ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SCHOOL OF ENGINEERING (STI)
Institute of Electrical Engineering (IEL)

EE 557 - Semiconductor devices I

Responsible: Prof. Elison Matioli

Final Exam

December 18th, 2024

YOUR NAME____

General Instructions:

1. The exam consists of 4 problems. Please make sure you have all of the pages. Use additional sheets to show your work and the answer to the questions. Be sure to put your name on each additional sheet.
2. All sketches must be adequately labeled.
3. All needed values to solve the exercises are either given or determined from previous exercises in this exam.
4. You will be graded on both your solution (that is, the work shown) and your final answer. It is possible to get the right answer, but not receive full credit if your reasoning is unclear. A few words of explanation are required.
5. Indicate units on all numerical answers.
6. At the end of the exam, there is a page with useful material parameters.

Grade: **Problem 1 (3 points):**

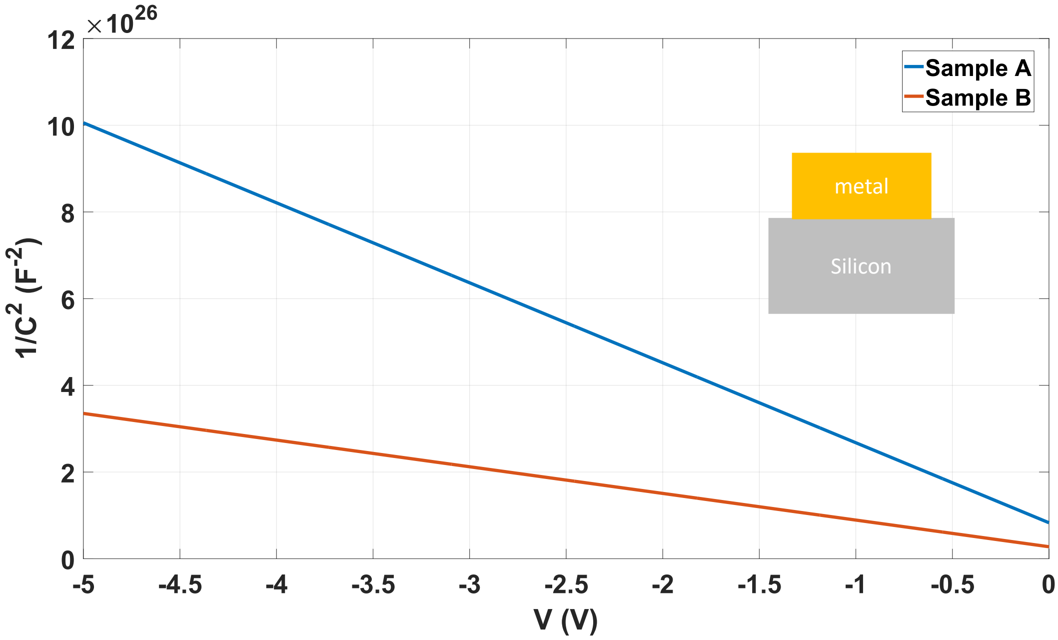
Problem 2 (7 points):

Problem 3 (7 points):

Problem 4 (3 points):

Total grade:

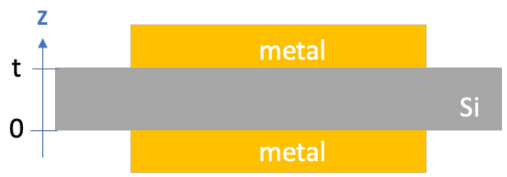
Exercise 1. You found in your lab two Silicon wafers with metallic contacts on top of area 16 × 16 µm². No information was given. You performed a C-V measurement to try to figure out what you had, and the result is shown below.



1. If you had to choose the highest doped wafer, which one would you choose? Is it p-type or n-type? What is the doping concentration of the chosen wafer? **(1 point)**

2. Sketch the $1/C^2$ curves for the case in which the doping type is the opposite than the one found previously, but with the same concentration and same $|\phi_{bi}|$. **(2 point)**

Exercise 2. Another Si wafer was found with metallization on both top and bottom, consisting of a Schottky barrier height of 0.7 eV and $N_D = 10^{16}$ cm^{-3}.



1. Calculate the expected built-in voltage. When you measured the built-in voltage, you find 0.2 V. Explain the possible differences to your calculation. **(1 point)**

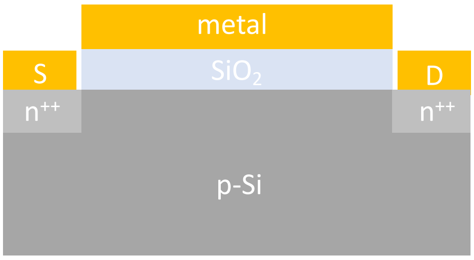
2. Determine the thickness *t* of the wafer? **(2 points)**

