Master of Electronics and Telecommunication Engineering Examination, 2025

(1st Semester)

Quantum and Nanoelectronic Devices (NV)

Time: **3 hours** Full Marks: **100**

Answer __FIVE__ questions.

Answer __Q8.__ and __any FOUR__ from the rest (choose __at least ONE__ from each group).

GROUP – CO 1

Q1.a)	Determine the variation of potential energy of an electron with distance along a one-dimensional mono-atomic crystal and construct the Kronig-Penney model for it.	5
b)	Using Newton's law, derive an expression for carrier effective mass that involves curvature of the *E-k* dispersion relation.	5
c)	Define *Reduced Brillouin Zone*. Explain why it is defined in *k*-space?	5
d)	For a semiconductor, the density-of-state (DOS) effective mass and conductivity effective mass are unequal. Mention the general features of its conduction band.	5
Q2.a)	Derive the wave function for an electron travelling in free space.	5
b)	Discuss how the above wave function gets modified if the electron experiences a potential that varies periodically in space.	5
c)	Assume an electron is incident on the left surface of one-dimensional potential barrier of height V_0 with (i) infinite width and (ii) finite width. Write and sketch the electron wavefunctions for different regions of the structure in cases (i), (ii), and compare them.	10

GROUP – CO 2

Q3.a)	With the help of an example, explain how problems involving multi-layered heterostructures can be solved using the *Transfer Matrix method*.	8
b)	State and explain the selection rule for inter-band optical transitions in a quantum well (QW).	4
c)	A 20 *nm* wide square QW is formed using $GaAs/Al_{0.3}Ga_{0.7}As$ material pair. Determine the number of heavy-hole subband and light-hole subband in the *GaAs* well. Given that Q (= $\frac{\Delta E_C}{\Delta E_g}$) = 0.62, $E_g(GaAs) = 1.43\ eV$, $E_g(AlAs) = 2.16\ eV$, $m_{hh}^*(GaAs) = 0.50 m_0$ and $m_{lh}^*(GaAs) = 0.074 m_0$.	8

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Q4.a)	Neatly draw the equilibrium energy band diagram for *N-i* anisotype heterojunction.	6
b)	Explain what is M*odulation doping* and how it is superior to conventional doping. Also explain the relevance of a *Spacer layer* here.	5+2
c)	What is the effect of strain on the valence band (VB) structure in a pseudomorphic $Si_{1-x}Ge_x$ layer grown over thick *Si* - substrate? How the VB structure gets modified if the layer and substrate materials are reversed in the above situation?	7

GROUP – CO 3

Q5.a)	Describe an *Exciton.* Discuss how excitons can survive in the presence of an electric field.	3+3
b)	What is *Phonon*? Compare the features of two fundamental phonons.	3+6
c)	Mention the primary scattering mechanisms that may appear in the following materials: (i) Silver *(Ag)* (ii) Intrinsic *Ge* (iii) *n*-type *GaP*.	5
Q6.a)	Derive the conditions for *Lasing* and explain how they are satisfied in a laser diode.	6+6
b)	Describe the features of the optical gain spectra and their influences on the performance of various quantum lasers.	8
Q7.a)	Explain formation of a Q1D electron system in a bulk semiconductor by application of a strong magnetic field.	8
b)	What is *Magneto-size quantization*? Determine the capacity of a Landau level in presence of such quantization.	3+3
c)	Describe the *Quantum Hall effect.*	6

GROUP – CO 4

Q8.	Write notes on ***any TWO:*** a) SEED as optical switch b) Quantum Cascade laser c) Resonant tunnelling diode d) Coulomb blockade.	2X10