BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

K.K BIRLA GOA CAMPUS

FIRST SEMESTER (2022-23) Comprehensive Examinations

Physics and Modeling of Microelectronic Devices (MEL G631)

Date: 27-12-2022 Time : 180 min Maximum Marks: 70 (35%) Closed Book

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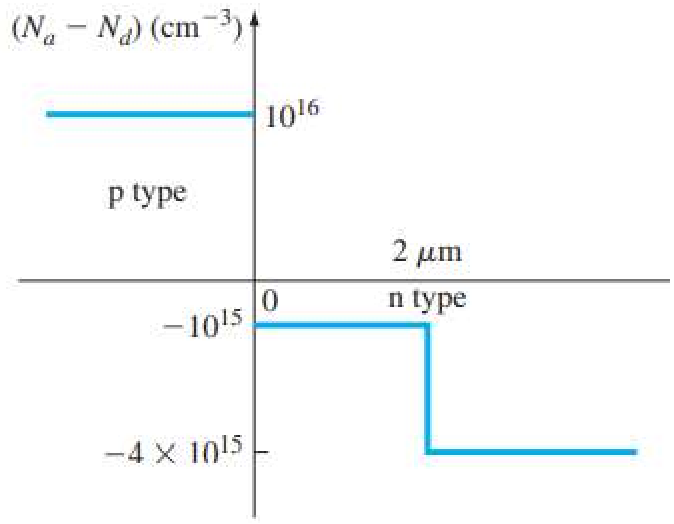
Instructions: **(i) Answer All questions.**

(ii) Any required data not explicitly given, may be suitably assumed and stated.

(iii) All answers and figures should be written using PEN only.

(iv) Enclose the final answer in a box.

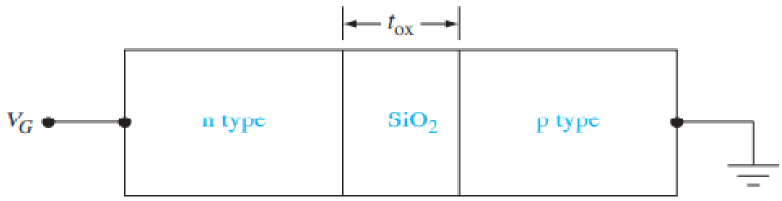
Q1. Consider the impurity doping profile shown in Figure in a silicon pn junction. For zero applied voltage, (a) Determine V_0, (b) Calculate x_n and x_p, (c) Sketch the thermal equilibrium energy-band diagram, and (d) Plot the electric field versus distance through the junction. **[7]**



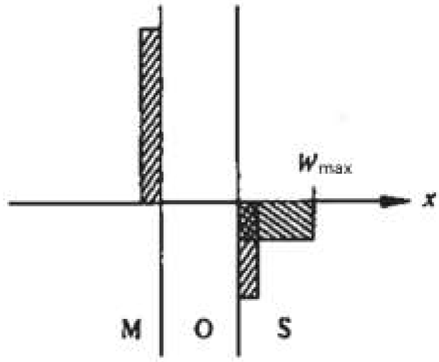
Q2. A germanium P^+N junction diode has the following parameters: $N_a = 10^{18}$ cm^{-3} , $N_d = 10^{16}$ cm^{-3} , $D_p = 49$ cm^2 /s, $D_n = 90$ cm^2 /s, $\tau_{p0} = \tau_{n0} = 5\mu s$, and $A = 10^{-4}$ cm^2. Determine the diode current for (a) a forward-bias voltage of 0.25 V and (b) a reverse-bias voltage of 4.5 V. **[7]**

Q3. A Schottky diode and a pn junction diode have cross sectional areas of $A = 5\times10^{4}$ cm^2. The reverse saturation current density of the Schottky diode is 3×10^{-8} A/cm^2 and the reverse saturation current density of the pn junction diode is 3×10^{-12} A/cm^2 at T=300K. Determine the forward bias voltage in each diode required to yield a current of 2 mA. Comment on the results. **[7]**

Q4. Consider an SOS capacitor as shown in Figure. Assume the SiO_2 is ideal (no trapped charge) and has a thickness of $t_{ox} = 500\times10^{-8}$ cm. The doping concentrations are $N_d = 10^{16}$ cm^{-3} and $N_a = 10^{16}$ cm^{-3} . (a) Sketch the energy-band diagram through the device for (i) flat band, (ii) $V_G = 3$ V, and (iii) $V_G = -3$ V. (b) Calculate the flat-band voltage. (c) Estimate the voltage across the oxide for (i) $V_G = 3$ V and (ii) $V_G = -3$ V. (d) Sketch the high-frequency C–V characteristic curve. **[7]**

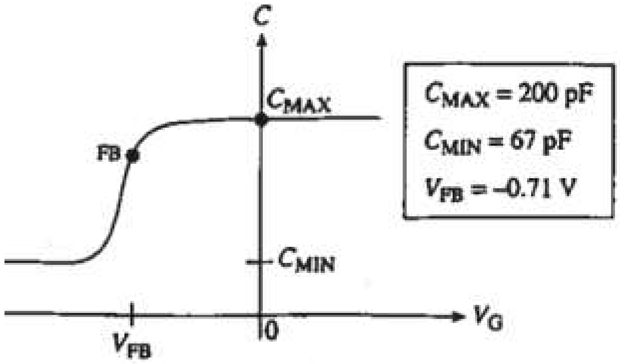


Q5 The fig shows the charge state of an ideal MOS-capacitor.



