March 10, 1999 - Quiz #1

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 mo 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 answe 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 withou units or with wrong units.

- Use the following fundamental constants and physical parameters for silicon and silicon dioxide at roo temperature:

$$n_i = 1 \times 10^{10} \ cm^{-3}$$
$$kT/q = 0.026 \ V$$
$$q = 1.60 \times 10^{-19} \ C$$
$$\epsilon_s = 1.05 \times 10^{-12} \ F/cm$$
$$\epsilon_{ox} = 3.45 \times 10^{-13} \ F/cm$$

1. *(30 points)* You are given a semiconductor with a total length of 6 μm. It is doped with both donors and accept with a resulting net doping profile that has a linear distribution in space, as shown in the figure below. G is gradient of the net doping concentration. Assume that the semiconductor is in thermal equilibrium.
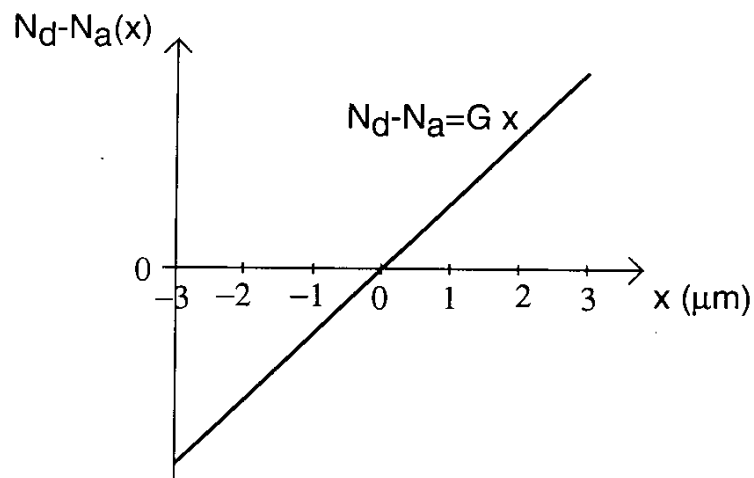
This doping distribution results in a space charge layer (a depletion layer) of width W that separates two quasi-neut regions. The resulting charge density distribution is sketched below.
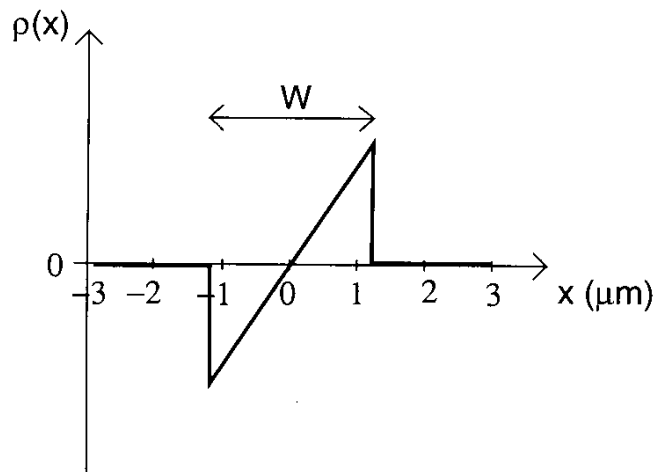
1a) *(5 points)* Sketch the electric field in the depletion region. Derive an expression for the value of the electric fie[
at its peak magnitude. Use the depletion approximation and express your answer in terms of W and G.
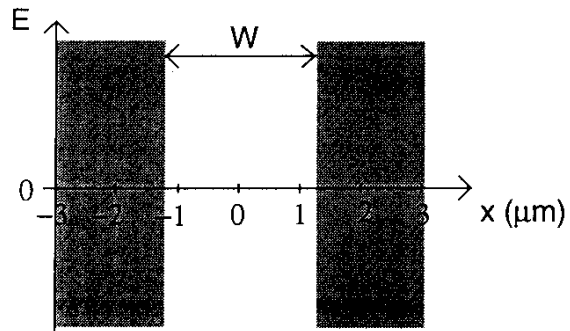
$|E_{max}|=$ _____

1b) *(5 points)* Sketch the electrostatic potential in the depletion region. Provide an expression for the value of th
electrostatic potential at $x = 0$. Use the depletion approximation and express your answer in terms of W and G.


$\phi(x = 0)=$ _____
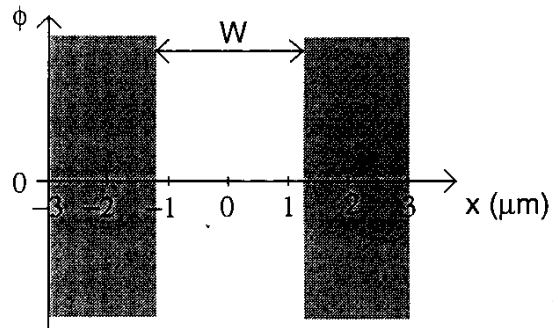
1c) *(5 points)* Using $G = 10^{17}$ $cm^{-3}/\mu m$, compute the electron concentration in the quasi-neutral region at $x = 2$ μm and $x = -2$ μm *(numerical answer expected)*.

