EE105 – Microelectronic Devices and Circuits
Spring 2026, Homework #7

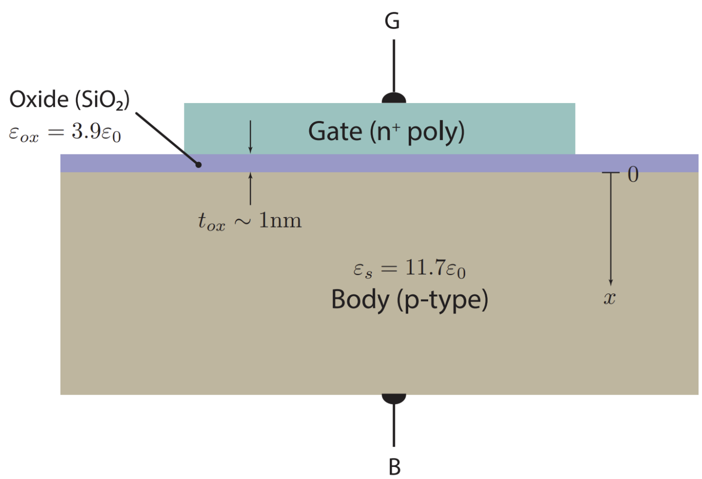
Assigned: **March 17, 2026**
Due: **March 31, 2026 (After Spring Break) at 11:59 PM on Gradescope**

1 Notes

Upload your notes from Lectures 14 and 15.

2 Problem Set

2.1 Problem 1: MOSCAP



For a MOSCAP with a p-type substrate. Given $V_{FB} = -0.53\,\text{V}$, $N_A = 10^{17}\,\text{cm}^{-3}$, oxide ($SiO_2$, $\epsilon_{ox} = 3.9\epsilon_0$) thickness of 3 nm, and silicon $\epsilon_{Si} = 11.7\epsilon_0$. Assume $T = 300\,\text{K}$ and $n_i = 10^{10}\,\text{cm}^{-3}$.

(a) Qualitatively explain: what is the condition for inversion to happen?

(b) Sketch the charge, electric field, and potential in depletion across the x-axis where the "metal" is on the left-hand side and the semiconductor on the right-hand side. The oxide to semiconductor interface is considered to be the reference point $x = 0$. Label the following key values on your plot: the charge concentrations, the max E-fields in terms of E_{Si} (E_{Si} is the max E-field in the semiconductor layer), the surface potential ϕ_s.

Hint: Figure 7.11 of the 105 reader.

(c) Calculate the surface potential ψ_s at the threshold ($V_{GB} = V_{Tn}$).

Hint: $n = \frac{n_i^2}{N_A} \exp\left(\frac{q\psi_s}{kT}\right)$ and $n = N_A$ at the surface of the p-well in strong inversion.

(d) Calculate the depletion width and depletion charge density at the threshold ($V_{GB} = V_{Tn}$).

Hint:

$$W_D = \sqrt{\frac{2\epsilon_{Si}\psi_s}{qN_A}}$$

(e) The threshold voltage can be computed by summing the flat-band voltage, the voltage across the oxide, and the surface potential at the threshold. Calculate the threshold voltage.

(f) Find the capacitance per area in inversion.

(g) Find the minimum capacitance per area (C_{min}).

Hint: Consider an ideal C-V curve. The minimum capacitance happens at the threshold, which is the series combination of oxide and depletion capacitances.

(h) Draw the C-V curve. Mark V_{FB}, V_T, C_{ox}, and C_{min} in your plot.

(i) Calculate the inversion charge density at $V_G = 1.5\,\text{V}$.

2.2 Problem 2: N-Channel MOSFET

An ideal N-channel MOSFET has the following parameters:

$$W = 100\,\mu\text{m}, \quad L = 1\,\mu\text{m}, \quad t_{ox} = 10\,\text{nm},$$

$$\text{oxide relative permittivity } \epsilon_{ox} = 4, \quad \text{silicon relative permittivity } \epsilon_{Si} = 12,$$

$$N_A = 10^{15}\,\text{cm}^{-3}, \quad n_i = 10^{10}\,\text{cm}^{-3}, \quad V_{FB} = -0.2\,\text{V},$$

$$\mu_n = 300\,\text{cm}^2/\text{V}\cdot\text{s}, \quad T = 300\,\text{K}, \quad \lambda = 0.$$

(a) Find the threshold voltage V_T.

(b) What is the minimum V_{DS} value for the MOSFET to be in the saturation region at $V_{GS} = 2\,\text{V}$?

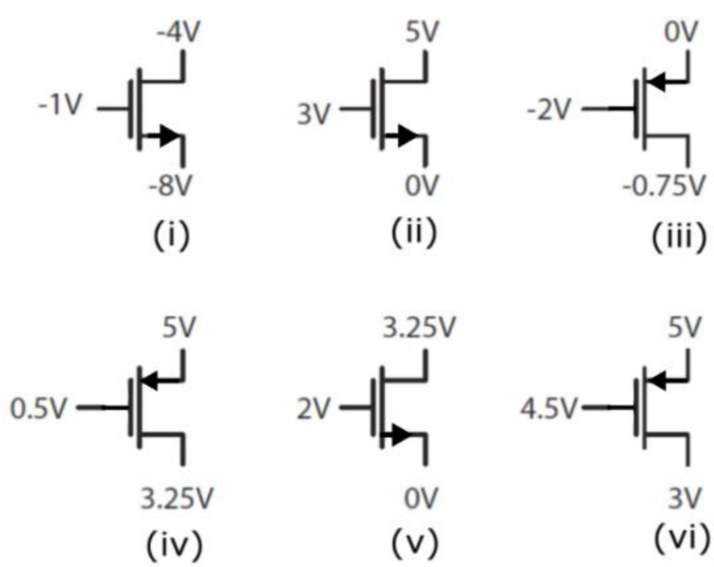
(c) Find the channel resistance at $V_{GS} = 2\,\text{V}$ and $V_{DS} = 0.01\,\text{V}$.

(d) Find I_D at $V_{GS} = 2\,\text{V}$ and $V_{DS} = 1\,\text{V}$.

(e) Find I_D at $V_{GS} = 2\,\text{V}$ and $V_{DS} = 3\,\text{V}$.

2.3 Problem 3: MOSFET Regions of Operation

For each of the devices and their respective bias voltages, report the region of operation: cutoff, linear/triode, or saturation. Consider $V_{TN} = 1$ V and $|V_{TP}| = 0.9$ V.



2.4 Problem 4: Short Channel Effects

Keeping in mind the ideal behavior of a transistor in digital or analog systems: explain why making transistors smaller is challenging and channel lengths cannot be reduced indefinitely in a lateral MOSFET.

You may use drawings, and band diagrams.