October 13, 2005 - Quiz #1

problem	grade
1	
2	
3	
4	
total	

Name: ______________________________

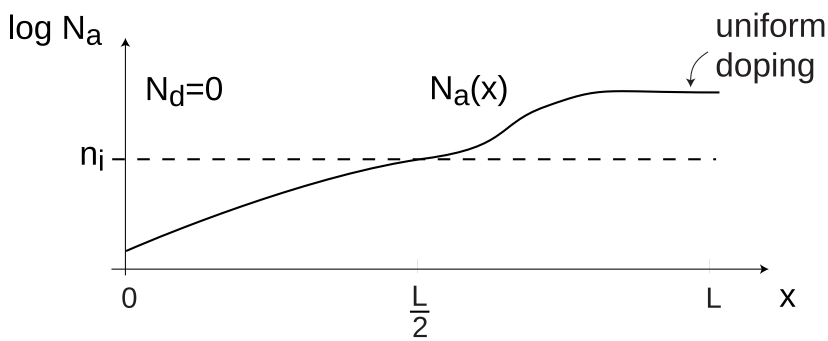
Recitation: ______________________________

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. If you need more space, use the back page.
- You have **120 minutes** to complete your quiz.
- Make reasonable approximations and *state them*, i.e. quasi-neutrality, depletion approximation, 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. μ_n, I_D, E, etc.
- Every numerical answer must have the proper units next to it. Points will be subtracted for answers without units or with wrong units.
- Use $\phi = 0$ at $n_o = p_o = n_i$ as potential reference.
- Use the following fundamental constants and physical parameters for silicon and silicon dioxide at room temperature:

$$n_i = 1 \times 10^{10}\ cm^{-3}$$
$$kT/q = 0.025\ V$$
$$q = 1.60 \times 10^{-19}\ C$$
$$\epsilon_s = 1.05 \times 10^{-12}\ F/cm$$
$$\epsilon_{ox} = 3.45 \times 10^{-13}\ F/cm$$

1. *(25 points)* A bar of silicon is doped with acceptors as shown below. The doping density variers smoothly and motononically in the x direction from $N_A \ll n_i$ at $x = 0$ to $N_A \gg n_i$ at $x = L$. $N_a(L/2) = n_i$. Around $x = L$, the acceptor profile becomes uniform. The donor density is zero everywhere. This is a thermal equilibrium situation.



On the basis of this description, answer the following questions by circling the correct answer. Write a brief justification for your choice below.

(1a) *(2 points)* Where is the hole concentration the greatest?

$x = 0$ $\quad$ $0 < x < L/2$ $\quad$ $x = L/2$ $\quad$ $L/2 < x < L$ $\quad$ $x = L$ $\quad$ uniform

(1b) *(2 points)* Where is the electron concentration the greatest?

$x = 0$ $\quad$ $0 < x < L/2$ $\quad$ $x = L/2$ $\quad$ $L/2 < x < L$ $\quad$ $x = L$ $\quad$ uniform

(1c) *(2 points)* In which direction does the hole diffusion current flow?

$-\vec{x}$ $\quad$ no current $\quad$ $+\vec{x}$

(1d) *(2 points)* In which direction does the hole drift current flow?

$-\vec{x}$ no current $+\vec{x}$

(1e) *(2 points)* In which direction does the electron diffusion current flow?

$-\vec{x}$ no current $+\vec{x}$

(1f) *(2 points)* In which direction does the electron drift current flow?

$-\vec{x}$ no current $+\vec{x}$

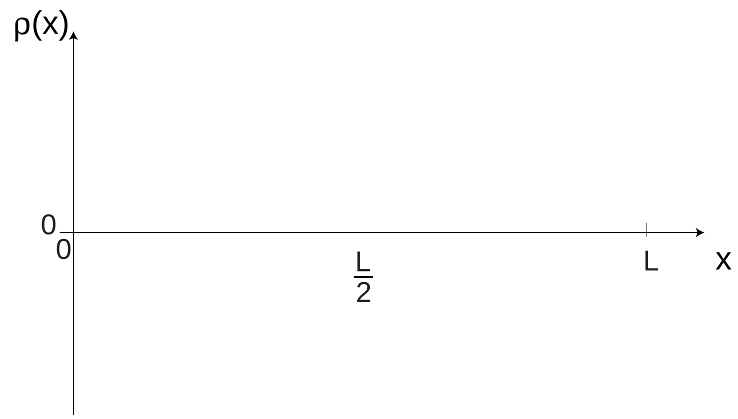
(1g) *(2 points)* In which direction does the electric field point?

