



Name :

Roll No. :

Invigilator's Signature :

**CS/M.Tech(ECE)VLSI/SEM-1/MVM-104-A/2009-10
2009**

SEMICONDUCTOR DEVICES : PHYSICS & MODELLING

Time Allotted : 3 Hours

Full Marks : 70

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Grading :

The reader can only assess what you put down on the exam paper. Please be concise with your answers. For answers requiring explanation, adding sketches can be very effective. To obtain full credit, show correct units and algebraic sign.

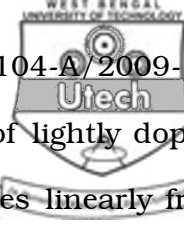
Answer Question No. 1 and any *four* from the rest. $5 \times 14 = 70$

1. Answer *all* questions : 7×2

- a) What is the Gate Oxide Breakdown in sub-micron MOSFET ?
- b) How does the Ballistic Transport effect the device performance ?
- c) Define in detail the Trap-assisted recombination / generation process with necessary diagram.



- d) How do Sub-threshold currents degrade the device performance ?
- e) Explain the Miller indices of a crystal with proper diagram.
- f) What is the Fermi level pinning ?
- g) "Fixed oxide charges are defects in oxide layer of the MOS structure." Explain why.
2. i) An electric field has a non-zero value at plane X1 (perpendicular to the x -axis) inside a silicon crystal. At X1, the electron density is non-uniform in the x direction. We observe that no-current flows across the plane.
- a) Explain with diagram why no current is flowing.
- b) If the electric field is -10^3 volt cm^{-1} , what is the electron gradient perpendicular to the plane ?
- 3 + 3
- ii) A silicon wafer has a 2-inch diameter and contains 10^{14} cm^{-3} electrons with a mobility of $1400 \text{ cm}^2/\text{V}/\text{sec}$. How thick should the wafer be so that the resistance between the front and back surfaces equals 0.1Ω ?
- 4



- iii) The electron concentration in a piece of lightly doped, n -type silicon at room temperature varies linearly from 10^{17} cm^{-3} at $x = 0$ to $6 \times 10^{16} \text{ cm}^{-3}$ at $x = 2 \text{ } \mu\text{m}$. Electrons are supplied to keep this concentration constant with time. Calculate the electron current density in the silicon if no electric field is present. Assume electron mobility $\mu_n = 1000 \text{ cm}^2/\text{V-s}$ and $T = 300 \text{ K}$.

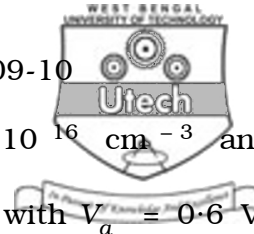
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3. i) Calculate :

- the depletion width
- maximum E-field and
- Depletion capacitance at zero bias for a $p^+ - n$ abrupt junction.

Here, Acceptor concentration $N_a = 10^{25} / \text{m}^3$, Donor concentration $N_d = 10^{22} / \text{m}^3$, Intrinsic carrier concentration $n_i = 1.5 \times 10^{16} / \text{m}^3$, Relative permittivity of silicon $\epsilon_s = 12$, Junction area $A = 4 \times 10^{-7} \text{ m}^2$.

2 + 2 + 2



- ii) An abrupt silicon p - n junction ($N_a = 10^{16} \text{ cm}^{-3}$ and $N_d = 4 \times 10^{16} \text{ cm}^{-3}$) is biased with $V_a = 0.6 \text{ V}$.

Calculate the ideal diode current assuming that the n -type region is much smaller than the diffusion length with $w_n' = 1 \text{ mm}$ and assuming a "long" p -type region.

