Course:	**Semiconductor Device Fundamentals**
Level:	**Undergraduate**
Module:	**C**
Test:	**C9**
Type:	***Open* Book, *Open* Notes**

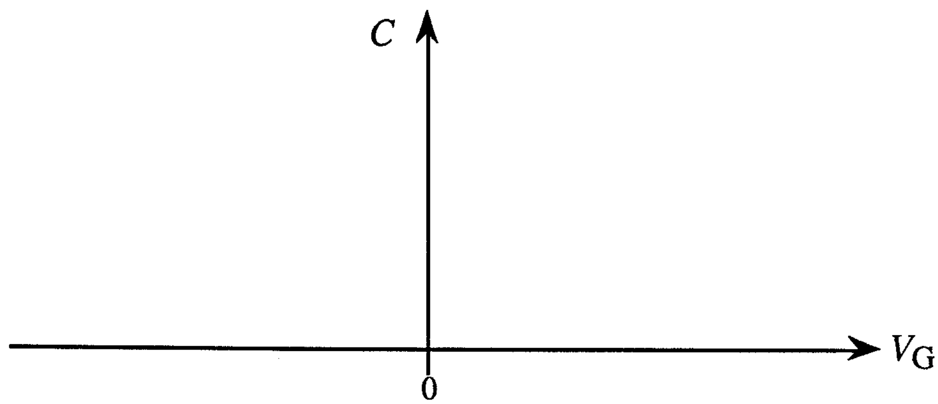
Problem Weighting is noted adjacent to each problem.

(There is the option of answering Problem 11A or 11B. Problem 11B will be graded only if 11A contains no answers.)

I. MOS Fundamentals

Answer Questions (1)–(7) assuming an ideal MOS-C, $T = 300\text{K}$, $x_o = 0.1\mu\text{m}$, $N_D = 2 \times 10^{15}/\text{cm}^3$, and $A_G = 10^{-3}\text{cm}^2$.

[4] **(1)** Sketch the general shape of the high-frequency C–V characteristic to be expected from the given device.



[4] **(2)** Defining C_{MAX} to be the maximum high-frequency capacitance, determine C_{MAX}.

[6] **(3)** Defining C_{MIN} to be the minimum high-frequency capacitance, determine C_{MIN}.

[4] **(4)** If $V_G = V_T$, determine ϕ_S. (Give both a symbolic and a numerical answer.)

[6] **(5)** Compute V_T.

[8] **(6)** Suppose the gate bias is such that $\phi_S = \phi_F$.

(a) Draw the MOS-C energy band diagram corresponding to the specified gate bias. (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.)

(b) Draw the block charge diagram corresponding to the specified gate bias.

[4] **(7)** The C–V characteristic of the device is measured as the d.c. bias is rapidly swept from accumulation into inversion. Using a dashed line, sketch the expected form of the resulting C-V characteristic on the same set of coordinates as the Question (1) answer.

II. FETs

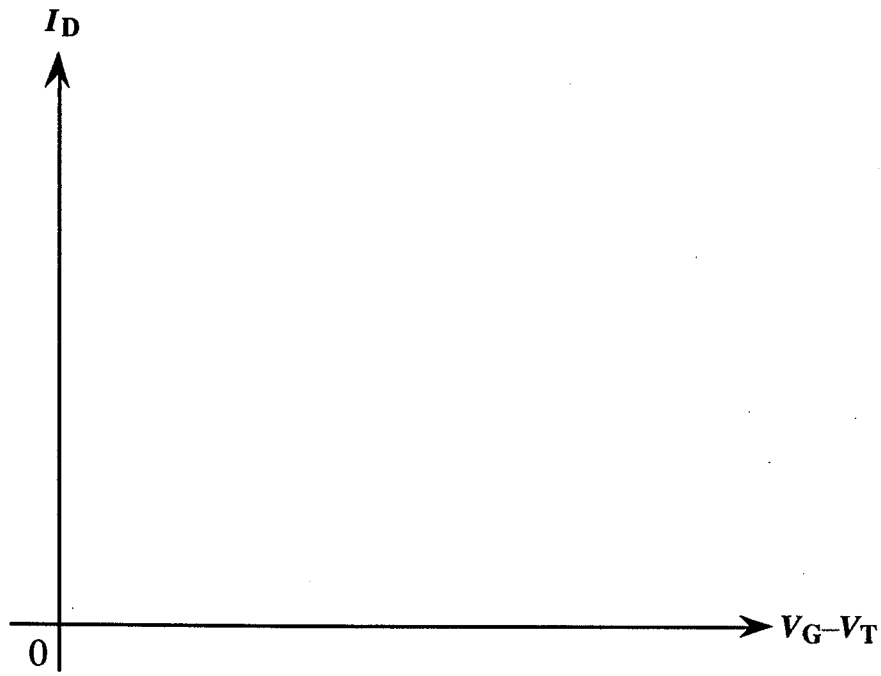
[8] **(8)** A *p*-channel MOSFET is biased into the saturation region of operation. Carefully sketch the inversion layer and depletion region inside the MOSFET. Be sure to label all parts of the transistor.

