November 5, 2002 - Quiz #2

Name: ______________________________

General guidelines (please read carefully before starting):

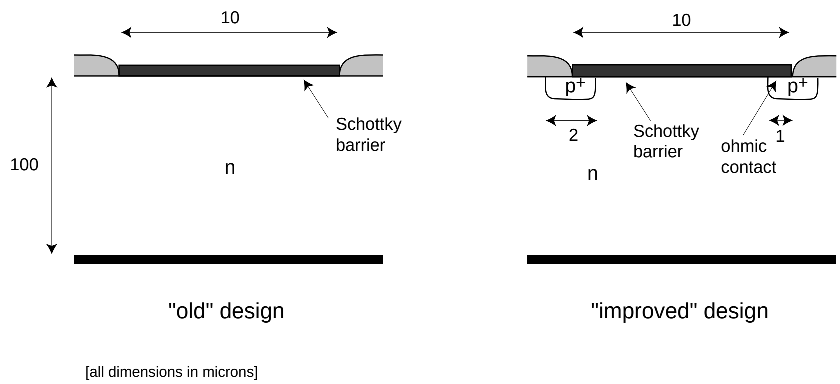
- Make sure to write your name on the space designated above.
- **Open book**: you can use any material you wish.
- All answers should be given in the space provided. Please do not turn in any extra material.
- You have **120 minutes** to complete your quiz.
- Make reasonable approximations and *state them*, i.e. low-level injection, extrinsic semiconductor, quasi-neutrality, etc.
- Partial credit will be given for setting up problems without calculations. **NO** credit will be given for answers without reasons.
- Use the symbols utilized in class for the various physical parameters, i.e. N_c, τ, $\mathcal{E}$, etc.
- Pay attention to problems in which *numerical answers* are expected. An algebraic answer will not accrue full points. Every numerical answer must have the proper *units* next to it. Points will be subtracted for answers without units or with wrong units. In situations with a defined axis, the *sign* of the result is also part of the answer.
- If needed, use the doping-dependent Si parameters graphed throughout del Alamo's notes.
- If needed, use physical parameters for silicon at room temperature listed in Appendix B of del Alamo's notes.
- If needed, use the values of fundamental constants listed in Appendix A of del Alamo's notes.

1. *(10 points)* In a metal-semiconductor junction that uses a metal with a large Schottky barrier height, an inversion layer of minority carriers might get formed at the metal-semiconductor interface in thermal equilibrium. Consider such a situation on n-type Si with $N_D = 10^{17}\ cm^{-3}$.

a) *(5 points)* Estimate the minimum Schottky barrier height for which this becomes a concern *(numerical answer expected)*.

b) *(5 points)* Sketch *to scale* the energy band diagram of such a metal-semiconductor junction in thermal equilibrium, i.e., label all key energy differences and horizontal dimensions.

2. *(30 points)* In order to improve the breakdown voltage of a Schottky barrier diode, a designer decides to introduce a p$^+$ guard ring, as sketched below. This problem is about evaluating the penalty in capacitance associated with this change.



In both designs, the Schottky barrier height is 0.8 eV, the doping of the semiconductor is $N_D = 10^{16}\ cm^{-3}$, and the wafer thickness is 100 μm. The ohmic contact to the body of the semiconductor is placed on the bottom surface of the wafer.

In the old design, the Schottky metal contacts the semiconductor over a $10 \times 10\ \mu m^2$ square window. In the new design, the Schottky metal is also $10 \times 10\ \mu m^2$. The n$^+$ guard ring is 2 μm wide and is centered around the edge of the metal. The p$^+$ region has a doping level of $N_A = 10^{19}\ cm^{-3}$.

Assume that any minority carrier physics in the pn diode are dominated by the n-type substrate. Answer all the following questions at room temperature.

a) *(5 points)* Estimate the capacitance of the old design at $V = 0\ V$ *(numerical answer expected).*

b) *(5 points)* Estimate the capacitance of the new design design at $V = 0\ V$ *(numerical answer expected)*.

c) *(5 points)* Estimate the capacitance of the old design at $V = 0.5\ V$ *(numerical answer expected)*.

d) *(15 points)* Estimate the capacitance of the new design design at $V = 0.5\ V$ *(numerical answer expected)*.