3. What is the electron concentration at *t*/2. **(1 point)**

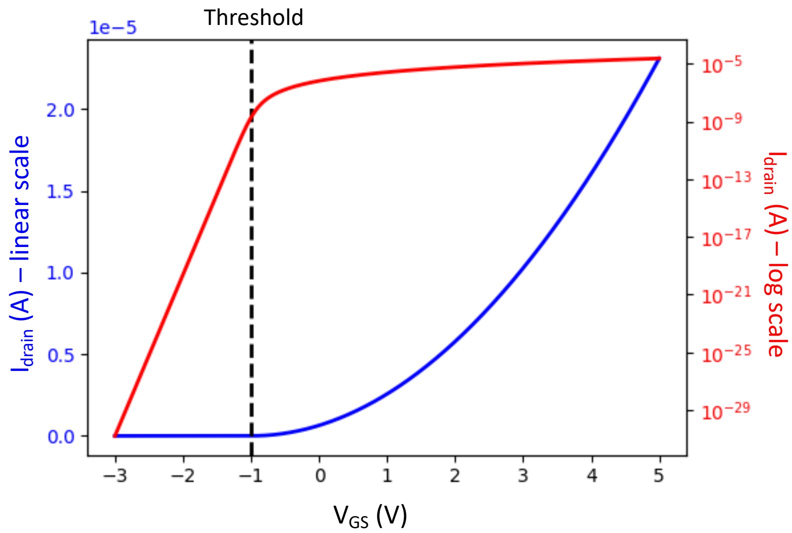
4. Draw the band diagram of this wafer as much in scale as possible, and indicate the distances of the bands in the middle of the wafer (t/2) with respect to the Fermi level. **(1 point).**

5. Calculate the electric field at z = 0, t/2 and t. Plot the electric field across the silicon wafer. **(2 points)**

Exercise 3. A third wafer is found containing only the following information: MOS structure with 10 nm of silicon dioxide on a p-type silicon substrate (N_A = 1×10^{17} cm^{-3}). The gate metal unfortunately is unknown.



1. Using a Source-Measurement-Unit (SMU) you measured the transfer characteristics of the device (shown below). From this measurement, determine the gate metal workfunction. (**2 points**)



2. What is the operating regime of this MOS structure and the extension of the depleted region in thermal equilibrium. **(2 points)**

3. What voltage needs to be applied at the gate to create a **sheet electron density** at the interface of **2.8×10^{12} electrons/cm^2**? (hint: consider the charge per electron and calculate the charge density at the interface?) **(1 point)**

4. What voltage needs to be applied at the gate to create a **sheet hole density** at the interface of **2.8×10^{12} holes/cm^2**? (hint: consider the charge per hole and calculate the charge density at the interface?) **(1 point)**

5. For a voltage equal to the voltage calculated in Q3.2, what will be the current through the gate terminal? **(1 point)**

Exercise 4. Consider the following list of materials and of their properties.

Material	Band Gap (eV)	Critical Electric Field (MV/cm)	Permittivity (εr)	Electron Mobility (cm²/V·s)	Electron Saturation Velocity (×10⁷ cm/s)
Si	1.12	0.3	11.8	1450	1
GaAs	1.43	0.4	12.9	8500	1
InP	1.35	0.5	12.5	5400	1
4H-SiC	3.03	2.5	9.7	900	2
GaN	3.45	3.3	10.4	2260	2.5
AlN	6	15.3	9.8	426	2
Ga_2O_3	4.9	8	10	200	2
Diamond	5.45	13	5.7	2200	2.7

1. Which of these materials is the most ideal for a power device? Quantify and justify your choice **(1.5 points)**.

2. Which of these materials is the most ideal for an RF device? Justify your choice. **(0.5 points)**

3. Suppose that you want to make a p-i-n power device that can withstand voltages up to 1kV. What would be the smallest expected specific on-resistance (in Ω cm^2) of the drift layer that can be obtained for the chosen material? **(1 point)**

Extra Information:

Physics constants:

$q = 1.6\times10^{-19}$ C
$\varepsilon_0 = 8.85\times10^{-14}$ F/cm
$k = 1.38\times10^{-23}$ J/K
$m_e = 9.1\times10^{-31}$ kg

SiO_2 constants:

$\varepsilon^r_{SiO_2} = 3.9$
$\epsilon^{crit}_{SiO_2} = 10\times10^7$ V/cm

Si constants:

$m_e^* = 0.26\ m_e$
$m_h^* = 0.36\ m_e$
$E_g = 1.12$ eV @ RT
$v_{sat\_n} = 1\times10^7$ cm/s
$v_{sat\_p} = 0.7\times10^7$ cm/s
$k_{rad} = 2\times10^{-15}$ cm³/s
$k_{eeh} = 1.8\times10^{-31}$ cm⁶/s
$k_{ehh} = 0.95\times10^{-31}$ cm⁶/s
$c_e = 1\times10^{-11}$ cm³/s
$c_h = c_e$;
$\varepsilon^r_{Si} = 11.68$
$\chi_{Si} = 4.04$ eV