Course:	**Semiconductor Device Fundamentals**
Level:	**Undergraduate**
Module:	**C**
Test:	**C2**
Type:	**Closed Book, Closed Notes**
Note:	**Available Info/Equation Sheets**

Problem Weighting---
F-1...20 (a-4, b-8, c-4, d-4)
F-2...20 (a-2, b,c,d-5, e-3)
F-3...20 (4 each part)
F-4...14 (2 each part)
F-5...12 (3 each part)
F-6...14 (a-6, b-8)

F – 1

[Outcome–(v)] Score_______/20

The C–V characteristic exhibited by an MOS-C (assumed to be ideal) is displayed below.

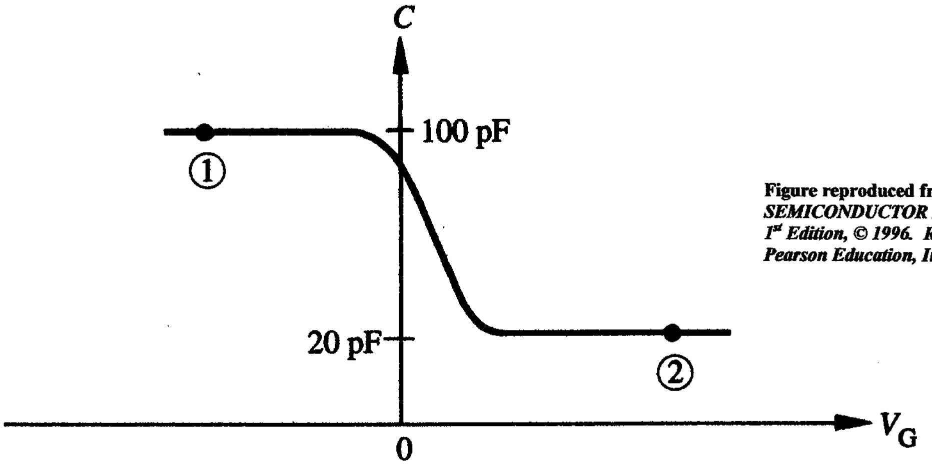


Figure reproduced from *PIERRET, ROBERT F., SEMICONDUCTOR DEVICE FUNDAMENTALS, 1st Edition, © 1996. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.*

(a) Is the semiconductor component of the MOS-C doped *n*-type or *p*-type? Indicate how you arrived at your answer. **(4 Points)**

(b) Draw the MOS-C energy band diagram corresponding to point (2) on the C–V characteristic. (Be sure to include the diagrams for all three components of the MOS-C, show the proper band bending in both the oxide and semiconductor, and properly position the Fermi level in the metal and semiconductor.) **(8 Points)**

(Continued)

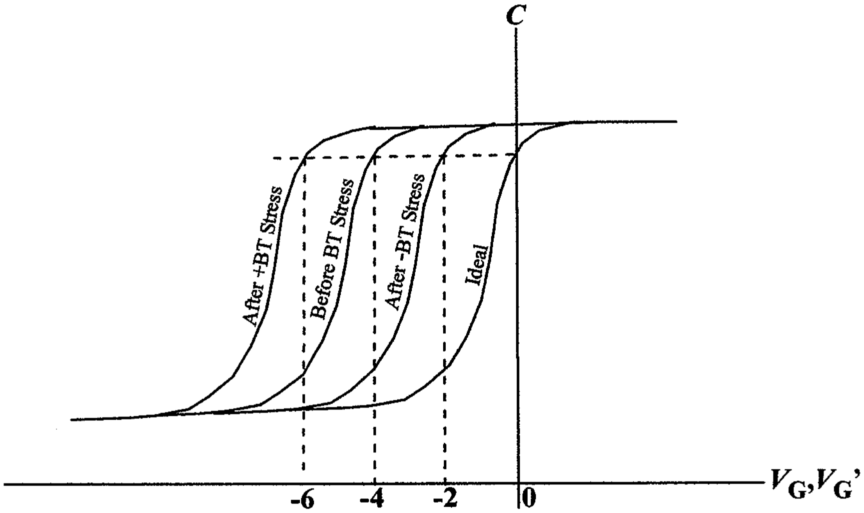
(c) Draw the block charge diagram corresponding to point (1) on the *C–V* characteristic. **(4 Points)**

(d) If the area of the MOS-C is 3 X 10^{-3} cm^2, what is the oxide thickness (x_o)? **(4 Points)**

$\boxed{\text{F}-2}$

[Outcome–(v)] Score______/20

An Al-SiO$_2$-Si MOS-C subjected to Bias-Temperature (BT) stressing yields the after +BT stressing and after –BT stressing C–V_G characteristics pictured below. Also shown on the same plot is the characteristic observed before any BT stressing and the ideal C–V_G' characteristic. The maximum observed capacitance is 100pF, the Si doping is $N_D = 10^{15}/\text{cm}^3$, and the gate area $A_G = 10^{-2}\text{cm}^2$.