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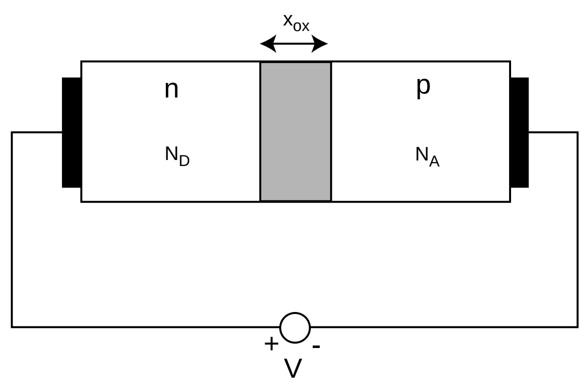
3. *(40 points)* Consider a n-Si/oxide/p-Si (Semiconductor-Oxide-Semiconductor or SOS) structure as sketched below. The doping level in both regions is identical: $N_A = N_D$. The oxide thickness is x_{ox}.



a) *(5 points)* Sketch the charge distribution across the SOS structure at $V = 0$.

b) *(5 points)* Sketch the energy band diagram at $V = 0$.

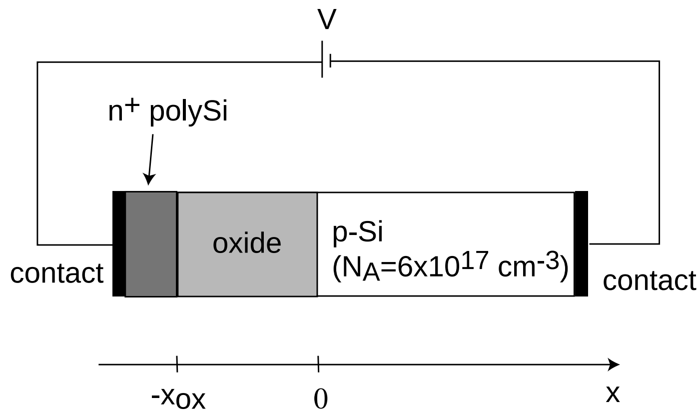
c) *(5 points)* Derive an expression for the built-in potential of this structure at $V = 0$.

d) *(10 points)* Now apply a negative voltage, V, across the structure. At a certain voltage, a characteristic situation occurs. How would you describe it? Derive an expression for the applied voltage required to produce this situation. Sketch the energy band diagram across the SOS structure at this bias.

e) *(10 points)* Now apply a positive voltage across the structure. At a certain voltage, a characteristic situation occurs. How would you describe it? Derive an expression for the applied voltage required to produce this situation. Sketch the energy band diagram across the SOS structure at this bias.

f) *(5 points)* Sketch the capacitance-voltage characteristics of this structure at low frequency. Place suitable tickmarks in the C and V axis.

4. *(20 points)* Consider the following MOS structure at room temperature:



The oxide thickness is $x_{ox} = 5\ nm = 5 \times 10^{-7}\ cm$. The gate is made out of n$^+$-polySi with $W_M = \chi_S = 4.04\ eV$.

To save you time, for this structure:

$$C_{ox} = \frac{\epsilon_{ox}}{x_{ox}} = 6.9 \times 10^{-7}\ F/cm^2$$

$$\gamma = \frac{1}{C_{ox}}\sqrt{2\epsilon_s q N_A} = 0.65\ V^{1/2}$$

a) *(10 points)* What is the magnitude of $\mathcal{E}_{ox}$ (electric field across the oxide) for a condition in which $Q_G = -2 \times 10^{-7}\ C/cm^2$? *(numerical answer expected).*

b) *(10 points)* What is the capacitance of the MOS structure at a bias point for which the total charge in the semiconductor is equal to $-2 \times 10^{-7}\ C/cm^2$? *(numerical answer expected).*