[8] **(9)** Biases $V_G = 3V$ and $V_D = 0$ are applied to an ideal *n*-channel MOSFET with $Z = 70\mu m$, $L = 7\mu m$, $\bar{\mu}_n = 550\ cm^2/V\text{-}sec$, $x_o = 0.05\mu m$, and $V_T = 1V$. Making use of the *Square-Law* theory:

(a) Determine the inversion layer charge/cm^2 at the midpoint ($y = L/2$) of the channel.

(b) Determine the drain conductance (g_d) at the specified bias point.

[8] **(10)** It is standard practice to plot I_D versus V_D with V_G or $V_G–V_T$ held constant at selected values. Suppose instead one plots I_D vs. $V_G–V_T$ with V_D held constant at selected values. Sketch the expected shape of an I_D vs. $V_G–V_T$ plot for an <u>n-channel</u> MOSFET where say one sets V_D = 1, 2, 3, 4, and 5 volts. Explain how you arrived at your sketch. (NOTE: The <u>above</u> threshold characteristics are desired here.)



Answer EITHER 11A or 11B. 11B will not be graded if 11A contains answers.

[8] **(11A)** Relative to Modern FET structures...

(a) In your own words, and concisely as possible, qualitatively explain why the magnitude of the threshold voltage in a small-dimension MOSFET increases with decreasing channel width.

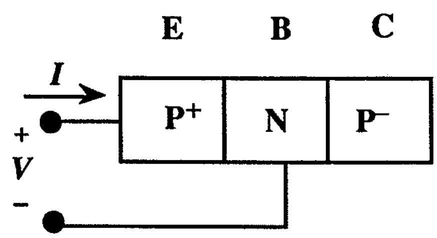
(b) What is the physical difference between a MODFET and a MOSFET?

III. BJTs

The following question will be graded only if 11A contains no answers.

[8] **(11B)** For an NPN transistor, sketch the energy band, charge density, electric field, and potential diagrams as a function of position throughout the device for the case of active mode biasing.

[12] **(12)** A PNP transistor is connected as shown below with the collector floating. I and V are as defined in the figure. Assuming V is negative and more than $10kT/q$ in magnitude...

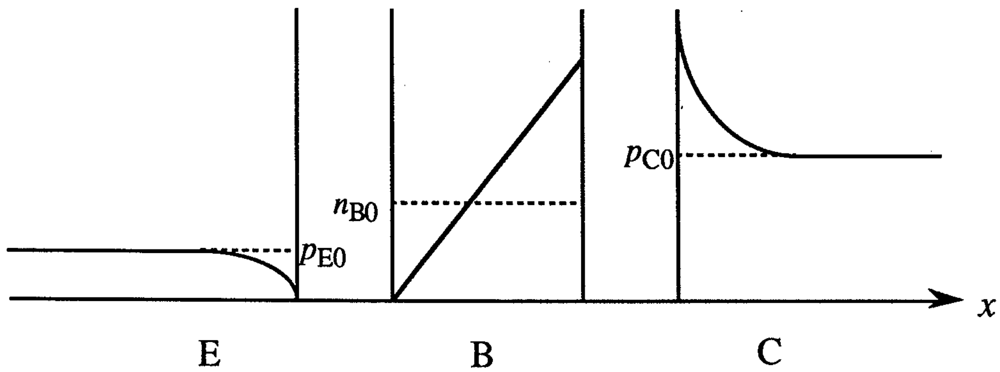


(a) Establish an expression for I using the Ebers-Moll equations.

(b) Develop an expression for V_{CB} in terms of relevant Eber-Moll parameters.

(c) Sketch the minority carrier distribution in the base for the specified condition. Explain how your arrived at your sketch.

[12] **(13)** Given the minority carrier distribution for a BJT sketched below, answer the questions that follow.



(a) What type of device is it? Circle one→ PNP NPN

(b) What is the bias condition? Active Cutoff Saturation Inverted Active

(c) V_{EB} is (circle one) > 0 < 0 $= 0$

(d) V_{CE} is (circle one) > 0 < 0 $= 0$

[4] **(14)** Recombination in the quasi-neutral base increases the total base current and therefore decreases the current gain of a BJT. Circle one→ True False

[4] **(15)** Concisely stated, why does one typically dope the emitter of a standard BJT heavily?