NANO ELECTRONICS AND NANO PHOTONICS
(ECEN 4244)

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) The Schrödinger equation tells us
(a) kinetic energy + potential energy = total energy
(b) kinetic energy - potential energy = total energy
(c) kinetic energy × potential energy = $\frac{\hbar}{2\pi}$
(d) kinetic energy × potential energy $\geq \frac{\hbar}{2\pi}$

(ii) The total energy of an electron in free space is
(a) $\frac{h^2k^2}{2m}$ (b) $\frac{h^2k^2}{2m^2}$ (c) $\frac{\hbar^2k^2}{2m}$ (d) $\frac{h^2k^2}{m}$.

(iii) The discrete energy states of a particle bounded in a quantum well if width a are
(a) $\frac{\hbar^2\pi^2n^2}{a^2}$ (b) $\frac{\hbar^2\pi^2}{2ma^2}$ (c) $\frac{\hbar^2\pi^2n^2}{ma^2}$ (d) $\frac{\hbar^2\pi^2n^2}{2ma^2}$.

(iv) According to Heisenberg's Uncertainty principle
(a) $\Delta p\Delta x = \hbar$ (b) $\Delta p\Delta x \geq \hbar$ (c) $\Delta p\Delta x > \hbar$ (d) $\Delta p\Delta x \leq \hbar$.

(v) Super-lenses can be realised using
(a) meta-materials (b) photonic crystals
(c) plasmonic (d) all of (a), (b) & (c).

(vi) Surface Plasmons used to describe excitations at
(a) Metal – metal interface (b) Metal – dielectric interface
(c) Dielectric – dielectric interface (d) All of (a), (b) & (c).

(vii) Electron waves partially reflect upon being incident on a potential barrier if the energy of the wave is less than the potential barrier. The reflection coefficient can be expressed as
(a) $\frac{h^2k^2}{2m}$ (b) $\left(\frac{2k_1k_2}{k_1+k_2}\right)^2$ (c) $\left(\frac{k_1-k_2}{k_1+k_2}\right)^2$ (d) $\left(\frac{2\sqrt{k_1k_2}}{k_1+k_2}\right)^2$.

(viii) The electric field in the case of optical absorption
(a) reduces the energy of electron and hole
(b) reduces the energy of electron only
(c) reduces the energy of hole only
(d) has no effect on energies.

(ix) The probability of finding an electron within a quantum well of width a along the z is
(a) $\int_{-\frac{a}{2}}^{\frac{a}{2}} |\psi(z)|^2 dz$ (b) $\int_{-\frac{a}{2}}^{\frac{a}{2}} \psi(z)\, dz$
(c) $\int_{-\frac{a}{2}}^{\frac{a}{2}} \left|\frac{1}{2}\psi(z)\right|^2 dz$ (d) $\int_{-\frac{a}{2}}^{\frac{a}{2}} \left|\sqrt{\psi(z)}\right|^2 dz$.

(x) Photonic crystal band structure can be determined using
(a) Plane Wave expansion method (b) Transfer Matrix method
(c) FDTD method (d) All of (a), (b) & (c).

Group - B

2. (a) State Bragg condition and explain its importance in understanding energy band formation. *[(CO1)(Understand/LOCQ)]*
(b) Derive the expression of discrete energy states and wave function for a particle in an infinitely deep potential well. Sketch the necessary diagram. *[(CO1)(Analyze/IOCQ)]*
(c) Electrons in a partly filled band carry a current in an electric field rather than performing Bloch oscillations – Justify the statement. *[(CO1)(Evaluate/HOCQ)]*

4 + 5 + 3 = 12

3. (a) Compare the electron transport phenomenon as expected classically & quantum mechanically when encounters a potential step with necessary diagram. *[(CO2)(Understand/LOCQ)]*
(b) Deduce the expression of relationship of wave function coefficients for electron propagation through a potential step of height V_0 located at $x = 0$ for both the cases $E > V_0$ and $E < V_0$, where the notations have their usual physical significance. *[(CO2)(Apply/IOCQ)]*
(c) Consider the potential barrier

$$V(x) = 0, \quad \text{for } x \le 0$$
$$= V_0, \text{ for } 0 < x < a$$
$$= 0, \text{ for } x \ge a$$

Determine the values of the energy E, for a particle of mass m, such that the reflected wave is absent (total transmission). Distinguish between the two cases $E \le V_0$ and $E > V_0$. *[(CO2)(Evaluate/HOCQ)]*

4 + 5 + 3 = 12

Group - C

4. (a) Explain formation of conduction and valance band of hetero-structure, grown with materials of different band-gap. *[(CO4)(Remember/LOCQ)]*

(b) What is modulation doping and modulation doped field effect transistor? *[(CO2)(Analyze/IOCQ)]*

6 + 6 = 12

5. (a) Briefly explain *2DEG* in quantum well. *[(CO2)(Understand/LOCQ)]*
   (b) Compare between the density-of-states plot of the quantum well and quantum wire structures and also write the relevant Schrödinger's equation, energy and wave function expressions. *[(CO2)(Apply/IOCQ)]*
   (c) In a region of space, a particle with mass m and with zero energy has a time-independent wave function $\psi(x) = Ax\exp\left(-\frac{x^2}{L^2}\right)$ where, A and L are constants. Determine the potential energy $V(x)$ of the particle. *[(CO1)(Evaluate/IOCQ)]*

4 + 5 + 3 = 12

Group - D

6. (a) Briefly explain the translational and chiral vector of a single-walled carbon nanotube (*CNT*) structure. *[(CO6)(Understand/LOCQ)]*
   (b) Electronic transport in *CNT* is quantized in nature – Justify the statement. *[(CO6)(Analyze/IOCQ)]*
   (c) Elucidate the effects of disorder on the electronic transport of CNTs. *[(CO6)(Evaluate/HOCQ)]*

4 + 5 + 3 = 12

7. (a) How the CN-FETs are different from the conventional MOSFETs? Describe the working principle of CN-FETs. *[(CO1)(Remember/LOCQ)]*
   (b) What are ambipolar transistors? Briefly discuss about such type of transistors. *[(CO1)(Analyze/IOCQ)]*

6 + 6 = 12

Group - E

8. (a) Briefly explain surface plasmon resonance phenomenon. *[(CO5)(Understand/LOCQ)]*
   (b) Analyze how plasmonic guiding can be used to generate fluorescence excitation in a dye. *[(CO5)(Apply/IOCQ)]*
   (c) Suggest few application areas of subwavelength aperture plasmonics. *[(CO5)(Create/HOCQ)]*

4 + 5 + 3 = 12

9. (a) Explain the basic concept and special features of photonic crystal. *[(CO1)(Remember/LOCQ)]*
   (b) What is MEMS and NEMS? Briefly explain why the MEMS and NEMS are so popular for different applications? *[(CO2)(Analyse/IOCQ)]*

6 + 6 = 12

Cognition Level	*LOCQ*	*IOCQ*	*HOCQ*
Percentage distribution	*39.58*	*47.92*	*12.50*

Course Outcome (CO):

After the completion of the course students will be able to
1. Understand the quantum mechanical properties and phenomena for low-dimensional systems
2. Apply the concept of band gap engineering, novel electronic transport & optical interaction properties of nanostructures for diverse practical applications
3. Understand the fundamentals of nanophotonics, and photonic crystals
4. Identify the application areas of nanophotonics and photonic crystals
5. Understand the basic concepts of plasmonics as a developing field from nanophotonics
6. Identify and analyze the latest research trends & challenges in the real life applications of nanoelectronics and nanophotonics.

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