(a) $Q_{IT} = 0$, where Q_{IT} is the interface trap charge. How does one come to this conclusion by inspecting the given characteristics? **(2 Points)**

(b) $Q_M = ?$, where Q_M is the total mobile ion charge in the oxide. **(5 Points)**

(Continued)

(c) Recalling $\Phi_M' - \chi' = -0.03$ eV in an Al-SiO2-Si structure, what is the metal-semiconductor workfunction difference (φ_{MS}) in the given MOS-C? **(5 Points)**

(d) Q_F = ?, where Q_F is the fixed charge at the oxide-semiconductor interface. **(5 points)**

(e) Indicate the physical cause of the oxide charges listed below. (Possible causes include Phosphorus ions, Sodium ions, Nitrogen ions, Dangling bonds at the Si surface, Trapped electrons, Ionized Si waiting to be oxidized, Ionized oxygen waiting to form SiO2, and Trapped holes.) **(3 Points)**

Q_{IT}...physical cause is –

Q_M...physical cause is –

Q_F...physical cause is –

F – 3

[Outcome–(v)] Score______/20

(a) A MOSFET exhibits I_D–V_D characteristics with values of 1V, 2V, and 3V for V_{Dsat} and values of 1A, 4A, and 9A for I_{Dsat} when V_G–V_T is respectively equal to 1V, 2V, and 3V. Are the V_{Dsat} and I_{Dsat} values consistent with the Square Law theory? Explain. **(4 Points)**

(b) What is going on physically inside the MOSFET when $V_D = V_{Dsat}$? **(4 Points)**

(c) Based on the Square Law theory and assuming an *n*-channel device, what is the charge/cm^2 in the channel [$Q_N(y)$] at the source when $V_D = V_{Dsat}$? Indicate how you arrived at your answer. **(4 Points)**

(d) The MOSFET Bulk-Charge theory corrects what deficiency in the MOSFET Square Law theory? **(4 Points)**

(e) A *p*-channel MOSFET will exhibit a smaller drain current than a similarly biased *n*-channel MOSFET with identical substrate doping and channel dimensions. Explain why. **(4 points)**

$\boxed{\text{F – 4}}$

[Outcome–(vi)]

Score______/14

Given a *pnp* BJT where $I_{Ep} = 1$ mA, $I_{En} = 0.01$ mA, $I_{Cp} = 0.98$ mA, and $I_{Cn} = 0.1$ μA, calculate: **(each part 2 points)**

(a) α_T

(b) γ

(c) I_E, I_C, I_B

(d) α_{dc} and β_{dc}

(Continued)

(e) I_{CB0} and I_{CE0}

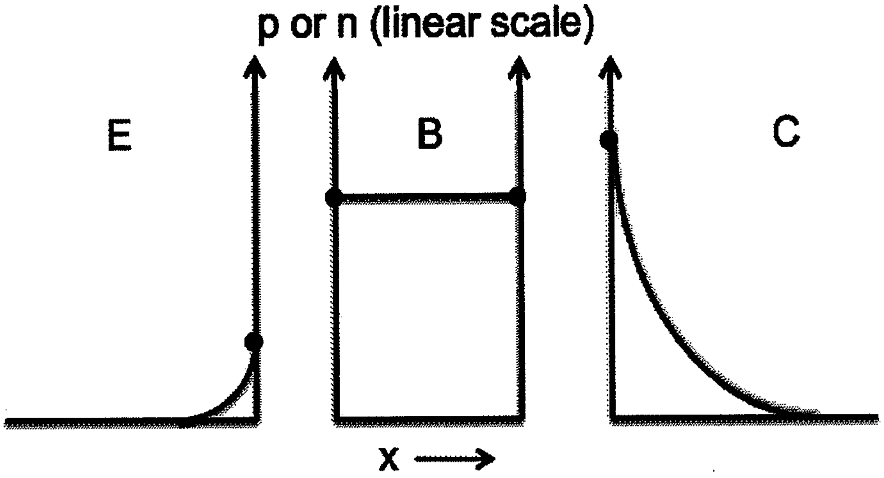
(f) I_{Cp} is increased to a value closer to 1 mA while all other components remain fixed. What effect does the I_{Cp} increase have on β_{dc}? Explain.

(g) I_{En} is increased while all other current components remain fixed. What effect does the I_{En} increase have on β_{dc}? Explain.

F – 5

[Outcome–(vi)] Score_______/12

The figure below is a schematic diagram of the minority profile for a biased ideal Si *pnp* BJT. Based on this diagram, circle the correct or best answer for the following questions: (each answer worth **3 points.)**



(a) The transistor is biased in which of the following modes.

i. forward active
ii. inverted active
iii, saturation
iv. cutoff
v. none of the above

(b) The transistor is doped such that:

i. $N_C > N_B > N_E$
ii. $N_C < N_B < N_E$
iii. $N_C = N_B = N_E$
iv. Cannot tell from the figure

(c) The thickness of the base, W, is such that:

i. $W \ll L_P$
ii. $W = L_P$
iii. $W > L_P$
iv. Cannot tell from the figure

(d) For this bias condition:

i. $I_{Ep} > I_{En}$
ii. $I_{Ep} = 0$
iii. $|I_{Cn}| < |I_{Cp}|$
iv. Cannot tell from the figure

F – 6

[Outcome–(vi)]

Score______/14

Given an ideal Si *pnp* BJT biased in the forward active mode. The β_{dc} of this transistor was measured to be 200. Furthermore, $D_E = D_B$, $L_E = L_E = 20W$, where W is the width of the quasi-neutral region in the base, and $I_{Cp} = I_{Ep}$. You may neglect the $(W/L_B)^2$ term in the equation for β_{dc} in the crib sheets.

(a) Is there recombination occurring in the base region, yes or no? Explain you answer. **(6 points)**

(b) What is the numerical value of the ratio of N_E/N_B. **(8 points)**