Homework #4 - EE 531

due 5/6/09

1. (a) Using the charge sheet approximation, determine the first-order Taylor expansion of the maximum depletion charge around $V_{CS} = 0$. Show that using this approximation, the drain current matches the expression provided in class. What is the appropriate expression for $\delta = m - 1$?

   (b) For a silicon-gate NMOS process,

$$\begin{aligned} N_a &= 5 \times 10^{18} \text{cm}^{-3} \quad \text{(uniform)} \\ t_{ox} &= 1.5\text{nm} \quad \text{(gate oxide)} \\ \phi_{MS} &= -0.95 \,\text{volts} \\ Q'_{ox} &= 5 \times 10^{10} \text{cm}^{-2} \quad \text{(interface oxide charge)} \\ V_{BS} &= -1.0\,\text{V} \quad \text{(substrate bias)} \\ W/2 = L &= 90\,\text{nm} \end{aligned}$$

   Determine the value of δ such that with $V_{GS} = V_{DS} = 1.5$V, the simplified model (with δ) and the accurate model (with 3/2 power) predict the same drain current. Compare your result to the δ value which is most accurate for small V_{DS} (answer to part (a)). Calculate the error between the models for $V_{GS} = 1.5V$, $V_{DS} = 0.8$V using the values of δ you calculated.

2. Consider an MOS capacitor with an n^+ channel contact, an n^+ polysilicon gate doped so that $E_f = E_c$, $x_{ox} = 5$ nm, $N_a = 5 \times 10^{17}\text{cm}^{-3}$, and a density of fast surface states within the bandgap of

$$N'_{ss}(E) = \left[5 \times 10^{10} + 10^{11} \left(\frac{E - E_i}{1\text{eV}} \right)^2 \right] \text{cm}^{-2}\text{eV}^{-1}.$$

   Assume that these states are a mixture of donor and acceptor levels such that the Si/SiO_2 interface charge (Q_{ss}) is zero when $E_f = E_i$.

   (a) Assuming that the states below E_{fn} at the surface are filled and those above are empty, determine an expression for the oxide charge due to fast surface states as a function of ψ_s and V_{CB} (voltage applied to channel contact).

   (b) Use your result to derive an expression for $C'_{it} = dQ'_{ss}/d\psi_s$.

   (c) Write V_{GB} as a function of ψ_s and V_{CB}. Use a first-order Taylor expansion to derive a linear expression for V_{GB} versus ψ_s around $\psi_s - V_{CB} = 2|\psi_B|$.

   (d) Calculate the subthreshold slope factor ($\eta = dV_{GB}/d\psi_s$) with and without interface states for $V_{CB} = 0$ and $V_{CB} = 3\,$V.

3. Initial Sentaurus-Device (device simulation) problem.

   (a) Run examples "simple Id-Vg" and "advanced Id-Vg"