Homework #2 - EE 531

due 4/16/09

1. A MOS capacitor is made with a silicon substrate doped with $N_a = 2\times10^{18}\text{cm}^{-3}$ of boron, 1 nm of silicon dioxide, and an n^+ polysilicon gate doped such that $E_f - E_c = 0.05\,\text{eV}$. The interface charges are constant with $Q'_{ss}/q = 5 \times 10^{10}\,\text{cm}^{-2}$. Assuming that inversion and accumulation charges approximate a sheet of charge at the interface and that weak inversion charges can be neglected (see T&N 3.1.2.1), determine the charge on the gate, the voltage dropped across the oxide and the voltage dropped across the silicon with the following voltages applied between the gate and the substrate:

   (a) $V_{gb} = -0.5\,\text{V}$

   (b) $V_{gb} = 0.2\,\text{V}$

   (c) $V_{gb} = 1\,\text{V}$

   Sketch the charge densities, electric fields and energy band diagrams in each case. What are the capacitances at low and high frequencies in each of the above cases?

2. Problem 2.6 in Text (Taur and Ning).

3. Problem 2.9 in Text (Taur and Ning).

4. As an extension to Problems 2.6 and 2.9, numerically integrate expressions for Q_d and Q_i in T&N P2.6.

   (a) Compare (via plot and discussion) your result for Q_d to T&N Eq 2.161.

   (b) Compare (via plot and discussion) your result for Q_i to T&N Eq 2.164.

   (c) Suggest an effective approximate expression for Q_i as function of V_{gb} in strong inversion.

5. Consider an MOS capacitor with $x_{ox} = 1.5$ nm, a p^+ poly gate doped with $N_a = 4 \times 10^{19}\,\text{cm}^{-3}$, a substrate uniformly doped with $N_d = 10^{18}\,\text{cm}^{-3}$ and negligible oxide charges.

   (a) Including poly depletion (use depletion approximation) and the finite thickness of the inversion layer (use appropriately simplified version of Eq. 2.154), derive an expression for $dQ'_I/dV_{GB} \approx dQ'_s/dV_{GB}$ in very strong inversion ($Q_I \gg Q_d$).

   (b) Using this expression, determine by what factor the coupling of gate voltage to inversion charge is reduced due to these two effects for $V_{GB} = V_T - 0.3V$ and $V_{GB} = V_T - 1V$, where V_T is defined by $|\psi_s| = 2|\psi_B|$. Which effect is more significant in each case?