Take a screen shot of these characteristics for later use. Turn in this graph. Download the data to your local machine.

4. From the transfer characteristics and using the model described in class, extract $\mu_n C_{ox}$ and the threshold voltage, V_{To}, for this MOSFET [*Suggestions: use the transfer characteristics in saturation, say for* $V_{DS} = 4\ V$*, to determine* V_{To}*. You can define* V_{To} *as the gate-source voltage that results in a drain current of* $5\ \mu A$*. 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 great. These MOSFETs do not perfectly follow the behavior of the ideal MOSFET model*].

5. From the backgate characteristics, and using the model described in class, extract the values of γ and ϕ_p that best describe this MOSFET [*Suggestion: use the procedure mentioned above to extract* V_T *as a function of* V_{BS}*; then try values of* ϕ_p *in the* -0.3 *to* $-0.5\ V$ *range and extract the value of* γ *that is most consistent among the entire data set.*]