Problems

1. Consider an n-type MOSFET, which consists of a 10 nm thick oxide (ε_r = 3.9) and has a gate length of 1 micron, a gate width of 20 micron and a threshold voltage of 1.5 Volt. Calculate the resistance of the MOSFET in the linear region as measured between source and drain when applying a gate-source voltage of 3 Volt. What should the gate-source voltage be to double the resistance? The surface mobility of the electrons is 300 cm^2/V-sec.

2. Consider an n-type MOSFET with an oxide thickness t_{ox} = 20 nm (ε_r = 3.9) and a gate length, L = 1 micron, a gate width, W = 10 micron and a threshold voltage, V_T = 1 Volt. Calculate the capacitance per unit area of the oxide, C_{OX}, and from it the capacitance of the gate, C_G. Calculate the drain current, I_D, at a gate-source voltage, V_{GS} = 3 Volt and a drain-source voltage, V_{DS} = 0.05 Volt. The surface mobility of the electrons μ_n = 300 cm^2/V-sec. Use the linear model of the MOSFET.

3. A MOSFET (L = 1 μm, t_{ox} = 15 nm, V_T = 1 V and μ_n = 300 cm^2/V-sec) must provide a current of 20 mA at a drain-source voltage of 0.5 Volt and a gate-source voltage of 5 Volt. How wide should the gate be?

4. A MOSFET (L = 1 μm, t_{ox} = 10 nm, V_T = 1 V and μ_n = 300 cm^2/V-sec) is to be used as 50 Ω terminating resistor when applying a gate-source voltage, V_{GS} = 5 Volt. How wide should the gate be?

5. The capacitance of an n-type silicon MOSFET is 1 pF. Provided that the oxide thickness is 50 nm and the gatelength is 1 micron, what is the resistance of the MOSFET in the linear regime when biased at a gate voltage which is 5 Volt larger than the threshold voltage? Use a reasonable value for the surface mobility knowing that the bulk mobility equals 1400 cm^2/V-sec.

6. Consider a p-channel silicon MOSFET with an aluminum gate.

   a) Draw the energy band diagram of the MOS structure for $V_G = V_{FB}$. Indicate the workfunction of the metal and the semiconductor, as well as the electron affinity.

   b) Draw the field distribution for $V_G = V_T$ (onset of inversion).

   c) Calculate the depletion layer width and the field in the oxide at the onset of inversion. ($N_d = 10^{16}$ cm^{-3}, t_{ox} = 100 nm, V_{FB} = -0.5V)

7. Calculate the depletion region width within a p-type bulk silicon MOS- capacitor with $N_d = 10^{17}$ cm^{-3}, at the onset of inversion.

8. A silicon p-substrate ($p \cong N_a = 10^{16}$ cm^{-3}) MOSFET with t_{ox} = 0.1 μm, $\varepsilon_{ox}/\varepsilon_0$ = 3.9 and a negative interface charge per unit area of -10^{-8} C/cm^2, has a threshold voltage which is 1 Volt smaller than desired. By what value should one change the oxide thickness to obtain the desired threshold voltage? Should one increase or decrease the oxide thickness?

9. A silicon MOSFET ($n_i = 10^{10}$ cm^{-3}, $\varepsilon_s/\varepsilon_0$ = 11.9 and $\varepsilon_{ox}/\varepsilon_0$ = 3.9) is scaled by reducing all dimensions by a factor of 2 and by increasing the doping density of the substrate by a factor of 4.

Calculate the ratio of the following parameters of the scaled device relative to that of the original device: (make approximations if necessary)

- The transconductance at V_{GS} - V_T = 1 V.
- The gate capacitance
- The transit frequency at V_{GS} - V_T = 1 V. (Assume that C_{DS} = 0)
- The threshold shift when increasing the reverse bias of the source-bulk diode from 1 Volt to 3 Volt.
- The breakdown voltage of the oxide assuming the breakdown field to be constant.
- The breakdown voltage of the drain-to-bulk p-n diode assuming the breakdown field to be constant.

10. A silicon p-substrate ($p \cong N_a = 10^{16}$ cm^{-3}) MOSFET with $t$ox = 0.1 µm, $\varepsilon_{ox}/\varepsilon_0$ = 3.9 and V_{FB} = -0.2 V, has a threshold voltage which is 1 Volt smaller than desired. By what value should one change the oxide thickness, t_{ox}, to obtain the desired threshold voltage? Should one increase or decrease the oxide thickness?