1) Measured IV data for an n-channel MOSFET are shown below. Relevant parameters for this MOSFET are:

\[ T = 300 \text{ K} \]

Oxide thickness: \( x_0 = 2.2 \text{ nm} \)
Relative dielectric constant: \( K_O = 4 \)

Power supply voltage: \( V_{DD} = 1.2 \text{ V} \)  
Series resistances: \( R_s = R_D = 100 \text{ } \Omega \mu \text{m} \)

Actual channel length = 85 nm

Assume that the MOSFET is 1 micrometer wide, \( W = 10^{-4} \text{ cm} \).

\[ I_{ON} = 1120 (\mu \text{A/}\mu \text{m}) \]

\[ R_{TOT} = \frac{V_{DS}}{I_D} = 340 (\text{ } \Omega \mu \text{m}) \]
HW Week 13 (continued)

Answer the following questions:

1a) From the so-called “on-current”, \(I_D(V_{GS} = V_{DD}, V_{DS} = V_{DD}) = 1.2\ V\), estimate the average velocity of electrons in the channel at the source end of the channel. (Note: You will need to correct for the effect of the series resistance as discussed in HW12.)

1b) From the linear region of operation, estimate the effective mobility of this MOSFET.

2) Assume the square law theory of the MOSFET:

\[
I_D = \frac{W\bar{n}C_{ox}}{L} \left[ (V_G - V_T) V_D - \frac{V_D^2}{2} \right] \quad 0 \leq V_D < V_{Dsat} \quad V_G \geq V_T
\]

\[
I_D = \frac{W\bar{n}C_{ox}}{2L} (V_G - V_T)^2 \quad V_D \geq V_{Dsat} \quad V_G \geq V_T
\]

2a) Derive an expression for the electric field vs. position along the channel in the linear region of operation.

2b) Derive an expression for the electric field vs. position along the channel at \(V_D = V_{Dsat}\).

3) There is often a sheet of “fixed charge” at the oxide-semiconductor interface. (By fixed charge, we mean a charge that does not vary with surface potential, \(\phi_S\).) Assume a 1.5 nm thick oxide with a relative dielectric constant of 4.0. Answer the questions below.

3a) Assume that a fixed charge of \(Q_F/q = 10^{11}\ cm^2\) is present. Explain how the fixed charge shifts the threshold voltage. What is the direction of this shift (e.g. is it a positive or negative voltage shift?).

3b) In HW 1, we saw that the number of atoms per cm\(^2\) on a (100) Si surface is \(N_S = 6.81 \times 10^{14}\ cm^2\). Assume each atom has one charged dangling bond, so a fixed charge of \(Q_F/q = 6.81 \times 10^{14}\ cm^2\) is present. How much is the voltage shift now?
HW Week 13 (continued)

4) The gate electrode of an MOS capacitor is often a heavily doped layer of polycrystalline silicon with the Fermi level located at $E_F = E_C$ for an n$^+$ polysilicon gate and $E_F = E_V$ for a p$^+$ polysilicon gate. These heavily doped semiconductors act almost like metals. Sketch the following four equilibrium energy band diagrams:

4a) An n-type Si substrate ($N_D = 10^{17}$ cm$^{-3}$) with an n$^+$ polysilicon gate.

4b) An n-type Si substrate ($N_D = 10^{17}$ cm$^{-3}$) with a p$^+$ polysilicon gate.

4c) A p-type Si substrate ($N_A = 10^{17}$ cm$^{-3}$) with an n$^+$ polysilicon gate.

4d) A p-type Si substrate ($N_A = 10^{17}$ cm$^{-3}$) with a p$^+$ polysilicon gate.

5) Compute the “metal”-semiconductor workfunction difference for each of the cases above.

5a) An n-type Si substrate with an n$^+$ polysilicon gate.

5b) An n-type Si substrate with a p$^+$ polysilicon gate.

5c) A p-type Si substrate with an n$^+$ polysilicon gate.

5d) A p-type Si substrate with a p$^+$ polysilicon gate.