The LNM Institute of Information Technology, Jaipur

Department of Electronics and Communication Engineering

Modeling and Simulation of MOS Transistor (ECE4181)

Mid Term

Time: 90 Minutes **Date:** 25/09/2019 **Maximum Marks:** 30

Instructions: There are total 5 Questions. All the Questions are Compulsory.

Q.1: (a) In a MOS capacitor with an oxide layer thickness of 10 nm, the maximum depletion layer thickness is 100 nm. The permittivities of the semiconductor and the oxide layer are ε_s *and* ε_{ox} respectively. Assuming $\varepsilon_s / \varepsilon_{ox} = 3$, Find the ratio of the maximum capacitance of the minimum capacitance of this MOS capacitor. [4]

(b) What is Fermi Potential? Explain Fermi potential of P type Silicon and N type silicon. [2]

Q.2: (a) A voltage V_G is applied across the MOS capacitor with metal Gate and p – type silicon substrate at $T = 300\ K$. The inversion carrier density (in number of units per unit area) for $V_G = 0.8V$ *is* $2 \times 10^{11} cm^{-2}$ and *for* $V_G = 1.3V$, the inversion carrier density is $4 \times 10^{11}\ cm^{-2}$. [4]

What is value of inversion carrier density of $V_G = 1.8V$.

(b) Explain the effect of gate-body voltage on surface conditions of a MOS Capacitor [2]

Q.3: (a) Calculate the flatband voltage for a p-type body with $N_a = 3x10^{18}\ cm^{-3}$. A SiO_2 insulator with a thickness = 2 nm, and an n-type polysilicon gate with $N_d = 10^{20}\ cm^{-3}$. The interface charge Q' is 10^{-8} C⁄cm^2. Estimate the threshold voltage V_{T0} assuming at the onset of strong inversion, Surface potential $\Psi s = 2\phi_F$. [4]

(Given: ϕ_{ms}= -1.036 V, Temperature=300K, Body coefficient γ=0.337, Intrinsic carrier concentration $n_i=10^{10}\ cm^{-3}$)

(b) Derive the expression for carrier concentration at the surface of a MOS capacitor [2]

Q.4: (a) Briefly explain small signal capacitance in the two terminal MOS structure. Draw suitable diagrams and explain the capacitance value in each region of operation [4]

(b) Draw and explain (i) and (ii) for all regions of operation when Flat band voltage is zero. [2]

i. Surface potential vs Gate voltage
ii. Channel charge vs Gate voltage

Q.5: (a) Neatly draw and explain the energy band diagram for the following in a MOS Capacitor (Assume ϕ_{ms} =0 and oxide interface charge=0) [4]

i. Flat Band condition
ii. Accumulation
iii. Depletion
iv. Inversion

(b) Write the summary of what you learnt in this Course and how it is useful for your future perspective. [2]

MASMT Mid Term, [25/09/19]

Q) 1: Ans: Maximum Capacitance $C_{max} = C_{ox}$ = Oxide Capacitance → 1 mark

Minimum Capacitance $C_{min} = \dfrac{C_{ox} \cdot C_{depletion}}{C_{ox} + C_{depletion}}$ → [1 mark]

C_{ox} and $C_{depletion}$ are capacitance per unit area.

$$\frac{C_{max}}{C_{min}} = \frac{C_{ox}}{\dfrac{C_{ox} \cdot C_{dep}}{C_{ox} + C_{dep}}} = \frac{C_{ox} + C_{dep}}{C_{dep}}$$

$$= 1 + \frac{C_{ox}}{C_{dep}} = 1 + \frac{\varepsilon_{ox}/t_{ox}}{\varepsilon_s/d}$$

$$= 1 + \frac{\varepsilon_{ox}}{\varepsilon_r} \cdot \frac{d}{t_{ox}} = 1 + \frac{1}{3} \times \frac{100}{10} = 4.33$$ — (2 marks)

Q) 1: b: Refer class Note definition [1 mark]
p type & n type [0.5 + 0.5]

Q) 2: a) Ans:

For $V_G = 0.8\,V$, inversion carrier density $= 2 \times 10^{11}\ cm^{-2}$.

For $V_G = 1.3\,V$, Inversion layer Carrier density $= 4 \times 10^{11}\ cm^{-2}$.

For MOS Capacitor

Charge $Q \propto (V_G - V_T)$

$Q_1 = k\,(V_G - V_T)$. — 1 mark

$Q_1 = qA \times$ inversion carrier density.

$$\frac{2 \times 10^{11} \cdot qA}{4 \times 10^{11}\ qA} = \frac{0.8 - V_T}{1.3 - V_T}$$ — 1 mark

$V_T = 0.3\,V$.

For $V_G = 1.8\,V$

$$\frac{\varphi_i \; q . A}{2 \times 10^{11} \; q . A} = \frac{1.8 - 0.3}{0.8 - 0.3}$$

$\varphi_i = 6 \times 10^{11} / cm^2$. ——— [2 marks]

Q) 2: b: For details refer class note.

Flat Band
Accumulation
Depletion
Inversion

Eq^s
diagrams
Explanations

[2 marks]

Q) 3: a: $\phi_F = \frac{KT}{q} \ln\left(\frac{N_A}{n_i}\right) = 0.508$ ——[1 mark]

$2\phi_F = 1.02\,V$

$\phi_{ms} = -1.036\,V$.

$$V_{FB} = -1.036 - \frac{Q_0'}{C_{ox}'}$$

$= -1.036 - 0.006\,V = -1.042\,V$ —[1 mark

$V_{T0} = -1.042\,V + 1.02 + 0.332\sqrt{1.02}\,V$

$= 0.318\,V$

[2 mark].

$$\frac{n_{surface}}{n_0} = e^{\psi_s/\phi_t}$$ —[2 marks]

$$\phi_F = \phi_t \ln \frac{N_A}{n_i}$$

$$n_{surface} = N_A \, e^{(\psi_s - 2\phi_F)/\phi_t}$$

For details, verify class Note.

4) a: Diagram
Expression } 2 marks
Explanation for all region — 2 marks.

(b): Diagram and explanation — 1 mark
" " → 1 mark.

5) a: Diagram and explanation for each region – 1 mark

b: Discussed in class.