Use $\mu_{\text{Error!}}$ = 1000 cm **Error!**/V-s and $\mu_{\text{Error!}}$ = 300 cm² /V-s. The minority carrier lifetime is 10^{-2} s and the diode area is $100 \times 100 \text{ mm}^2$. 4

- iii) A student has to study the I-V characteristics of a P-N junction diode using AC voltage source. What kind of a circuit arrangement should he/she use for this purpose ? Determine the current through resistance "R" in each circuit. Diodes D1 and D2 are identical and ideal. 2 + 2

Dia.



4. a) Consider a chrome-silicon metal-semiconductor junction with $N_d = 10^{17} \text{ cm}^{-3}$. Calculate the depletion layer width, the electric field in the silicon at the metal-semiconductor interface, the potential across the semiconductor and the capacitance per unit area for an applied voltage of -5 V .

Here, metal work function $\Phi_m = 4.5 \text{ eV}$, electron affinity $\chi = 4.03 \text{ eV}$. 2 + 2 + 2 + 2

- b) What is a flatband diagram? Explain with proper sketch.

Define the barrier height of a metal-semiconductor junction. Can the barrier height be negative? Explain.

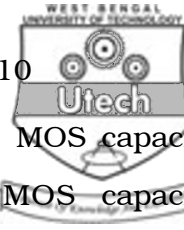
3 + 3

5. a) A silicon $n\text{MOS}$ capacitor with a substrate doping $N_a = 10^{17} \text{ cm}^{-3}$, a 20 nm thick oxide ($\epsilon_{ox} = 3.9 \epsilon_0$), $\epsilon_s = 12 \epsilon_0$ ($\epsilon_0 = 8.85 \times 10^{-14} \text{ F/cm}$) and an aluminium gate ($\Phi_M = 4.1 \text{ V}$). Assume there is no fixed charge in the oxide or at the oxide-silicon interface.

Calculate :

- i) flat band voltage
- ii) threshold voltage
- iii) oxide capacitance and
- iv) high frequency capacitance in inversion.

3 + 3 + 1 + 3



- b) "The high frequency capacitance of the MOS capacitor is constant in inversion mode of MOS capacitor analysis." Explain. 4

6. a) Using the quadratic model derive the expression of the drain current for saturation region of MOSFET output I-V characteristics. 4

- b) Calculate the drain current of an n MOS FET in saturation region for gate to source voltage $V_{GS} = 0V, 1V, 2V$ with device parameters as $W = 5$ micron, $L = 1$ micron, $V_{DS} = 0.1V$, $V_{th} = 1V$ and

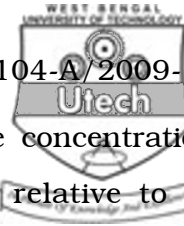
$$\mu_n C_{ox} = 25 \mu A/V^2. \quad 1 + 1 + 4$$

- c) Using the same device parameters, obtain the transconductance in linear and saturation region with $V_{DS} = 0.1V$ and $4V$. 2 + 2

7. Calculate the maximum fraction of the volume in a simple cubic crystal occupied by the atoms.

How do you explain that the allowed energies for electrons in solids are restricted to energy bands ?

Explain physically why the band gap of a semiconductor decreases with temperature. What is the value of the Fermi function at energy, which is $3kT$ larger/lower than the Fermi energy ? 4 + 4 + 3 + 3



8. a) Find the equilibrium electron and hole concentrations and the location of the Fermi energy relative to the intrinsic energy in silicon at 27°C, if the silicon contains the following concentrations of shallow dopants.

i) $1 \times 10^{16} \text{ cm}^{-3}$ boron atoms.

ii) $3 \times 10^{16} \text{ cm}^{-3}$ arsenic atoms and $2.9 \times 10^{16} \text{ cm}^{-3}$ boron atoms. 2 + 2 + 2 + 2 + 2

- b) Calculate the probability that a state in the conduction band is occupied by electron and calculate the thermal equilibrium electron concentration in silicon at

$T = 300 \text{ K}$.

[Here, $E_c - E_f = 0.25 \text{ eV}$, $N_c = 2.8 \times 10^{19} \text{ cm}^{-3}$]

2 + 2

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