1d) *(5 points)* Using $G = 10^{17}$ $cm^{-3}/\mu m$, compute the electrostatic potential ϕ at $x = 2$ μm and $x = -2$ μm *(numerical answer expected)*.

1e) *(5 points)* Using $G = 10^{17}$ $cm^{-3}/\mu m$ and $\mu_n = 1000$ $cm^2/V \cdot s$, calculate the electron diffusion current J_n^{diff} at $x = 2$ μm and $x = -2$ μm *(numerical answer expected)*.

1f) *(5 points)* Using the knowledge that you are in thermal equilibrium and the results of *1e)*, compute the electr field at $x = 2$ μm *(numerical answer expected)*.

2. *(30 points)* You are given an MOS capacitor fabricated with a p^+ polysilicon gate and a p-type substrate with doping concentration of $N_a = 10^{15} \ cm^{-3}$, as sketched below.
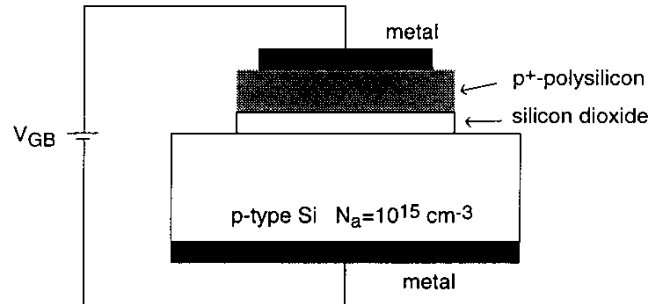
The capacitance-voltage curve for this device is shown below:
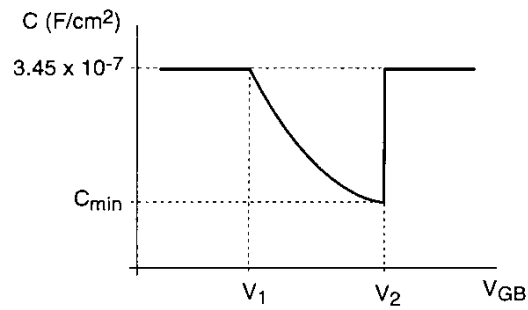
2a) *(5 points)* Calculate $V_{GB} = V_1$.

2b) *(5 points)* Calculate the oxide thickness.

2c) *(5 points)* Calculate $V_{GB} = V_2$.

2d) *(5 points)* Calculate C_{min}.

2e) *(5 points)* Calculate the electric field in the oxide when $V_{GB} = V_2 + 1\ V$.

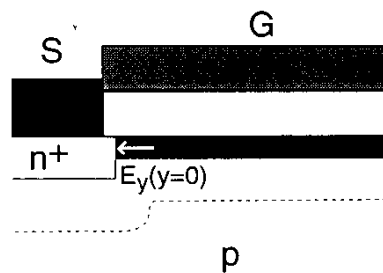2f) *(5 points)* Calculate the electric field in the oxide when $V_{GB} = V_1 - 1\ V$.

3. *(40 points)* Consider an n-channel MOSFET with gate length $L = 1 \ \mu m$, gate width $W = 10 \ \mu m$, inversion lay electron mobility $\mu_n = 300 \ cm^2/V \cdot s$, threshold voltage $V_T = 1 \ V$, oxide thickness $t_{ox} = 15 \ nm$, body paramet $\gamma = 0.5 \ V^{1/2}$, and potential in substrate $\phi_p = -0.4 \ V$.

□ Answer the following questions when the device is biased with $V_{GS} = 3 \ V$, $V_{DS} = 0.1 \ V$ and $V_{BS} = 0 \ V$.

3a) *(5 points)* In what regime is the device operating? Explain.

3b) *(5 points)* Calculate the drain current, I_D.

3c) *(5 points)* Calculate the *lateral* electric field at the source end of the channel, $E_y(y = 0)$ (this is the field in t channel in the direction of the channel, as sketched below).
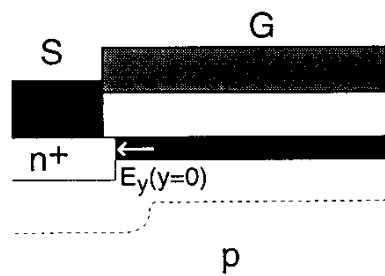
□ Answer the following questions when the device is biased with $V_{GS} = 3\ V$, $V_{DS} = 3\ V$ and $V_{BS} = 0\ V$.

3d) *(5 points)* In what regime is the device operating? Explain.

3e) *(5 points)* Calculate the drain current, I_D.

3f) *(5 points)* Calculate the *lateral* electric field at the source end of the channel, $E_y(y = 0)$ (this is the field in t.
channel in the direction of the channel, as sketched below).

□ Answer the following questions when the device is biased with $V_{GS} = 1.5$ V, $V_{DS} = 3$ V and $V_{BS} = -4$ V.

3g) *(5 points)* In what regime is the device operating? Explain.

3h) *(5 points)* Calculate the drain current, I_D.