Problems

1. Consider an n-type MOSFET, which consists of a 10 nm thick oxide ($\varepsilon_r = 3.9$) 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 ($\varepsilon_r = 3.9$) 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 $\mu_n = 300$ cm$^2$/V-sec. Use the linear model of the MOSFET.

3. A MOSFET ($L = 1$ $\mu$m, $t_{ox} = 15$ nm, $V_T = 1$ V and $\mu_n = 300$ 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 ($L = 1$ $\mu$m, $t_{ox} = 10$ nm, $V_T = 1$ V and $\mu_n = 300$ cm$^2$/V-sec) is to be used as 50 $\Omega$ 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 gate length 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, $V_{FB} = -0.5$V)

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 ($\rho \equiv N_d = 10^{16}$ cm$^{-3}$) MOSFET with $t_{ox} = 0.1$ $\mu$m, $\varepsilon_{ox}/\varepsilon_0 = 3.9$ 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 ($\rho_i = 10^{10}$ 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 $V_{GS} - V_T = 1 \text{ V}$.
- The gate capacitance
- The transit frequency at $V_{GS} - V_T = 1 \text{ V}$. (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 ($p \equiv N_a = 10^{16} \text{ cm}^{-3}$) MOSFET with $t_{ox} = 0.1 \mu \text{m}$, $\varepsilon_{ox}/\varepsilon_0 = 3.9$ and $V_{FB} = -0.2 \text{ V}$, 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?