Homework #7 - October 25, 2002

Due: November 1, 2002 at lecture

1. *[10 points]* Select the work function of the gate material of an MOS structure that is needed to obtain $V_{FB} = 0\ V$ on an n-type substrate with $N_D = 10^{17}\ cm^{-3}$ and $x_{ox} = 10\ nm$. Sketch the energy band diagram of this structure in thermal equilibrium.

2. *[45 points]* Consider a MOS structure that consists of a n^+-poly-Si gate, an 9 nm SiO_2 insulator, on a p-Si substrate with a doping level $N_A = 3\times10^{17}\ cm^{-3}$. At room temperature and for $V_G = -3$, 0, 0.3 and 3 V, compute numerical values for:

a) the surface potential;

b) the total charge per unit area in the semiconductor and its breakdown into electron charge and hole charge;

c) the electric field in the oxide;

d) the extension of the depletion region in the semiconductor;

e) the low-frequency capacitance.

f) the high-frequency capacitance.

Do not solve the problem numerically. Use the analytical approximations described in class. Treat the n^+ poly-Si gate as a metal in which the Fermi level sits at the conduction band edge irrespective of bias.

Additionally, calculate:

g) the threshold voltage,

h) the inversion layer charge at the oxide breakdown condition,

i) the accumulation layer charge at the oxide breakdown condition.

The oxide breakdown field is 4 MV/cm.

3. *[30 points]* Consider an n$^+$-poly Si gate ($W_M = \chi_S = 4.04\ eV$) MOS structure with a gate oxide thickness of $x_{ox} = 15\ nm$ and a semiconductor doping level of $N_A = 10^{17}\ cm^{-3}$.

Answer the following questions at 300 K. For each question, state in what regime the MOS structure is operating. V refers to the voltage of the gate with respect to the body of the semiconductor.

To save you time, for this structure:

$$C_{ox} = \frac{\epsilon_{ox}}{x_{ox}} = 2.3 \times 10^{-7}\ F/cm^2$$

$$\gamma = \frac{1}{C_{ox}}\sqrt{2\epsilon_s q N_a} = 0.8\ V^{1/2}$$

a) Compute the electric field across the oxide for $V = -2\ V$.

b) Compute the hole concentration at the oxide/semiconductor interface when there is a depletion region in the semiconductor of $x_d = 50\ nm$.

c) Compute the electric field on the semiconductor side of the oxide semiconductor interface when, in steady state, there is a inversion layer charge of $|Q_i| = 5 \times 10^{-7}\ C/cm^2$.

d) Estimate the surface potential right after a pulse of $V = 4\ V$ is applied at $t = 0$ to the MOS structure in equilibrium.

e) Estimate the charge at the gate/oxide interface under the same conditions as d).

f) Estimate the high-frequency capacitance of the MOS structure under the same conditions as d).

4. *[15 points]* You have learned that there is a simple technique of extracting the flat-band voltage from the high-frequency capacitance-voltage characteristics of an MOS structure. The only thing you know about this technique is that it is somehow based on graphing $1/C_{HF}^2$ vs. V.

In order to figure out how this technique might work, derive a complete analytical description of $1/C_{HF}^2$ vs. V for a MOS structure with an p-type body from accumulation to inversion. Sketch this relationship in a linear scale.

Discuss how one could extract V_{FB} from this graph.