ELECTRONIC DEVICES
(ECEN 2204)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

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

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) Piezoelectricity is exhibited by
(a) Silicon (b) Germanium (c) GaAs (d) Quartz.

(ii) The relation of density of states function with the energy of electron is
(a) linear (b) inversely proportional
(c) parabolic (d) none of these.

(iii) Which one of the following devices does not require any external biasing for operation?
(a) LED (b) solar sell (c) Schottky diode (d) Varicap.

(iv) The threshold inversion point of the *MOS* capacitor is defined when the surface potential (φ_S) satisfies
(a) $\phi_s = \frac{\phi_{fp}}{2}$ (b) $\phi_s = 2\phi_{fp}$ (c) $\phi_s = \phi_{fp}^{\,2}$ (d) $\phi_s = \sqrt{\phi_{fp}}$

(v) Which one of the following devices can be used to generate microwave frequencies?
(a) Schottky diode (b) Tunnel diode (c) Photodiode (d) None of these.

(vi) At room temperature the intrinsic semiconductor behaves as
(a) Metal (b) Semiconductor (c) Insulator (d) Superconductor.

(vii) The Early effect in a Bipolar Junction Transistor caused by
(a) fast turn-on of the device
(b) fast turn-off of the device
(c) increase in collector-base reverse bias
(d) increase in emitter-base forward bias.

(viii) With rise in temperature reverse saturation current
(a) increases linearly (b) increases exponentially
(c) decreases linearly (d) decreases exponentially.

(ix) The threshold voltage of an n-channel enhancement type MOSFET is 2 V. When the device is biased at a gate voltage of 5 V, pinch-off would occur at drain voltage of

(a) 2 V (b) 2.5 V (c) 3 V (d) 3.5 V

(x) The channel length modulation effect of MOSFET is observed in

(a) linear mode (b) saturation mode
(c) cut-off mode (d) both linear and saturation modes.

Group - B

2. (a) Briefly discuss the effect of doping and temperature on the shift of Fermi energy level in semiconductor. [(CO2)(Understand/LOCQ)]

(b) Derive the expression of drift current density in a semiconductor sample. [(CO1)(Analyze/IOCQ)]

(c) The electron concentration in an *n-type GaAs* semiconductor maintained at $T = 300\ K$ varies linearly from 1×10^{8} *to* $8\times10^{17}\ cm^{-3}$ over a distance of *0.12 cm*. The electron diffusion coefficient for the material is $D_n = 225\ cm^2/sec$. Determine the diffusion current density. [(CO1)(Evaluate/HOCQ)]

4 + 5 + 3 = 12

3. (a) Evaluate the electron concentration in conduction band of semiconductor under equilibrium. [(CO1)(Evaluate/HOCQ)]

(b) Find out the position of Fermi energy level in an intrinsic semiconductor under equilibrium. [(CO2)(Apply/IOCQ)]

(c) The electron concentration in a sample of uniformly doped n-type Silicon at 300 K varies linearly from $10^{17}/cm^3$ at x = 0 to $6 \times 10^{16}/cm^3$ at x = 2 μm. Assume a situation that electrons are supplied to keep this concentration gradient constant with time. If electronic charge is 1.6×10^{-19} Coulomb and the diffusion constant D_n=35 cm^2/s, find the current density in the Silicon considering no electric field present. [(CO1)(Apply/IOCQ)]

4 + 4 + 4 = 12

Group – C

4. (a) Find out the built–in potential V_{bi} expression for a simple p-n junction using energy band diagram. [(CO5)(Apply/IOCQ)]

(b) Construct a Ohmic contact using n-type Si and a metal and draw the proper energy band diagram for the same. [(CO6)(Create/HOCQ)]

(c) An n-p-n transistor at room temperature has its emitter open circuited. A voltage of 5 V is applied between collector and base with collector positive and a current of 0.2 μA flows. When the base is open circuited and the same voltage is applied between collector and emitter, the current is found to be 20 μA. Find α, I_E and I_B, when collector current is 1 mA. [(CO4)(Apply/IOCQ)]

5 + 4 + 3 = 12

5. (a) Explain the principle of operation of the *p-n* junction solar cell.
[(CO4)(Understand/LOCQ)]

(b) An *n-p* heterojunction is formed between *GaAs* and *Ge*. Draw the corresponding energy band diagram and show the conduction and valence band offsets (ΔE_C and ΔE_V) with proper values.
Assume, E_g (GaAs) = 1.45eV, E_g (Ge) = 0.7eV, χ_{GaAs} = 4.07eV and χ_{Ge} = 4.13eV. Here, E_g and χ denote energy bandgap and electron affinity respectively.
[(CO6)(Evaluate/HOCQ)]

