Fall 2008

EE 612: Nanoscale Transistors

HW2: DUE WEDNESDAY, SEPTEMBER 09

MOS Electrostatics (classical)

The purpose of this exercise is to review MOS electrostatics using the numerical simulation program, MOSCap, which is part of the ABACUS suite of educational tools on nanoHUB.org. Before you begin this assignment, familiarize yourself with using MOSCap on nanoHUB.org. After logging on, find the tool ABACUS. After starting it up, select the tool, MOSCap, from the drop down menu.

1) Perform a MOSCap simulation with the default parameters. Check at least one output result with a simple hand calculation to be sure that MOSCap is producing reasonable results. EXPLAIN clearly how you did the check.

   (The first thing that a prudent engineer does when using a new simulation program is to check the results to be sure that he or she using the program properly and that the program is producing correct results – at least for one problem similar to the problem of interest. Normally, the test would be more involved that the single one that I am asking you to do here, but I hope that this exercise will sensitize you to the need to be careful. Good engineers take responsibility to be sure that a simulation tool is producing correct results for their problem.)

For the remaining exercises, use the same parameters we used for the 45nm N-MOSFET in HW1:

$N_A = 2.7 \times 10^{18}$ cm^{-3} for the bulk doping
$EOT = 1.1$ nm
$Q_F = 0.0$
$T = 300$K
$V_{DD} = 1.0$V
Assume an n$^+$ polysilicon gate with $(E_F - E_C) = 0.0$ and ignore poly depletion.

2) Determine the following quantities by **analytical calculations** (assume $V_G = 0.0$V). You should use the delta-depletion approximation for these calculations.

   (i) The flatband voltage, V_{FB}
   (ii) The surface potential, ψ_S

(iii) The electric field in the oxide, E_{OX}
(iv) The electric field in the silicon at the surface, E_S
(v) The depletion region depth, W_D
(vi) The charge in the silicon, Q_S
(vii) The charge on the gate, Q_G
(viii) The voltage drop across the oxide, V_{OX}
(ix) The threshold voltage for this MOS capacitor, V_T

2) Simulate the above MOS capacitor using MOSCap on the nanoHUB. Use the same p-type doping and gate oxide thickness as in problem (1), and a voltage range of 2V to -4V. You can answer the following questions by reading the data from the MOSCap plots or by downloading the data as text. From the results, deduce the following quantities:

(i) The flatband voltage, V_{FB} (HINT: Deduce this from the $V_G = 0$ results.)
(ii) The surface potential, ψ_S (as defined in the text by Taur and Ning – be careful MOSCap does not use the same reference potential as Taur and Ning. That is, ψ is not 0 in the bulk.)
(iii) The electric field in the oxide, E_{OX}
(iv) The electric field in the silicon at the surface, E_S
(v) The depletion region depth, W_D
(vi) The charge in the silicon, Q_S
(vii) The charge on the gate, Q_G
(viii) The voltage drop across the oxide, V_{OX}
(ix) The threshold voltage for this MOS capacitor, V_T

Explain how you deduced these parameters, and compare them to the values in part 1. Some of these values will not be given directly by MOSCap – you will have to deduce them from the results that are given.

3) From the simulated low frequency C-V characteristics of this MOS capacitor answer the following questions:

(i) Deduce the effective thickness of the gate insulator under inversion conditions ($V_G = 1.0$ V) from the definition, $C_G \equiv \varepsilon_{OX}/EOT_{elec}$ and compare EOT_{elec} to the physical oxide thickness, t_{OX}. (When deducing EOT_{elec}, be sure to use the dielectric constant of SiO$_2$, $\varepsilon_{OX} = 3.9\varepsilon_0$.)

(ii) From the computed C-V plot, deduce the flatband voltage.

(iii) Deduce the semiconductor capacitance in accumulation and compare it to the expected value, $Q_S/(2k_BT/q)$.

4) Estimate the effect of poly depletion (which is not included in MOSCap) on this capacitor by computing C_{MAX}/C_{OX} for N_P = 1e20, 1.5e20, and 3e20 cm^{-3}.

Documenting MOSCap homework.....

You should document the MOSCap input to show exactly what simulation you did. Include MOSCap plots labeled with the data that are relevant to answering each specific question. Clearly identify each answer and discuss it, when that is appropriate. Annotations to discuss the answer should be clearly identified by writing them by hand on the printed copy or by using a different typeface e.g. bold). The key message is that clarity and brevity are highly valued in documenting your simulation homework.

I encourage students to discuss homework with each other, but I assume that you are each doing your own work. The rule is that you can discuss how you approached the problem, but DO NOT show someone else your solution. If you have not done your own work, it will be very clear when grading homework.