Homework #3 - February 28, 2003

Due: March 7, 2003 at recitation (Rm. 26-310, 1 PM)
(late homework will not be accepted)

Please write your recitation session time on your problem set solution.

1. [40 points] Consider a MOS structure that consists of a n⁺-poly-Si gate, a 9 nm SiO₂ insulator, on a p-Si substrate with a doping level \( N_a = 3 \times 10^{17} \text{ cm}^{-3} \). At room temperature and for \( V_{GB} = -3, 0, 0.3 \text{ and } 3 \text{ V} \), compute numerical values for:

a) [6 points] the surface potential;

b) [10 points] the total charge per unit area in the semiconductor and its breakdown into depletion charge and carrier charge;

c) [6 points] the electric field in the oxide;

d) [6 points] the extension of the depletion region in the semiconductor;

e) [6 points] the capacitance.

Additionally, calculate:

f) [2 points] the threshold voltage,

g) [2 points] the inversion layer charge at the oxide breakdown condition,

h) [2 points] the accumulation layer charge at the oxide breakdown condition.

The oxide breakdown field is 4 MV/cm.
2. [30 points] Consider a metal-oxide-semiconductor structure as sketched below. In this structure, directly underneath the oxide over a depth \( x_i \), the doping level in the semiconductor is negligible. Below \( x_i \) it increases to very high p-type value. The gate is made out of n\(^+\)-polySilicon.

![MOS structure diagram]

a) [6 points] Sketch the volume charge density distribution along \( x \) at zero bias.

b) [6 points] Sketch the electric field distribution along \( x \) at zero bias.

c) [6 points] Sketch the electrostatic potential distribution along \( x \) at zero bias.

d) [6 points] Derive an analytical expression for the charge in the semiconductor at zero bias as a function of relevant material-related parameters.

e) [6 points] Derive an analytical expression for the threshold voltage of this MOS structure in terms of relevant material-related parameters.

3. [30 points] You are given an MOS capacitor fabricated with a n\(^+\) polysilicon gate and a p-type substrate with a doping concentration of \( N_a = 10^{16} \) cm\(^{-3}\), as sketched below on the left. The capacitance-voltage curve for this device is shown below on the right.

![MOS capacitor diagram and capacitance-voltage curve]

a) [5 points] Calculate \( V_{GB} = V_1 \).
b) [5 points] Calculate the oxide thickness.

c) [5 points] Calculate $V_{GB} = V_2$.

d) [5 points] Calculate $C_{min}$.

e) [5 points] Calculate the electric field in the oxide when $V_{GB} = V_2 + 1 \text{ V}$.

f) [5 points] Calculate the electric field in the oxide when $V_{GB} = V_1 - 1 \text{ V}$. 