NANOELECTRONICS & NANOPHOTONICS
(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 material of choice for NEMS oscillator is
(a) Silicon (b) Germanium
(c) Carbon nanotube (d) Gallium Arsenide.

(ii) Carbon nanotubes are attractive for nanoelectronics applications due to the following properties
(a) conduction and valence bands are symmetric
(b) band structure is direct
(c) highly resistant to electromigration
(d) all of the above.

(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 the above.

(vi) The wavelength of the absorption peak maximum due to surface Plasmon absorption band is dependent on the
(a) size of the nanocrystals
(b) shape of the nanocrystals
(c) dielectric environment surrounding the particles
(d) all of the above.

(vii) 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.

(viii) Photonic crystals are ordered nanostructures with periodicity of the order of
(a) wavelength of light (b) wavelength of sound waves
(c) wavelength of acoustic phonons (d) wavelength of optical phonons.

(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 the above.

Group- B

2. (a) Briefly explain wave-particle duality principle. [(CO1)(Understand/LOCQ)]
(b) Derive the solution of the one-dimensional time-dependent Schrödinger equation using the method of separation of variables. Identify the Hamiltonian operator with proper mathematical expression. [(CO1)(Apply/IOCQ)]
(c) The Hamiltonian of a particle in one-dimension is $H = (P^2/2m) + V(q)$. Assume that $V(q) = V(-q)$ and that H only has discrete eigenvalues. Let I be the operator that represents the spatial inversion : ($I\, q\, I^{-1} = -q$) and ($I\, p\, I^{-1} = -p$). Evaluate may observables ζ exist that commute with H, but not with I? Also justify what happens if H has continuous eigenvalues. [(CO1)(Evaluate/HOCQ)]

4 + 5 + 3 = 12

3. (a) With suitable figures explain resonant tunnelling phenomena. [(CO2)(Understand/LOCQ)]
(b) With appropriate diagrams explain construction and current transport within a tunnel diode. [(CO1)(Analyze/IOCQ)]

6 + 6 = 12

Group - C

4. (a) Explain how the conduction and valance bands of a hetero-structure are formed when the hetero-structure is grown with materials of different band-gap. [(CO4)(Remember/LOCQ)]
(b) With suitable diagram explain modulation doping and modulation doped field effect transistor. [(CO2)(Analyze/IOCQ)]

6 + 6 = 12

5. (a) Briefly discuss the merits of the lasers utilizing quantum-confined structures as lasing media. [(CO3)(Understand/LOCQ)]

(b) Justify the presence of lines just below the energy band gap in the absorption spectra. Distinguish the difference in the occupation functions when a system is driven out of equilibrium by injecting current into p-n junction or optical pumping. [(CO3)(Apply/IOCQ)]

(c) Compare the coherence lengths of conventional and laser radiation sources. If the radiation emitted from a low pressure sodium lamp with a typical linewidth of sodium *D* lines (both lines taken together) at $\lambda = 589\mu m$ is 5.1×10^{11} *Hz*, and if the laser radiation at $\lambda = 633nm$ emitted from a *HeNe* laser operating in a single mode with linewidth of *1MHz*. [(CO6)(Evaluate/HOCQ)]

4 + (3 + 2) + 3 = 12

Group - D

6. (a) Briefly describe the atomic structure of single-walled carbon nanotube with necessary diagram. [(CO2)(Understand/LOCQ)]

(b) Distinguish the principle of operation of a CNTFET as a Schottky-barrier device and as a ballistic MOSFET physically. [(CO6)(Analyze/IOCQ)]

(c) Justify the impact of multi-gate if used in CNTFET device. [(CO6)(Evaluate/HOCQ)]

4 + 5 + 3 = 12

7. (a) Mention the mechanical aspects of nanoscale structures NEMS researchers explore for sensing applications. [(CO6)(Remember/LOCQ)]

(b) What are ambipolar transistors? Briefly discuss about such type of transistors. [(CO1)(Analyze/IOCQ)]

(c) Signify the absence of saturation and photobleaching in the photoconductivity plot of the CNTFET photodetector. [(CO4)(Evaluate/HOCQ)]

4 + 5 + 3 = 12

Group - E

8. (a) Briefly explain surface plasmon resonance in metallic nanostructures. [(CO5)(Understand/LOCQ)]

(b) Analyze how optical resonance can be tuned in metallic nanoshells. [(CO5)(Understand/LOCQ)]

(c) Elucidate the application of metal nanoshells in whole blood immunoassay. [(CO6)(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	44	40	16

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 7 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