$-\vec{x}$ no field $+\vec{x}$

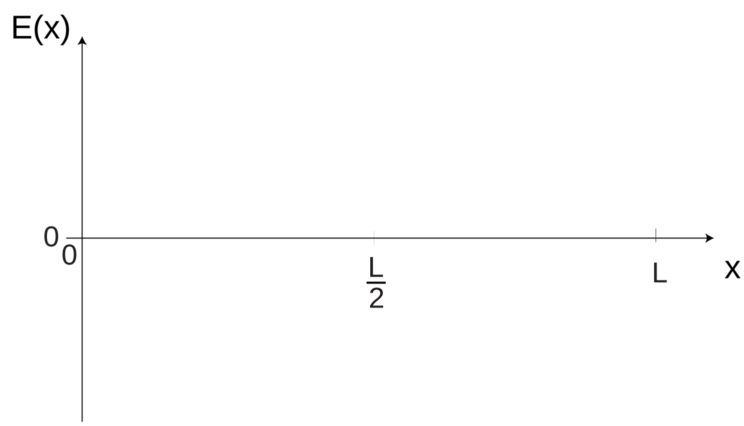
(1h) *(2 points)* Where is the electrostatic potential the greatest?

$x = 0$ $0 < x < L/2$ $x = L/2$ $L/2 < x < L$ $x = L$ uniform

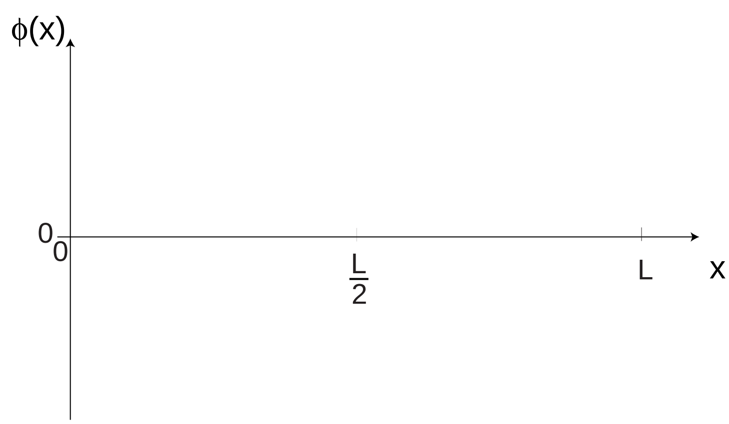
(1i) *(3 points)* In the axis provided below, sketch the volume charge density along x.



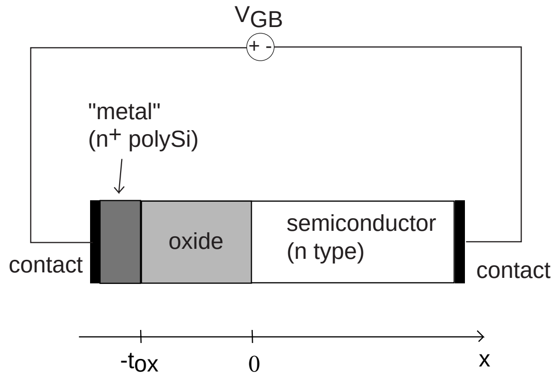
(1j) *(3 points)* In the axis provided below, sketch the electric field distribution along x.



(1k) *(3 points)* In the axis provided below, sketch the electrostatic potential distribution along x. Use as reference $\phi = 0$ at $n_o = p_o = n_i$.

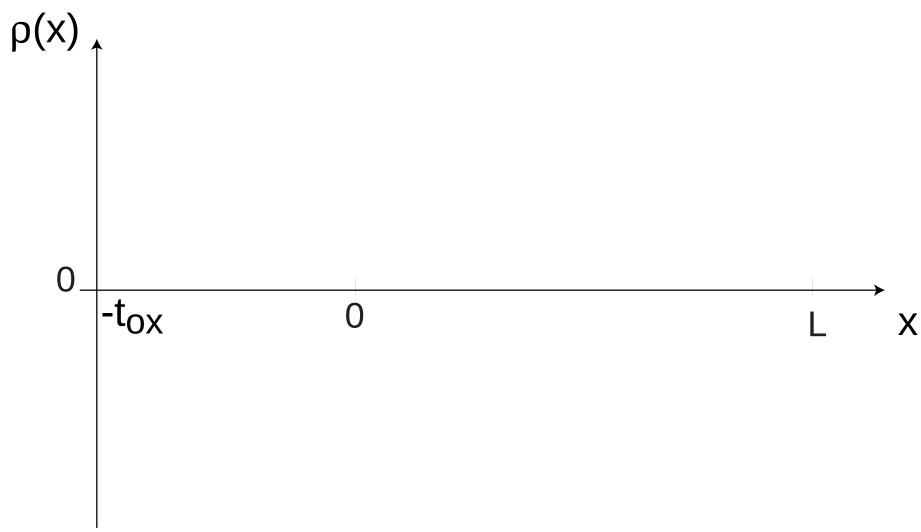


2. *(10 points)* Consider an MOS structure on an n-type substrate:



