MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 MICROELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 5

Issued: October 7, 2009 **Due:** October 14, 2009

Reading Assignments:

Lecture 9 (10/8/09) - Chap. 9 (9.1, 9.2, 9.3, 9.4)
Lecture 10 (10/15/09) - Chap. 9 (9.3, 9.4)
Lecture 11 (10/20/09) - Chap. 10 (10.1.1a)

Problem 1 - Two short MOS capacitor problems from the textbook:

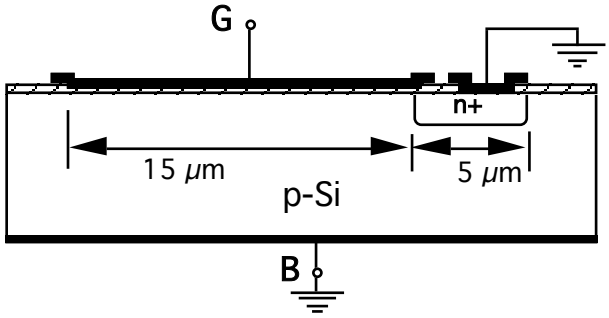
a) Do Problem 9.1 in the course text, Parts a, b, c, and d, only. In Part d) ii) use the value 1000 $cm^2/V\text{-}s$ for the electron mobility.

b) Do Problem 9.8 in the course text. A MOSFET connected as it is in this question is simply a MOS capacitor.

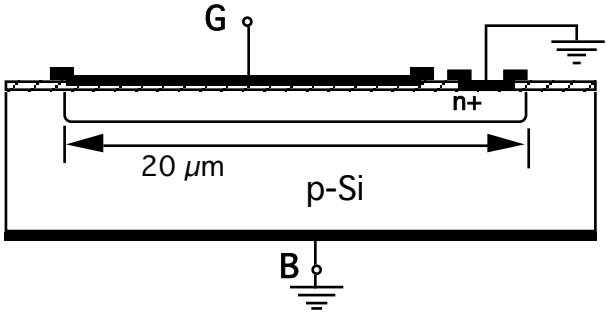
Problem 2 – We have only plotted the net sheet charge densities and the electrostatic potential through the MOS capacitors we have discussed, but we have not said anything about the electric field. To address this issue, sketch and label the electric field through an MOS capacitor for biases corresponding to the five conditions illustrated in Figure 9.3 (parts a thru f) on pages 244 and 245 in the course text. That is, make the electric field sketches that correspond to this set of charge density and electrostatic potential plots.

Problem 3 – Consider the two silicon device structures shown in cross-section below:

Device A:



Device B:



Both of these devices are made on p-type silicon with a net doping level of 10^{17} cm^{-3}, and are 20 μm wide normal to the page. The n^+ regions are doped to 10^{18} cm^{-3}, and the n^+-p junction is 1 μm from the top surface. The thin oxide is a high quality

thermal oxide 16 nm thick, and covers an area 20 μm wide by 15 μm long. In Device A the n^+ region is 20 μm wide by 5 μm long and extends just up to the edge of the thin oxide, while in Device B it is 20 μm wide by 20 μm long and extends all the way under the thin oxide, as shown in the figure.

You may assume that throughout the silicon the electron mobility, μ_e, is 1600 $cm^2/V\text{-}s$ and the hole mobility, μ_h, is 600 $cm^2/V\text{-}s$ (except in an inversion layer in which case μ_e = 600 $cm^2/V\text{-}s$ and μ_h = 400 $cm^2/V\text{-}s$); that the intrinsic carrier concentration, n_i, is 10^{10} cm^{-3} at room temperature; and that the dielectric constant, ε_{Si}, is 10^{-12} F/cm. The dielectric constant of the oxide, ε_{ox}, is 3 x 10^{-13} F/cm, and the electrostatic potential of the gate metal relative to intrinsic Si is 0.3 V. (Note: There is more information here than you need.)

a) i) What is the electrostatic potential of the p-type silicon, relative to intrinisic silicon, in thermal equilibrium at room temperature?

