Semiconductor Device Theory:
MOS Capacitors –Theoretical Exercise 3

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1. For an MOS structure, find the charge per unit area in fast surface states (Q_s) as a function of the surface potential φ_s for the surface states density uniformly distributed in energy throughout the forbidden gap with density $D_{st} = 10^{11}$ cm^{-2}eV^{-1}, located at the boundary between the oxide and semiconductor. Assume that the surface states with energies above the neutral level ϕ_0 are acceptor type and that surface states with energies below the neutral level ϕ_0 are donor type. Also assume that all surface states below the Fermi level are filled and that all surface states with energies above the Fermi level are empty (zero-temperature statistics for the surface states). The energy gap is E_g=1.12 eV, the neutral level ϕ_0 is 0.3 eV above the valence band edge, the intrinsic carrier concentration is n_i=1.5×10^{10} cm^{-3}, and the semiconductor doping is N_A=10^{15} cm^{-3}. Temperature equals T=300 K.

2. Express the capacitance of an MOS structure per unit area in the presence of uniformly distributed fast surface states (as described in the previous problem) in terms of the oxide capacitance C_{ox}, per unit area. The semiconductor capacitance equals to C_s=-dQ_s/dφ_s (where Q_s is the charge in the semiconductor and φ_s is the surface potential), and the surface states capacitance is defined as C_{ss}=-dQ_{st}/dφ_s, where Q_{st} is the charge in fast surface states per unit area.

3. Using SCHRED, plot the conduction band profile and the electron density in a MOS capacitor with N_A=5×10^{17} cm^{-3} and d_{ox}=3 nm. For the applied voltage use V_G=1.0 V. Assume quantum model (nsub1=4, nsub2=2) for the charge distribution and: (a) metal gates with dski=0, and (b) poly-silicon gates with N_D=5×10^{19} cm^{-3}. Use T=300 K. Answer the following questions:
   (a) How does the electron density distribution changes when using classical and quantum charge distributions and metal gates. For the comparison, use the classical simulation results that you did in HW #8. How does the average distance of the carriers from the interface changes for these two cases. Explain the origin of the discrepancy using physical reasoning.
   (b) Explain the role of poly-gate depletion on the conduction band profile and the sheet charge density when using either classical or quantum charge description in the channel.

4. For the MOS capacitor from problem #3, calculate the low-frequency CV-curves using:
   (a) Classical charge description, Fermi-Dirac statistics and metal gates.
   (b) Classical charge description, poly-silicon gates and Fermi-Dirac statistics.
   (c) Quantum-mechanical charge description and metal gates.
   (d) Quantum-mechanical charge description and poly-silicon gates.

   The gate voltage should vary between -4 and 4V. A good voltage step would be 0.1 V. Overlay the curves that you have obtained from parts (a-d). Explain why did you get different results under strong inversion conditions. What is the origin of the observed threshold voltage shift?