(a) Is the semiconductor n- or p- type? Explain.
(b) Is the device accumulation, depletion, or inversion biased? Explain.
(c) Draw the energy band diagram corresponding to the charge state shown in the Fig.
(d) Sketch the general shape of the high-frequency C—V characteristics to be expected from the structure.
(e) Suppose the MOS system is biased such that it is totally depleted then draw the diagram describing the new charge state of the system **[7]**

Q6. The C—V characteristic of an Al-SiO_2-Si MOS capacitor maintained at T = 300 K is shown in Fig. Area of the gate is 2.9×10^{-3} cm^2.



(a) Suppose the MOS structure is an ideal one, then sketch the C-V curve one would expect from an ideal version of the given MOS-C. Also indicate the flat-band point on the ideal-device characteristics and explain.
(b) Determine the Oxide thickness, doping concentration on the substrate, and fixed charge/cm2 in the given device as per the C-V curve shown in the fig. **[7]**

Q7. The parameters of a p-channel Si MOSFET are μ_p= 310 cm^2/V-s, $t_{ox}(SiO_2)$= 220×10^{-8} cm, W/L = 60 and V_T= - 0.40 V. If the transistor is biased in saturation region, find the drain current for V_{SG}= 1, 1.5 and 2V. Now the transistor is to be redesigned by changing the W/L ratio such that I_D=200 μA when the transistor is biased in the saturation with V_{SG}= 1.25 V. **[7]**

Q8. Consider a Si n-channel MOSFET at T=300K with a substrate doping N_a= 3×10^{16} cm^{-3} and silicon dioxide thickness = 500×10^{-8} cm. Calculate the change in threshold voltage if the substrate is biased such that V_{SB}= 1.6 V. **[7]**

Q9. (a) Calculate the base transport factor, B, for x_B/L_B = 0.01, 0.10, 1.0, and 10. Assuming that γ is unity, determine β for each case. (b) Calculate the emitter injection efficiency, γ, for N_B/N_E =0.01, 0.10, 1.0, and 10. Assuming that B is unity, determine β for each case. **[7]**

Q10. Consider a npn silicon bipolar transistor at T=300K with the following parameters:

D_B= 25 cm^2/s D_E= 10 cm^2/s
τ_{B0}= 10^{-7} s τ_{E0}= 5×10^{-8} s
N_B= 10^{16} cm^{-3} x_E= 0.5 μm

Determine the maximum base width x_B to get a common emitter current gain of β=120. **[7]**

List of constants: n_i (Ge) = 2.4×10^{13} cm^{-3} , ϕ_m(Al)=4.28 eV
k= 8.62×10^{-5} eV/K At T=300K kT=0.0259 eV q= 1.6×10^{-19} C n_i (Si) = 1.5×10^{10} cm^{-3}
ε_o=8.854×10^{-14} F/cm ε (Si) = 11.8 ε_o μ_p (Si) = 480 cm^2/V-s N_c(Si)= 2.8×10^{19} cm^{-3}
μ_n (Si) = 1350 cm^2/V-s $\varepsilon(SiO_2)$ = 3.9 ε_o E_g(Si) = 1.1 eV χ(Si)= 4.01 eV N_V(Si) = 1.04×10^{19} cm^{-3}

$$I_{E_P} = qA\frac{D_p}{L_p}\left(\Delta p_E \,ctnh\frac{W_p}{L_p} - \Delta p_C \operatorname{csch}\frac{W_p}{L_p}\right)$$

$$Ic = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{csch}\frac{W_p}{L_p} - \Delta p_C \,ctnh\frac{W_p}{L_p}\right)$$

$$I_B = I_E - I_C = qA\frac{D_p}{L_p}\left((\Delta p_E + \Delta p_C)\tanh\frac{W_p}{2L_p}\right)$$

$$\operatorname{sech} y = 1 - \frac{y^2}{2} + \frac{5y^4}{24} - \dots$$

$$\operatorname{ctnh} y = \frac{1}{y} + \frac{y}{3} - \frac{y^3}{45} + \dots$$

$$\operatorname{csch} y = \frac{1}{y} - \frac{y}{6} + \frac{7y^3}{360} - \dots$$

$$\tanh y = y - \frac{y^3}{3} + \dots$$