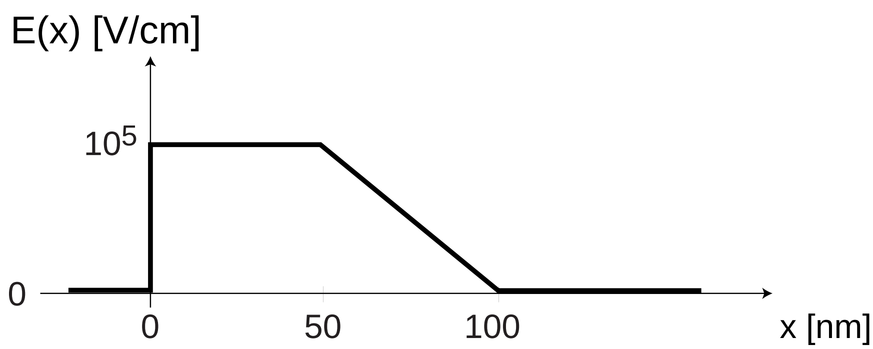
The doping level in the substrate (or body) is $N_D = 10^{17}\ cm^{-3}$. The doping level in the gate is $N_D^+ = 10^{20}\ cm^{-3}$.

(2a) *(5 points)* In the axis below, *qualitatively* sketch the volume charge density across this structure at zero bias. Explain your result.



(2b) *(5 points)* Calculate the flatband voltage of this structure *(numerical answer with appropriate sign and units expected).*

3. *(30 points)* Consider a pn junction at zero bias with an electric field distribution as sketched below. The metallurgical junction is placed at $x = 0$.



(3a) *(10 points)* Calculate the depletion capacitance at zero bias *(numerical answer with appropriate sign and units expected).*

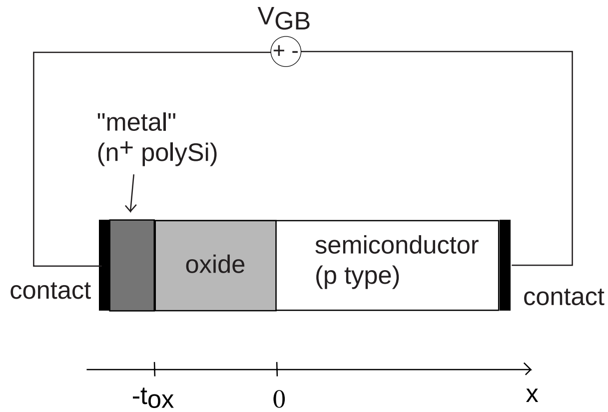
(3b) *(5 points)* Calculate the built-in potential *(numerical answer with appropriate sign and units expected).*

(3c) *(5 points)* Estimate the doping type and doping level of the region between $50 < x < 100$ nm *(numerical answer with appropriate sign and units expected).*

(3d) *(5 points)* What can you say about the doping type and doping level of the region between $0 < x < 50\ nm$?

(3e) *(5 points)* What can you say about the doping type and doping level of the region defined as $x < 0$?

4. *(40 points)* Consider a MOS structure as sketched below:



The oxide thickness os $t_{ox} = 50\ nm$ and the doping level in the substrate is $N_a = 10^{16}\ cm^{-3}$.

This problem is about calculating the hole concentration at $x = 0$ (the oxide-semiconductor interface) under the following conditions:

(4a) *(10 points)* At flatband *(numerical answer with appropriate sign and units expected).*

(4b) *(10 points)* At threshold *(numerical answer with appropriate sign and units expected).*

(4c) *(10 points)* At a condition in which the potential build up from the quasi-neutral body of the semiconductor to $x = 0$ is $0.5\ V$ *(numerical answer with appropriate sign and units expected).*

(4d) *(10 points)* At a condition when the capacitance per unit area of the MOS structure is $50\ nF/cm^2$ *(numerical answer with appropriate sign and units expected).*