

March 14, 2001 - Quiz #1

Name: \_\_\_\_\_

Recitation: \_\_\_\_\_

problem	grade
1	
2	
3	
4	
5	
6	
total	

**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.  $\mu_n$ ,  $I_D$ ,  $E$ , 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:

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

1. (10 points) Compute the equilibrium electron and hole concentrations,  $n_o$  and  $p_o$ , for silicon at room temperature doped with:

(1a) (2 points) Boron (B) concentration =  $10^{17} \text{ cm}^{-3}$ .

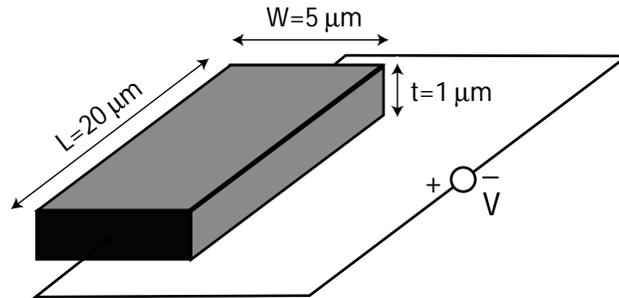
(1b) (2 points) Phosphorus (P) concentration =  $5 \times 10^{16} \text{ cm}^{-3}$  and Antimony (Sb) concentration =  $5 \times 10^{16} \text{ cm}^{-3}$ .

(1c) (2 points) Arsenic (As) concentration =  $10^{17} \text{ cm}^{-3}$  and Boron (B) concentration =  $10^{16} \text{ cm}^{-3}$ .

(1d) (4 points) In (1a) above, what is the magnitude of the electric field that must be applied to the sample for the magnitude of the majority carrier drift velocity to be equal to  $10^6 \text{ cm/s}$ ?

2. (10 points) An engineer is told that a region of silicon of length  $20\ \mu\text{m}$ , width  $5\ \mu\text{m}$  and thickness  $1\ \mu\text{m}$  is uniformly doped with a single kind of dopant with a concentration of  $10^{20}\ \text{cm}^{-3}$ . Ohmic contacts are formed at the ends of the region and she measures the I-V characteristics given in the table below. Is the sample n-type or p-type? Explain how you reach this conclusion. [Hint: think about the sample resistance.]

voltage (V)	current (A)
0	0
1	0.025
2	0.05



**3.** (10 points) In a certain n-type region of a semiconductor in thermal equilibrium, there is a hole concentration with the following spatial distribution:

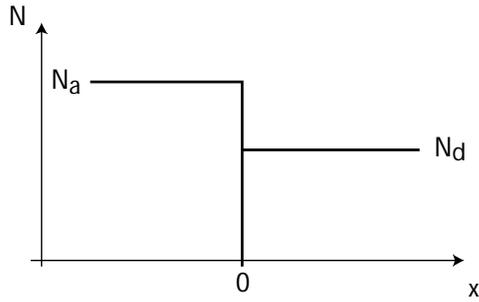
$$p_o(x) = 10^3(1 - 9 \times 10^3 x) \text{ cm}^{-3} \quad \text{for } 0 \leq x \leq 10^{-4} \text{ with } x \text{ in cm}$$

Assume that in this region, the electron mobility and hole mobilities are  $\mu_n = 500 \text{ cm}^2/\text{V} \cdot \text{s}$  and  $\mu_p = 200 \text{ cm}^2/\text{V} \cdot \text{s}$ , respectively.

(3a.) (5 points) Derive an expression for and sketch the hole diffusion current density in this region.

(3b.) (5 points) Derive an expression for and sketch the electric field distribution in this region.

4. (20 points) Consider an abrupt pn junction with  $N_a = 10^{17} \text{ cm}^{-3}$  and  $N_d = 10^{16} \text{ cm}^{-3}$ , as sketched below.



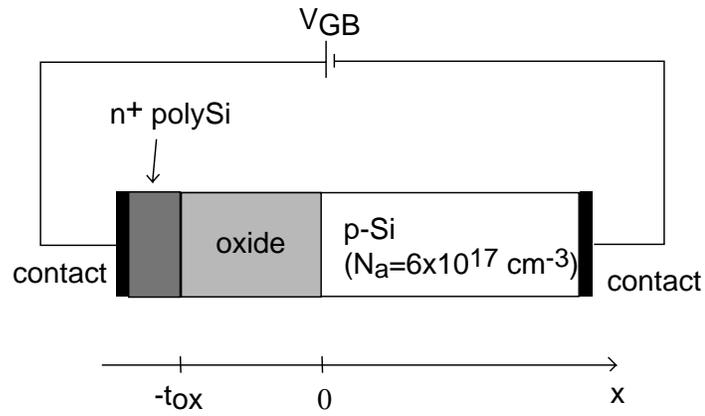
4a) (6 points) Compute the value of the electrostatic potential at  $x = 0$  in thermal equilibrium (numerical answer expected).

4b) (4 points) Compute  $n_o$  and  $p_o$  at  $x = 0$  in thermal equilibrium (numerical answer expected).

4c) (5 points) Compute the value of  $x$  for which  $n_o = p_o = n_i$  in thermal equilibrium (numerical answer expected).

4d) (5 points) Compute the total amount of charge per unit area on the p side of the junction when a reverse bias voltage of 5 V is applied to the diode (*numerical answer with appropriate sign expected*).

5. (30 points) Consider the following MOS structure:



The oxide thickness is  $t_{ox} = 5 \text{ nm} = 5 \times 10^{-7} \text{ cm}$ . To save you time, for this structure:

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

(5a) (5 points) Compute the threshold voltage of the structure (*numerical answer with appropriate sign expected*).

(5b) (5 points) What is the value of  $V_{GB}$  that leads to a sheet charge density in the inversion layer of  $Q_n = -10^{-6} \text{ C/cm}^2$ ? (numerical answer expected).

(5c) (5 points) What is the magnitude of  $E_{ox}$  (electric field across the oxide) for a condition in which  $Q_G = -2 \times 10^{-7} \text{ C/cm}^2$ ? (numerical answer expected).

(5d) (5 points) What is the magnitude of  $E_s = E(x = 0^+)$  (electric field on semiconductor side of oxide-semiconductor interface) at threshold? (numerical answer expected).

(5e) (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  $-2 \times 10^{-7} \text{ C/cm}^2$ ? (numerical answer expected).

**6.** (20 points) Consider a MOSFET made out of the MOS structure of problem 5. The gate length is  $L = 1 \mu\text{m}$ . The gate width is  $W = 10 \mu\text{m}$ . The electron mobility in the channel is  $200 \text{ cm}^2/\text{V} \cdot \text{s}$ .

The MOSFET is biased with  $V_{DS} = 0.1 \text{ V}$ ,  $V_{GS} = 1 \text{ V}$  and  $V_{BS} = 0 \text{ V}$ . If you did not compute the threshold voltage of this structure in section (5a), assume it to be  $0.5 \text{ V}$ .

(6a) (10 points) Compute the magnitude of the inversion layer charge density at the source-end of the channel:  $|Q_n(y = 0)|$  (numerical answer expected).

(6b) (10 points) Compute the magnitude of the electron velocity at the source-end of the channel:  $|v_y(y = 0)|$  (numerical answer expected).