Homework #7 - EE 482

due 12/4/02

1. 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, $x_{ox} = 40\,\text{Å}$ 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. $V_S = 0$, $V_B = 0V$, $V_G = 0V$, $V_D = 3V$.

2. A p-channel (n-type substrate) MOS transistor has a threshold voltage of -0.4V. The source and substrate are grounded. The gate is biased at -3V and the drain at -2V. The oxide thickness is 100 Å, the substrate doping is $N_d = 10^{17}\text{cm}^{-3}$ and $W/L = 2$.

   (a) Calculate the flatband voltage.

   (b) What mode (cutoff, linear, saturated, etc.) is the transistor operating in? Consider the change in depletion charge due to drain bias.

   (c) How much drain current is flowing (ignore channel length modulation)?

   (d) How large a positive substrate bias (V_{BS}) would be required to change the operating mode of the device keeping all other biasing the same? What would the new mode be?

   (e) If this transistor was implanted with a shallow dose of donors with a total dose of 10^{12}cm^{-2}, what would the new threshold voltage be ($V_{SB} = 0$). If the biasing remained the same, in what mode would the implanted device operate?

3. What is the output resistance of an n-channel silicon MOS transistor due to channel length modulation for $\Delta L \ll L = 0.3\mu\text{m}$ if $V_{DS} = V_{DS\text{sat}} + 0.5V$, $I_D = 1.0\,\mu\text{A}$ and $N_a = 2 \times 10^{17}\text{cm}^{-3}$.