Course:	**Semiconductor Device Fundamentals**
Level:	**Undergraduate**
Module:	**C**
Test:	**C13**
Type:	**Closed Book, Closed Notes**
Note:	**Available Info/Equation Sheets**

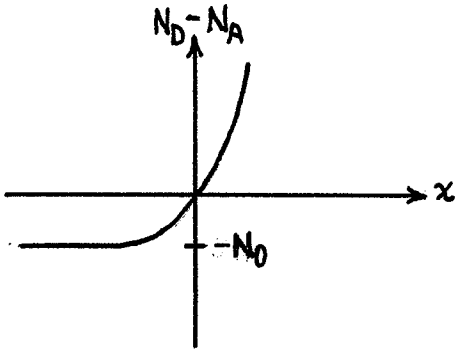
Problem Weighting--- **F-1...12**
F-2...13 (a-4, b-4, c-5)
F-3...15
F-4...27 (a,b-3, c-6, d,e,f-3, g-2,4)
F-5...12
F-6...21 (a-6, b-6, c-3, d-6)

NAME_____ F - 1 _____SCORE

A material crystallizes in the body-centered cubic (bcc) lattice. Paralleling silicon, the density of interfacial traps exhibited by the material in MIS-type devices is found to be proportional to the number of surface atoms. *For the bcc material under discussion*, will the (100) or (110) surface plane exhibit the higher density of interfacial traps? RECORD ALL WORK LEADING TO YOUR ANSWER.

NAME_____ F - 2 _____SCORE

The doping profile inside a PN junction diode is as shown below.

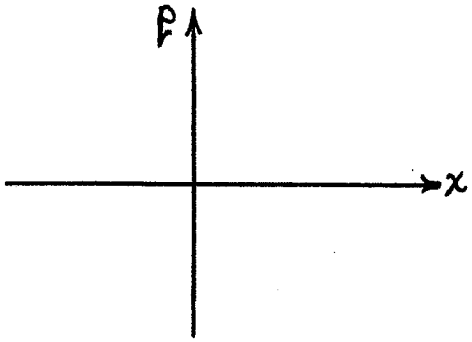


$$N_D - N_A = N_0 (e^{ax} - 1)$$

where N_0 and a are constants

(a) Give a concise statement of the depletion approximation.

(b) Invoking the depletion approximation, make a sketch of the charge density inside the diode.



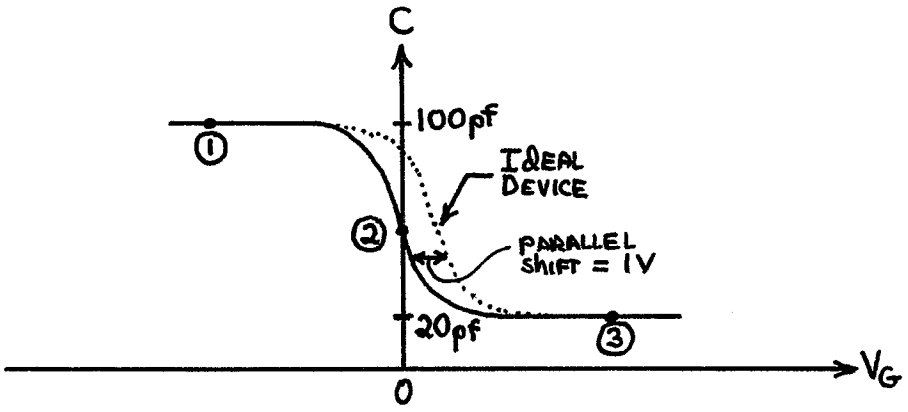
(c) Work out an expression for the electric field, $\mathcal{E}(x)$, inside the depletion region.

NAME_____ F - 3 _____SCORE

Compare (preferably with the aid of sketches) the I-V characteristics derived from an actual Si pn junction diode maintained at room temperature and the theoretical "ideal-diode" characteristic. In effecting your comparison, carefully note and (as necessary) clarify all deviations from the ideal. Finally, **identify the cause** of each deviation from the ideal theory. [NOTE: Devote no more than a sentence or two to the underlying cause of each deviation from the ideal. Do not waste time discussing the causes in detail.]

NAME_____ F - 4 _____SCORE

An MOS-C is ideal except for $\phi_{MS} \neq 0$. The C – V_G curve derived from the MOS-C is shown below along with the ideal-device characteristic.



(a) Is the semiconductor portion of the MOS-C doped n-type or p-type? Indicate how you arrived at your answer.

(b) ϕ_{MS} = ? Explain how you deduced your answer.

(c) Draw the MOS-C energy band diagram corresponding to point ③ on the C – V_G characteristic. Be sure to include the energy bands for all three components of the MOS-C, show the proper band bending in both the oxide and semiconductor, and show the Fermi level position in the metal and semiconductor.

NAME_____ F - 4 (Continued) _____SCORE

(d) Draw the Block Charge diagram corresponding to point (2) on the C – V_G characteristic.

(e) If $K_O = 3.9$ and the area of the MOS-C gate is 3×10^{-3} cm^2, what is the oxide thickness (x_o)?

(f) Determine W_T for the given MOS-C. Show your work.

(g) After fabrication, sodium ions are somehow introduced into the exact middle of the oxide. The sodium ion distribution in the oxide is given by $\rho_{ox} = Q_O \delta(x_o/2)$

where $Q_O/q = 10^{12}/cm^2$ and $\delta(x_o/2)$ is a delta function positioned at $x_o/2$.

(i) Indicate the general effect of the newly introduced sodium ions on the MOS-C C-V_G characteristic. Specifically, sketch in a "sodium-added" curve on the figure at the start of the problem.

(ii) Compute ΔV_G resulting from the newly introduced sodium ions ($K_O = 3.9$, $A_G = 3 \times 10^{-3}$ cm^2).

NAME_____ F-5 _____SCORE

Answer the following "information" questions as concisely as possible.

(a) What is the relationship between the depletion-inversion transition point voltage introduced in the MOS-C discussion and the threshold (or turn-on) voltage introduced in the MOSFET discussion?

(b) What is the observed dependence of the interfacial trap density (D_{IT}) on the silicon surface orientation?

(c) What is (or what is believed to be) the physical origin of the fixed oxide charge in MOS structures?

(d) Why is the mobility of carriers in a surface inversion layer different than the bulk mobility of the same carriers?

(e) Precisely, what is the "channel" in MOSFET terminology?

(f) What is the mathematical definition of the MOSFET (i) drain conductance and (ii) transconductance?

NAME_____ F - 6 _____SCORE

A MOSFET is fabricated with $\phi_{MS} = -0.38V$, $Q_M = 0$, $Q_{IT} = 0$, $Q_F/q = 10^{11}/cm^2$, $Q_I/q = -3X10^{11}/cm^2$, $x_o = 5 \text{ X } 10^{-6}$ cm, $A_G = 10^{-3}$ cm^2, and $N_D = 10^{15}/cm^3$. For computational simplicity use $kT/q = 0.026V$ and $n_i = 10^{10}/cm^3$. Assume the source and substrate are always grounded. NOTE: Q_I is the ion Implanted charge.

(a) Determine the flat band gate voltage, V_{FB}. (Provide both a symbolic and numerical answer.)

(b) Determine the gate voltage at the onset of inversion, V_T.

(Continued)

NAME_____ F - 6 (Continued) _____SCORE

(c) Is the given MOSFET an enhancement mode or depletion mode device. EXPLAIN.

(d) Sketch the inversion layer and depletion region inside the MOSFET **at pinch-off**. Show and label all parts of the transistor.