Fundamentals of Nanotransistors
Unit 2 Homework
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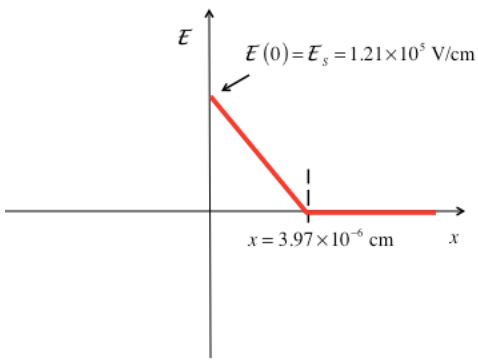
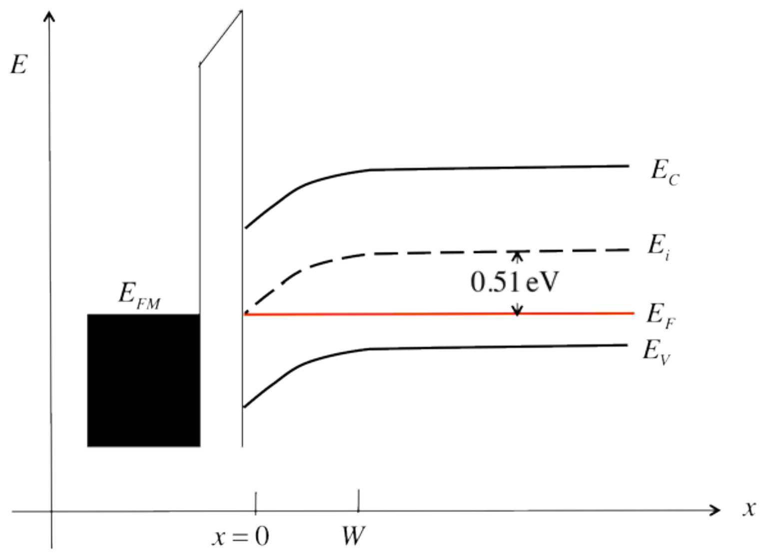
1) This problem concerns an MOS capacitor that consists of a metal electrode, a 2 nm thick silicon dioxide layer with $\kappa_{ox} = 3.9$, and a silicon substrate ($\kappa_S = 11.8$) that begins at $x = 0$. The electric field in the semiconductor is shown below. Assume that there is no charge at the oxide-Si interface, and no charge in the oxide.



Answer the following questions.

1a) What is the surface potential, ψ_S? (Assume that the potential is zero deep in the semiconductor.
1b) What is the doping density in the semiconductor?
1c) What is the electric field in the oxide?
1d) What is the voltage drop across the oxide?
1e) What is the electrostatic potential in the metal gate?

2) The energy band diagram for an MOS capacitor is sketched below. Assume T = 300K and an oxide thickness of $t_{ox} = 1.1$ nm, and an intrinsic carrier concentration of $n_i = 1\times10^{10}$ cm^{-3}. Answer the following questions using the depletion approximation as needed. (Note that $E_F = E_i$ at the oxide-silicon interface.)



2a) What is the surface potential?
2b) Sketch the electrostatic potential vs. position inside the semiconductor. Label the surface potential on your sketch.
2c) Sketch the electric field vs. position inside the oxide and semiconductor
2d) Do equilibrium conditions apply inside the semiconductor? Explain
2e) Sketch the hole concentration vs. position inside the semiconductor.
2f) What is the hole concentration in the bulk?
2g) What is the hole concentration at the surface?
2h) What is the gate voltage?
2i) What is the voltage drop across the oxide

3) Consider an MOS capacitor with a gate oxide 1.2 nm thick. The Si substrate doping is $N_A = 10^{18}$ cm^{-3}. The gate voltage is selected so that the sheet density of electrons in the inversion layer is $n_S = 10^{13}$ cm^{-2}. Assume room temperature and that $|Q_n| = qn_S \approx \sqrt{2\kappa_S \varepsilon_0 k_B T\, n_i^2 / N_A}\; e^{+q\psi_S/2k_BT}$ C/cm^2. Answer the following questions.

3a) What is the surface potential? Compare it with $2\psi_F$.

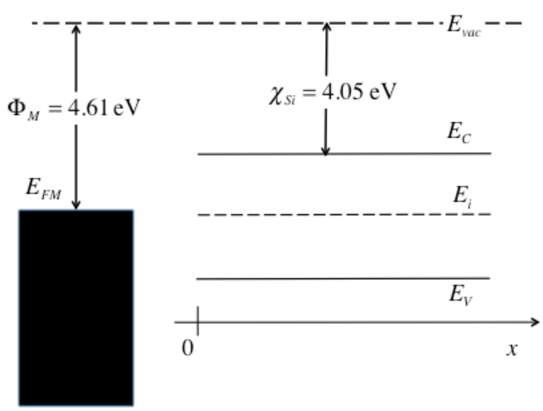
3b) How much does the **surface potential** need to increase to double the inversion layer density?

3c) How much does the **gate voltage** need to increase to double the inversion layer density?

3d) Explain in words why it is difficult to increase the surface potential for an MOS capacitor above threshold.

Unit 2 HW (continued)

4) Gate workfunctions must be chosen to produce the desired threshold voltage. If there is a difference between the metal gate and the semiconductor, then the flatband voltage is not zero. Consider the "mid-gap" workfunction shown below and assume that the semiconductor is silicon at room temperature with $N_C = 3.23\times10^{19}$ cm^{-3} and $N_V = 1.83\times10^{19}$ cm^{-3}.



4a) If the semiconductor is n-type with $N_D = 10^{18}$ cm^{-3}, then what is the flatband voltage? Explain the sign of the flatband voltage.

4b) If the semiconductor is p-type with $N_A = 10^{18}$ cm^{-3}, then what is the flatband voltage? Explain the sign of the flatband voltage.

5) Assume an MOS capacitor on a p-type Si substrate with the following parameters:

$N_A = 2.7\times10^{18}$ cm^{-3} for the bulk doping Oxide thickness: $t_{ox} = 1.1$ nm $\kappa_{ox} = 3.9$

$Q_F = 0$ (no charge at the oxide-Si interface) $T = 300$ K $V_G = 1$ V

Also assume that the structure is ideal with no metal-semiconductor workfunction difference. When working MOS problems, it is easiest to assume a surface potential, and then calculate the gate voltage that produced it, but in practice, we only have access to the gate terminal. In this problem, you are given the gate voltage and will be asked to find the surface potential. You may assume the depletion approximation, but you must check to be sure that it is valid.

Find the surface potential, ψ_S.