Homework #7 - EE 482

due Monday 2/28/11

1. An MOS capacitor is made on n-type silicon with an oxide thickness of 10nm, a positive interface charge of $Q'_{ss}/q = 5 \times 10^{10}\,\text{cm}^{-2}$ and a uniform positive oxide charge density of $\rho_{ox}/q = 2 \times 10^{16}\,\text{cm}^{-3}$ throughout the oxide. The substrate is doped with $N_d = 10^{17}\,\text{cm}^{-3}$ and the gate is polysilicon doped with boron just to the edge of degeneracy (p^+ poly, $E_f = E_v$).

   (a) Calculate the flat-band voltage V_{FB} and the threshold voltage V_T.

   (b) Sketch the charge density, electric field and energy-band diagram at flat-band and at the edge of strong inversion.

   (c) Sketch the high and low frequency capacitance as function of V_{gb}. C'_{min}, C'_{acc} and C'_{inv} should calculated and indicated on the sketch.

2. Consider a gated MOS capacitor with a p-type silicon substrate doped with 10^{18}cm^{-3}, a heavily-doped n-type channel contact, a 2 nm thick gate oxide, and an arsenic-doped gate with $E_f = E_c$.

   (a) Calculate and plot the depletion charge and inversion charge as function of voltage dropped across the semiconductor for $V_{CB} = 0$ and $V_{CB} = 1V$.

   (b) Under the same conditions as in (a), calculate and plot the voltage dropped across the oxide and the associated gate to channel voltage (V_{GC}). Don't forget to account for work function difference.

   (c) Calculate the threshold voltage (value of V_{GC} for which n at surface equals p in bulk) for each case. Comment on how the inversion charge varies with V_{GC} above threshold based on (a) and (b). For $V_{CB} = 1V$, sketch the band diagram from gate to substrate in inversion.

3. An n-channel silicon MOS transistor with a polysilicon gate doped to the edge of degeneracy with phosphorus ($E_f = E_c$) has doping of $N_a = 10^{18}\text{cm}^{-3}$ in the substrate, $x_{ox} = 4\,\text{nm}$ and $W = 2L = 1.0\mu\text{m}$. Assume oxide charges can be ignored.

   (a) Find the threshold voltage with $V_{SB} = 0$.

   (b) Calculate δ, the correction term for change in depletion charge as V_{CB} increases, in the improved square-law drain current equation:

   $$I_D = \frac{W}{L}\mu'_n C'_{ox}\left[(V_{GS} - V_T)V_{DS} - \frac{(1+\delta)V_{DS}^2}{2}\right]$$

   An appropriate value is $\delta = (1/C_{ox})(dQ_d^{max}/V_{CB}) = C_s^{depl}/C_{ox}$ determined near threshold with $V_{CB} = 0$.

   (c) Plot I_{DS} versus V_{DS} for $V_{GS} = 3V$ and $V_{SB} = 0$ using the three linear-region drain current equations ($\delta = 0$, δ as above, and Eq. (9) in notes). Include V_{DS} values at least up to saturation.

   (d) Using the linearized equation and δ as calculated, determine the operating regime and drain current under the following conditions. In each case, sketch the band diagram at the drain end of the channel.

      i. $V_S = 0$, $V_B = 0V$, $V_G = 3V$, $V_D = 1V$.

      ii. $V_S = 0$, $V_B = 0V$, $V_G = 3V$, $V_D = 3V$.

      iii. $V_S = 0$, $V_B = 0V$, $V_G = 0V$, $V_D = 3V$.