Problem 1

The device drawn below is biased as shown, and a capacitance-voltage (C-V) measurement is taken. The area of the device is $10^{-6}$ cm$^2$. Assume the electrostatic potential in the n+ silicon region, $\varphi_{n^+}=550$ mV.

A plot of $(1/C)^2$ as a function of the DC voltage, $V$, where $C$ is the capacitance is shown below. The device is in reverse bias. The slope, $S$, is $-4.8 \times 10^{26}$ F$^{-2}$ V$^{-1}$.
a) Derive an expression for the doping, $N_a$, in the p-type region in terms of the slope $S$, shown in the plot, and other known parameters (e.g. constants like $q \varepsilon_{Si}$, the device area).

b) Assume now that $N_a = 10^{16} \text{ cm}^{-3}$. Estimate the DC voltage $V'$ where the slope of the plot of $(1/C)^2$ vs. voltage changes, as seen in the graph.

**Problem 2**

A metal-oxide-semiconductor (MOS) device is pictured below. $T_{ox}$ is 15nm. Assume $\varphi_{n^+}=0.55\text{V}$, and that $N_a$ in the p region is $10^{17} \text{ cm}^{-3}$.

a) Find the threshold voltage of this device.

b) What applied bias leads to a sheet charge density in the inversion layer, $Q_N$, of $-10^6 \text{ C/cm}^2$?
c) What is the value of $E_{ox}$, the field in the oxide, when the charge on the gate, $Q_G = 10^{-6}$ C/cm$^2$?

Problem 3

Shown below is a capacitance-voltage plot for an MOS capacitor. The gate is n+, therefore you can assume its potential is 550mV. The silicon dioxide thickness is 15nm, and the body is doped with some concentration of acceptors, $N_a$.

![Capacitance-Voltage Plot]

a) Determine the threshold voltage, $V_T$, and the flatband voltage, $V_{FB}$, on the C-V plot.

b) Specify the range of voltages where the MOS capacitor is in inversion, depletion, and accumulation.

c) Calculate the doping concentration in the body, $N_a$, from the given information.

d) Now assume the gate is doped p+, so the potential of the gate is -550mV. Sketch the C-V, labeling $V_T$ and $V_{FB}$.

Problem 4

It is sometimes useful in analog circuits to use a transistor biased in triode as a voltage controlled resistor. Use the following parameters to design a p-channel MOSFET with a resistance of 100KΩ.

$\mu pCox=25\mu A/V^2$  $V_{tp}=-1V$  $V_{GS}=-1.2V$  $V_{BS}=0V$

a) If the device has a width of 10μm, what is the necessary length?

b) What is the necessary width to get a 10KΩ resistor, if the length is 5μm?
Problem 5

Hafnium dioxide (HfO$_2$, $\varepsilon = 25$) is an attractive replacement for silicon dioxide as a gate dielectric due to its high dielectric constant.

Consider an n-channel MOSFET. The channel length, $L = 2\mu m$, the width, $W = 30\mu m$, the electron mobility is $\mu_n = 300$ cm$^2$V$^{-1}$s$^{-1}$ and the substrate doping is $N_n = 10^{17}$ cm$^{-2}$. Assume the gate is n+ silicon, so its potential is $550\text{mV}$.

a) What thickness of HfO$_2$ is needed for $V_{Th} = 0.5$ V?

b) Find the backgate effect parameter, $\gamma_n$ for the hafnium dioxide gate insulator thickness from (a).

c) If $I = 5\mu A$, what is $V_{GS}$? Assume saturation. What is the minimum drain voltage to ensure saturation?