(c) Under the application of a bias, in a typical *p-n* junction structure, the hole current contribution is around *40%* of the total current. As a designer, what will you do to increase this hole current contribution to *80%*. Keeping in mind the Diode equation, suggest two possible approaches. [(CO4)(Apply/IOCQ)]

4 + 5 + 3 = 12

Group - D

6. (a) Explain the minority carrier concentration profile in the BJT with suitable diagram. [(CO4)(Understand/LOCQ)]

(b) Describe all the current components in *n-p-n BJT* with proper diagram.
[(CO4)(Understand/LOCQ)]

(c) A *BJT* has $\alpha = 0.99$, $i_B = I_B = 25\ \mu A$, and $I_{CBO} = 200\ nA$. Evaluate the *dc* collector current, *dc* emitter current, the percentage error in emitter current when leakage current is neglected. All the notations have their usual significance.
[(CO4)(Apply/IOCQ)]

4 + 3 + 5 = 12

7. (a) Derive the expressions of I_E, I_C, and I_B from the Ebers-Moll model of the *BJT* when operating in the forward active mode. Draw the corresponding energy band diagram. The notations have their usual significance. [(CO5)(Analyze/IOCQ)]

(b) Consider the circuit of *Fig.1*. The transistor has $V_{BE} = 0.75\ V$, $V_{CE(sat)} = 0.2\ V$, $\beta = 100$. Evaluate I_B, I_C, I_E and V_0. Determine the region of operation and draw the corresponding energy band diagram. Also, draw the load line for the given bias condition and label the *Q-point*. [(CO5)(Evaluate/HOCQ)]

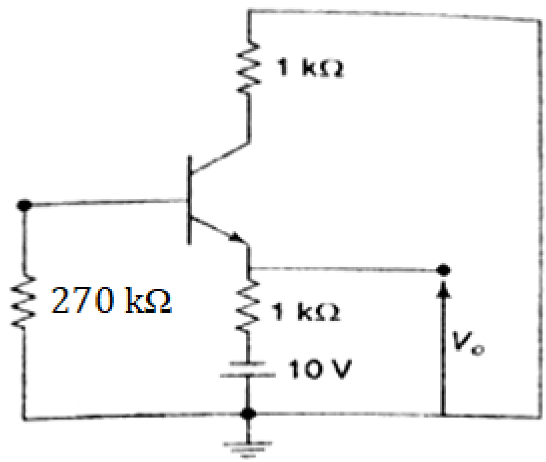

Fig.1

6 + 6 = 12

Group - E

8. (a) Create inversion layer in a MOS structure with p-type substrate and explain it using proper energy band diagram. [(CO4)(Create/HOCQ)]
   (b) Design a small signal equivalent model of an n-channel MOSFET and simplify it for low frequency cases. [(CO4)(Create/HOCQ)]
   (c) How does the channel length modulation affect the V-I relation of MOSFET? [(CO2)(Analyze/IOCQ)]

4 + 5 + 3 = 12

9. (a) Explain the principle of operation of *CMOS* inverter. [(CO4)(Understand/LOCQ)]
   (b) Derive the expression of metal-Semiconductor work-function difference (φ_{ms}) of the MOSFET with the help of energy band diagram. [(CO6)(Analyse/IOCQ)]
   (c) Consider the *aluminium – silicon Dioxide – Silicon*, *MOS* systems at $T = 300\ K$. Assume, $\varphi_m' = 3.20\ V$, $\chi' = 3.25$, and $E_g = 1.11\ eV$. Suppose *p*-type doping concentration is $N_a = 10^{15}\ cm^{-3}$. Calculate the work-function difference for the system. Consider, $n_i = 1.5\times10^{10}\ cm^{-3}$. [(CO6)(Evaluate/HOCQ)]

4 + 5 + 3 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	19.79	44.79	35.42

Course Outcome (CO):

After the completion of the course students will be able to

1. Apply the previous knowledge of basic electronics engineering to appreciate the contents of this paper.
2. Understand both the particle and wave natures of electrons in Solid State Devices.
3. Identify unknown extrinsic semiconductor type using Hall Effect.
4. Describe working principles of different devices using mathematical models and energy band diagrams.
5. Justify different operations of solid-state devices using relative position of Fermi energy levels across p-njunctions in devices.
6. Evaluate performance of different hetero junctions in semiconductor devices.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question.