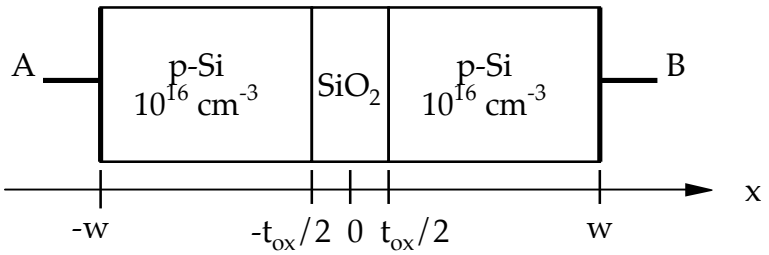
ii) What is the built-in potential of the unbiased n+-p junction at room temperature?

b) What are the flat band voltages, V_{FB}, of the MOS capacitor structures in Devices A and B, respectively?

c) The <u>magnitude</u> of the threshold voltage, $|V_T|$, for the MOS structure is 1 V in one of these devices, and 4 V in the other. Use this information and your knowledge of MOS capacitors to deduce the <u>magnitude and sign</u> of V_T for each of these MOS capacitors, i.e., the one made on p-Si and the made on n+-Si.

d) What is the condition (accumulated, depleted, or inverted) of the semiconductor surface under the thin oxide in each of these devices with a gate voltage, V_{GB}, of 2 Volts? Also give the identity and sheet density of any mobile holes or electrons induced at the oxide-silicon interface.

<u>Problem 4</u> - This problem concerns the novel semiconductor-oxide-semiconductor (SOS) structure illustrated at the top of the next page. The two semiconductor regions are both p-type silicon with a net acceptor concentration of 10^{16} cm^{-3}; the oxide is a 50 nm (5 x 10^{-6} cm) thick layer of silicon dioxide. The dielectric constant of silicon, ε_{Si}, is 10^{-12} F/cm and of silicon dioxide, ε_{ox}, is 3.5 x 10^{-13} F/cm.



Use the depletion approximation model when solving this problem. Assume that the depletion region widths are less than w/2. The drawing may not be to scale.

a) Sketch and label the electrostatic potential, $\phi(x)$, in this structure between -w/2 and +w/2 when $v_{AB} = 0$ and the structure is in thermal equilibrium.

b) A bias is applied to this device sufficient to make the electrostatic potential at $x = t_{ox}/2$ equal to $-\phi_p$, where ϕ_p is the thermal equilibrium electrostatic potential in the p-type regions, i.e., $\phi(t_{ox}/2) = -\phi_p$. We call this the onset of inversion on the right side, and name this bias the right-side threshold, V_{TR}.

(i) What is the sign of V_{TR}? Explain your answer.

(ii) What is the width of the depletion region to the right of $x = t_{ox}/2$ with this applied bias?

(iii) What is the condition of the left-hand semiconductor-oxide interface, the one at $x = -t_{ox}/2$ with this applied bias?

(iv) What is the value of V_{TR}?

c) Sketch and label the net charge density, $\rho(x)$, for $-w/2 < x < w/2$ when the bias voltage, V_{AB}, is V_{TR} + 2 Volts; recall V_{TR} was defined in Part (b). Be sure to label the vertical axis and to indicate the magnitude of any impulses (i.e., sheet charge densities).

d) Define the left-hand threshold, V_{TL}, of the structure as the bias voltage, V_{AB}, at which the potential at $x = -t_{ox}/2$ is $-\phi_p$. What is V_{TL}? (You can give your answer in terms of V_{TR}, if you wish. Making use of the mirror symmetry of the structure should simplify your calculation.)

e) Consider now a different SOS structure in which the left-hand semiconductor region is doped n-type, rather than p-type, with a net donor concentration of 10^{16} cm^{-3}.

(i) Sketch the electrostatic potential, $\phi(x)$ for $-w/2 < x < w/2$ in thermal equilibrium, i.e., $v_{AB} = 0$. Label the vertical axes but you do not calculate the widths of any depletion regions.

(ii) Sketch and label the electrostatic potential when v_{AB} is V_{TR} for this new structure, where V_{TR} has the same definition as before [see Part (b) above], but will not necessarily have the same value.

(iii) What is the value of V_{TL} for this new structure in terms of V_{TR} for this new structure, where V_{TR} and V_{TL} have the same definitions as earlier? (Making use of the inversion symmetry of the problem will simplify your solution.)

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