Problems

1. Consider an aluminum-SiO_2-silicon MOS capacitor (Φ_M = 4.1 V, $\varepsilon_{ox}/\varepsilon_0$ = 3.9, χ = 4.05 V and $N_a = 10^{17}$ cm^{-3}) MOS capacitor with t_{ox} = 5 nm.

   a) Calculate the flatband voltage and threshold voltage.

   b) Repeat for an *n*-type silicon substrate with $N_d = 10^{16}$ cm^{-3}.

   c) Repeat a) with a surface charge of 10^{-7} C/cm^2

   d) Repeat a) with a uniform charge density in the oxide of 10^{-1} C/cm^3

2. A high-frequency capacitance voltage measurement of a silicon MOS structure was fitted by the following expression:

   $$C(V_G) = 6 \text{ pF} + 12 \text{ pF}/(1 + \exp(3V_G))$$

   a) Calculate the oxide capacitance per unit area and the oxide thickness. The area of the capacitor is 100 x 100 micron and the relative dielectric constant equals 3.9.

   b) From the minimum capacitance, calculate the maximum depletion layer width and the substrate doping density.

   c) Calculate the bulk potential.

   d) Calculate the flatband capacitance and the flatband voltage.

   e) Calculate the threshold voltage.

3. A silicon MOS capacitor with an oxide thickness of 20 nm has an oxide capacitance, which is three times larger than the minimum high-frequency capacitance in inversion. Find the substrate doping density.

4. A CMOS gate requires *n*-type and *p*-type MOS capacitors with a threshold voltage of 2 and -2 Volt respectively. If the gate oxide thickness is 50 nm what are the required substrate doping densities? Assume the gate electrode is aluminum. Repeat for a p^+ poly-silicon gate. Use $\Phi_{s,poly} = \chi + E_g/q$.

5. Consider a *p*-MOS capacitor (with an *n*-type silicon substrate) and with an aluminum gate. Find the doping density for which the threshold voltage is 3 times larger than the flat band voltage. t_{ox} = 25 nm. Repeat for a capacitor with 10^{11} cm^{-2} electronic charges at the oxide-semiconductor interface.

6. A silicon *p*-MOS capacitor ($N_d = 4 \times 10^{16}$ cm^{-3}, t_{ox} = 40 nm) is biased halfway between the flatband and threshold voltage. Calculate the applied voltage and the corresponding capacitance per unit area.

7. A silicon *p*-MOS capacitor (t_{ox} = 20 nm, $N_d = 10^{16}$ cm^{-3}) has a flatband voltage of 1 V.

   a) Calculate the threshold voltage of the capacitor in the absence of any non-ideal charge in the oxide or at the oxide-silicon interface.

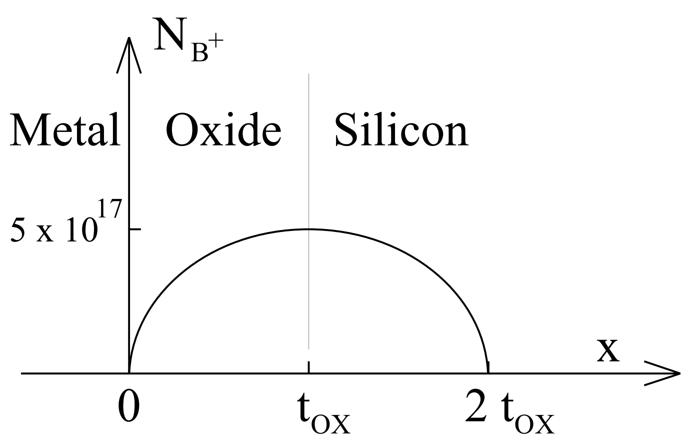
   b) Calculate the threshold shift due to a linearly varying charge density within the oxide with $\rho = 0$ C/cm^2 at the metal-oxide interface and $\rho = q \times 10^{18}$ C/cm^2 at the oxide-silicon interface.

8. The threshold of a silicon n-MOS capacitor ($\Phi_{MS} = 0$ V, $t_{ox} = 20$ nm and $N_a = 10^{17}$ cm^{-3}) is modified by implanting the structure with boron (B^+) ions yielding the following density of boron ions in the structure:

$$N_B^+ = 5 \times 10^{17} \sin\left(\frac{\pi x}{2\, t_{ox}}\right) \text{ cm}^{-3}, \text{ for } 0 < x < 2\, t_{ox}$$

$$N_B^+ = 0, \qquad \text{for } 2\, t_{ox} < x.$$

where x equals 0 at the metal-oxide interface and x equals t_{ox} at the oxide-semiconductor interface. Calculate the threshold shift due to the implanted boron ions. Assume that the boron ions in the oxide have a single positive charge and that the boron atoms in the silicon behave as shallow acceptors.



9. Draw the flatband diagram of an nMOS structure with a 10^{12} cm^{-2} electrons located in the middle of the oxide. Draw it approximately to scale using $\Phi_M = 4.1$ V, $\chi = 4.05$ V, $E_g = 1.12$ eV (silicon), $t_{ox} = 100$nm and $N_a = 10^{16}$ cm^{-3}. Use $\phi_F = 0.36$ V. Calculate the corresponding flatband voltage.

10. Consider an aluminum-SiO_2-silicon MOS capacitor ($\Phi_M = 4.1$ V, $\chi = 4.05$ V, $E_g = 1.12$ eV (silicon) and $N_a = 10^{17}$ cm^{-3}, $\varepsilon_{ox}/\varepsilon_0 = 3.9$, $\varepsilon_s/\varepsilon_0 = 11.9$) with $t_{ox} = 10$ nm.
   a) Calculate the flatband voltage and threshold voltage in the presence of a interface charge, $Q_i = 10^{-6}$ C/cm^2.
   b) Calculate the oxide capacitance, the flatband capacitance and the high-frequency capacitance in inversion. The area of the capacitor is 1 cm^2.

11. A silicon p-MOS capacitor with an aluminum gate (Φ_M = 4.1 V, $N_d = 10^{16}$ cm^{-3}, t_{ox} = 40 nm, $\varepsilon_{ox}/\varepsilon_0$ = 3.9) is biased halfway between the flatband and threshold voltage. The oxide contains a charge density of 10^{-4} C/cm^3 throughout the oxide and 10^{12} cm^{-2} electrons in the middle of the oxide. Calculate the applied voltage and the corresponding capacitance.

12. An silicon pMOS capacitor (Φ_M = 3.2 V, $N_d = 10^{17}$ cm^{-3} and t_{ox} = 30 nm) has a fixed charge density at the interface of 10^{11} electronc charges per square centimeter. Calculate the workfunction difference, Φ_{MS}, the flatband voltage, V_{FB}, the threshold voltage, V_T, the depletion layer width at threshold, $x_{d,T}$ and the high and low frequency capacitance at the onset of stong inversion.

13. A silicon MOS capacitor has a flatband voltage, which is exactly zero Volt. The threshold voltage is eight times larger than the absolute value of the bulk potential, while the oxide is 20 nm thick. Find the doping density of the substrate and indicate whether the substrate is doped with acceptors or donors.