Info and Equation Sheets Are Allowed:

Attempt All Questions:

Question 1:

a) A pn junction diode has the doping profile sketched in Figure 1. Mathematically \( N_D - N_A = N_0(e^{\alpha x} - 1)\), where \( N_0 \) and \( \alpha \) are constants.

I. Give a concise statement of the depletion approximation.

II. Invoking the depletion approximation, sketch the charge density inside the diode.

III. Establish an expression for the electric field \( E(x) \) inside the depletion region.

b) Figure 2 is a dimensioned plot of the steady state carrier concentrations inside a step pn junction diode maintained at room temperature.

I. Is the diode forward or reverse biased? Do low level injection conditions prevail in the quasineutral regions of the diode? Explain how you arrived at your answer.

II. What are the p-side and n-side doping concentrations?

III. Determine the diode current \( I \) and applied voltage \( V_A \) assuming \( I_0 = 100nA \).

Question 2:

a) The doping profile inside the semiconductor component of an MS diode is linearly graded; i.e., \( N_D(x) = ax \).

I. Derive solution for \( \rho(x), \ E(x), \ V(x) \), and \( W \) inside the semiconductor.

II. Indicate how \( V_{bi} \) is to be determined and computed.

III. Establish an expression for the junction depletion region capacitance.

b) The electron and hole currents inside a pnp BJT biased in the active mode are plotted in Figure 3. All the currents are referenced to \( I_1 \), the hole current injected into the base. Determine:

I. The emitter efficiency \( (\gamma) \), the base transport factor \( (\alpha_I) \), the common emitter d.c. current gain \( (\beta_{dc}) \).

II. The base current \( (I_B) \).
III. Derive the \( I-V_A \) relationship for the above transistor connected in the configurations shown in Figure 4 by appropriately using the Ebers-Moll model. The current \( I \) should be expressed only in terms of \( V_A \) and the Ebers-Moll parameters.

IV. Develop expressions for \( \Delta p_B(0)/\Delta p_{B0} \) and \( \Delta p_B(W)/\Delta p_{B0} \) in terms of \( V_A \) and the Ebers-Moll parameters.

Question 3: (15 marks)

a) The energy band diagram for an ideal \( x_o = 0.2 \mu \text{m} \) MOS-C operated at \( T = 300 \degree \text{K} \) is sketched in Figure 5. Note that the applied gate voltage causes band bending in the semiconductor such that \( E_F = E_i \) at the Si-SiO\(_2\) interface. Invoke the delta-depletion approximation as required in answering the questions that follow.

I. Sketch \( \rho, E, V \) inside the semiconductor as a function of position.

II. What is the electron concentration at the Si-SiO\(_2\) interface?

III. Calculate \( N_D, \phi_s, V_G \), and the voltage drop (\( \Delta \phi_{ox} \)) across the oxide at the pictured bias point.

IV. What is the normalized small-signal capacitance, \( C/C_o \), of the MOS-C at the pictured bias point?

b) Suppose a battery \( V_B \geq 0 \) is connected between the gate and drain of an ideal n-channel MOSFET as pictured in Figure 6. Using the square law results,

I. Sketch \( I_D \) versus \( V_D \) \((V_D \geq 0)\) for \( V_B = V_I/2, 2V_I \);

II. Sketch \( I_D \) versus \( V_B \) \((0 \geq V_B \geq 5V)\) for \( V_D=0, 5V \).

Good Luck

Examiner: Dr. Mohammed Morsy