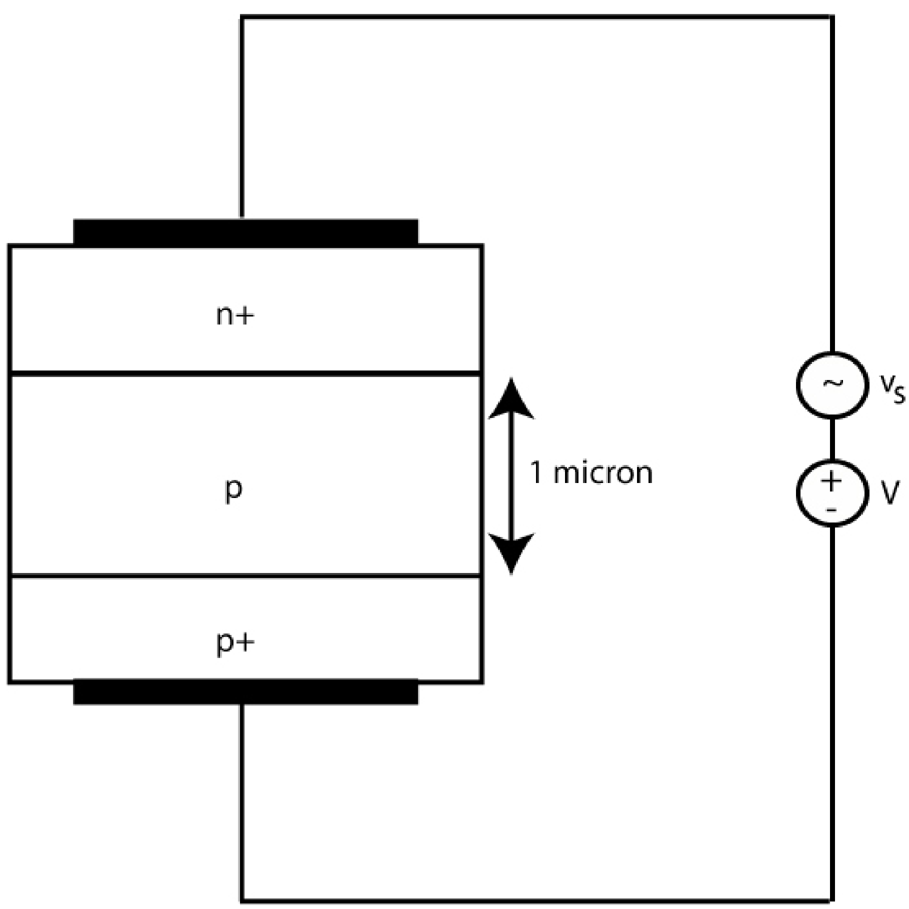
**Massachusetts Institute of Technology**
**Department of Electrical Engineering and Computer Science**
**6.012**
**Microelectronic Devices and Circuits**
**Spring 2007**
**February 28, 2007 - Homework #3**
**Due - March 8, 2007**

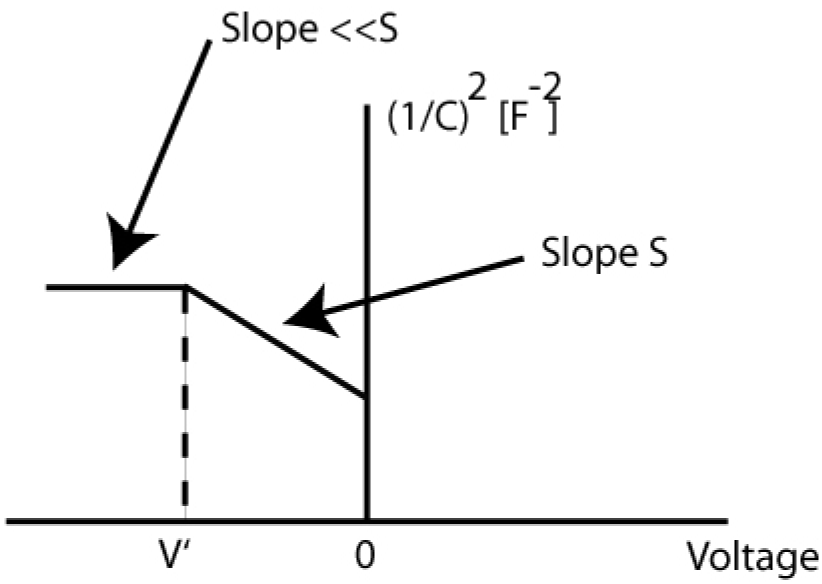
---

## 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, $\varphi_{n+}$=550mV.

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 $-4.8 * 10^{26}$ $F^{-2}$ $V^{-1}$.

