August 2014 QE

All problems assume temperature $T = 300$ K, and consequently $kT = 0.0259$ eV; $kT/q = 0.0259$ V
Constants: $q = 1.6 \times 10^{-19}$ coulomb; $\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm; $k = 8.617 \times 10^{-5}$ eV/K; ln10 = 2.303

Problem #1 (50 points):

A metal-oxide-semiconductor (MOS) capacitor is made from aluminum ($\Phi_M = 4.1$ V), 15 nm thick silicon dioxide ($\varepsilon_r = 3.9\varepsilon_0$) and p-doped silicon with $\varepsilon_s = 11.9\varepsilon_0$, $\chi = 4.05$ V, $E_g = 1.12$ eV, and doping level of $N_a = 10^{17}$ cm^{-3}. Assume there is no fixed charge in the oxide or at the oxide-silicon interface.

1a: (10 points) Calculate the oxide capacitance, C_{ox}.

1b: (10 points) What is the semiconductor surface potential, ϕ_S, when inversion is on-set? What is the depletion width in silicon, W_d, at inversion threshold?

1c: (10 points) Calculate the high frequency capacitance for voltages beyond the onset of inversion.

1d: (10 points) Calculate the flat band voltage, V_{FB}, and threshold voltage, V_T.

1e: (10 points) Sketch the capacitance of this MOS-C over a large applied voltage range at *low* measurement frequencies. The applied voltage range should be large enough so that you can clearly mark the threshold voltage, flat band voltage, and mark with reasonable accuracy the capacitances at the flat band and threshold voltages based on calculations in parts a-d.

Problem #2 (50 points):

An n-channel silicon MOSFET has a threshold voltage $V_T = 1$ V, channel width $W = 5$ μm, channel length $L = 1$ μm, and oxide thickness $t_{ox} = 10$ nm. The effective mobility is $\mu_n = 288.5$ cm^2/Vs, and the body voltage V_{BS} is set to 0 V. Using square law and assume gate voltage $V_{GS} =$ 3 V and drain voltage $V_{DS} = 5$ V, answer the following questions:

2a: (5 points) What regime, *e.g.* triode, saturation, or sub-threshold, is this device operating at?

2b: (10 points) What is the drain current, I_D?

2c: (10 points) Calculate the transconductance, g_m.

2d: (10 points) Assume that $V_{GS} = 3$ V but drain voltage is now $V_{DS} = 0$ V. Calculate the drain or channel conductance, defined as $g_d = \dfrac{\partial I_D}{\partial V_G}$.

2e: (15 points) If we go beyond the square law, and consider the changes in the depletion width along the channel, how would the drain current change when compared with the values predicted by square-law, assuming the same V_{GS} and V_{DS}? How would the onset voltage of current saturation, V_{Dsat}, change? Please give quantitative reasoning for your predictions.

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