Problem Set #5

Assigned: Wednesday, October 3, 2007
Due: Friday, October 12, 2007 at recitation

Reading Assignments: Howe and Sodini 3.9, 4.1-4.3
Lecture Notes #8 and #9

PLEASE WRITE YOUR RECITATION SESSION TIME ON YOUR PROBLEM SET SOLUTION

Problem 1. [30 points]

A 3-terminal MOS structure is fabricated on a p-type silicon substrate with a p^+-doped gate; the gate material thermal equilibrium potential is $\phi_{p^+} = -550\text{ mV}$. The substrate doping is $N_a=10^{17}$ cm^{-3}, and the oxide thickness, t_{ox}=3.4 nm. The doping of the contact region is $N_d=10^{20}$ cm^{-3}.

(a) What is the value of the contact junction built-in potential, ϕ_J?
(b) What is the value of the Flatband voltage, V_{FB}?
(c) A gate-to-body voltage, V_{GB}=5 V is applied. Find the contact-to-body voltage V_{CB} at which the magnitude of the channel charge drops to ½ its value for V_{CB}=0, i.e. $Q_N(V_{CB})=Q_N(V_{CB}=0)/2$. Explain clearly.
(d) A contact-to-body voltage, V_{CB}=3 V is applied. Find the gate-to-contact voltage V_{GC} at which the magnitude of the channel charge is equal to its value for V_{CB}=0, i.e. $Q_N(V_{CB})=Q_N(V_{CB}=0)$. Explain clearly.

Problem 2. [20 points]

A 3-terminal MOS structure is fabricated on a p-type silicon substrate. The flat-band voltage is, V_{FB}=-1 V; other parameters include, $N_a=10^{17}$ cm^{-3}, and $\gamma=0.5\ V^{0.5}$.

(a) Calculate the value of V_{T0n}, i.e. V_{Tn} for V_{CB}=0 V.
(b) Calculate the depletion depth, x_d, at $V_{GC}=V_{T0n}$ with V_{CB}=0 V.
(c) Voltages V_{GB}=6V, V_{CB}=4 V are applied. Calculate the depletion depth, x_d.
(d) The applied voltages change to V_{GB}=4V, V_{CB}=4 V. Calculate the depletion depth, x_d.

Problem 3. [50 points]

MOSFET characterization

In this project, you will characterize the current-voltage characteristics of an n-channel MOSFET using iLab. You will use the "6.012 MOSFET" n-channel MOSFETS available in the Device Menu. 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.

Important note: For all measurements, hold V_{GS} and V_{DS} between 0 and 4 V. Unless specified, use $V_{BS} = 0\ V$. When relevant, examine V_{BS} ($=V_{SB}$) between 0 and -4 V. As inputs to this exercise, you need the dimensions of the MOSFET: $L = 1.5\ \mu m$, $W = 46.5\ \mu m$, and $t_{ox}=33\ nm$.

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 a 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. Using either a user defined function in Weblab or your favorite program in your local machine plot the square root of I_D vs. V_{GS} from the transfer curve (above) at V_{DS}=4V. According to our simple model you would expect this curve to be a straight line intercepting the V_{GS} axis at V_{T0n}. You will notice two effects that our simple "strong-inversion" model does not capture: (a) the curve intercepts the V_{GS} axis very gently such that V_{T0n} cannot be defined unambiguously; this is due to the moderate and weak inversion regions of operation of the transistor that, as we discussed in class, the simple model ignores. (b) The curve reaches a maximum slope and then its slope decreases with increasing V_{GS}; this is due to decrease in mobility as V_{GS} increases that our model also ignores.

   From the above plot you can extract V_{T0n} by the V_{GS} axis intercept of the tangent to the point of maximum slope. Turn in the plot and your extracted value of V_{T0n}.

4. With V_{T0n} extracted use the same transfer curve to extract the electron mobility, μ, that best fits the curve. Obviously, you cannot have a perfect fit for the reason discussed above. Explain your process and give your value of mobility.

5. 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 $\Delta V_{BS} = -1\ V$. You should use the same V_{DS}

for all curves. You may want to use the same as in (3) above. Take a screen shot of these characteristics for later use. Turn in this graph. Download the data to your local machine.

6. From the backgate characteristics, and using the model described in class, extract the values of γ and ϕ_{Fp} 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_{Fp} *in the* 0.3 *to* 0.5 *V range and extract the value of γ that is most consistent among the entire data set]*.