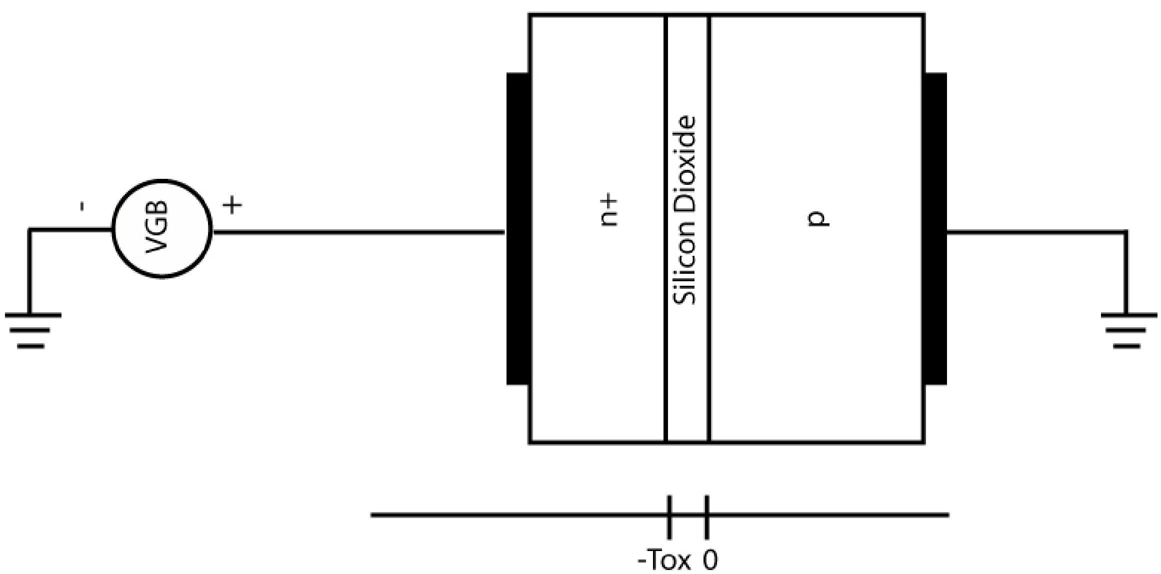





a) Derive an expression for the doping, $N_a$, in the p-type region in terms of the slope S, shown in the plot, and other known parameters (e.g. constants like q $\varepsilon_{Si}$, the device area).
b) Assume now that $N_a$ is $10^{16}$ $cm^{-3}$. Estimate the DC voltage V' where the slope of the plot 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 $\varphi_{n+}$=0.55V, and that $N_a$ in the p region is $10^{17}$ $cm^{-3}$.

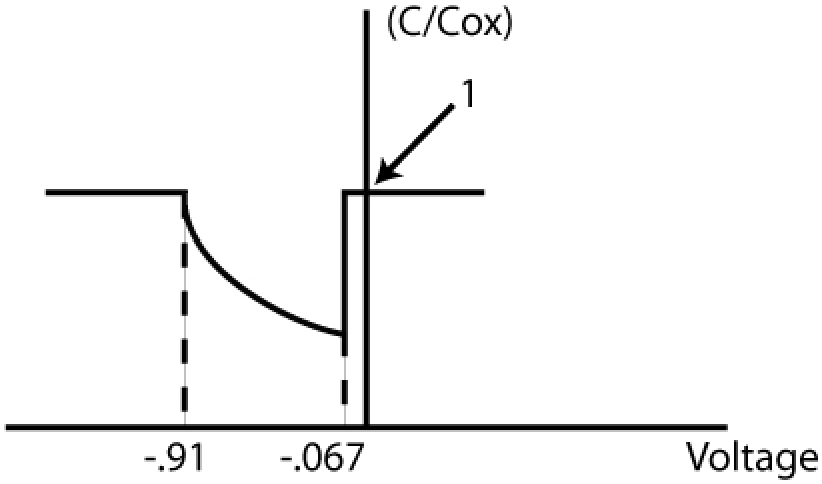



a) Find the threshold voltage of this device.
b) What applied bias leads to a sheet charge density in the inversion layer, $Q_N$, of -$10^{-6}$ $C/cm^2$?

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, $N_a$.




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.

$\mu_p C_{ox}$=25μA/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 = 2μm, the width, W = 30μm, the electron mobility is $\mu_n$ = 300 $cm^2V^{-1}s^{-1}$ and the substrate doping is $N_a = 10^{17}cm^{-3}$. Assume the gate is n+ silicon, so its potential is 550mV.

a) What thickness of $HfO_2$ is needed for $V_{Tn}$ = 0.5 V?
b) Find the backgate effect parameter, $\gamma_n$ for the hafnium dioxide gate insulator thickness from (a).
c) If I=5μA, what is $V_{GS}$? Assume saturation. What is the minimum drain voltage to ensure saturation?