M. Sc. (Physics) 4th Semester Examination 2019
PHY 521 (Adv I: Quantum Electronics)

Full Marks – 50 **Time- 2Hours**

Answer Q.No.1 and any three from the rest

1. Answer any five questions:- **4 x 5**

(a) A p-n homojunction laser is formed between degenerate semiconductors. How is population inversion condition achieved in this case? Establish schematically that the inversion region in semiconductor laser increases with increase in forward bias. **2+2**

(b) Establish the relation between density of states (DOS) and energy for quantum well and quantum wire. **2+2**

(c) If an electric field is applied in a direction perpendicular to the layer structure in a quantum well, what does the qualitative changes occur in the plot of variation of absorption coefficient against photon energy in comparison to the case that has been performed in absence of any electric field? Explain the physical origin of these changes. **2+2**

(d) The rate equation for a two-level atom interacting with a radiation field can be written as

$$\dot{\rho}_{aa} = \lambda_a - \gamma_a \rho_{aa} - R(\rho_{aa} - \rho_{bb})$$
$$\dot{\rho}_{bb} = \lambda_b - \gamma_b \rho_{bb} + R(\rho_{aa} - \rho_{bb})$$

Obtain the steady state solution for unsaturated population difference. Explain Hole burning in the population difference curve. **2+2**

(e) Considering the interaction of a two-level atom with a strong electromagnetic field obtain an expression for the Rabi oscillation frequency of the atomic system. **4**

(f) Explain the leaky structure of an optical waveguide. What are the characteristics of a quasimode propagating in such a waveguide? **2+2**

2. (a) Draw the physical structure of double heterojunction (DH) laser. How many and what types of heterojunctions exist in DH laser? Which of those heterojunctions can exhibit two dimensional electron gas (2 DEG) and two dimensional hole gas (2 DHG). Draw band diagrams of all those heterojunctions schematically [Among those band diagrams one should be of 2 DEG and another should be of 2 DHG]. **1+2+1**

(b) (i) Draw the energy band diagram of a single quantum well laser with steplike structure. Mention its advantage over double heterojunction laser.
(ii) Draw the energy band diagram of a multiple quantum well laser with steplike structure. Point out the advantage of this multiple quantum well laser with steplike structure over single quantum well laser with steplike structure.
(iii) Draw the energy band diagram of a single quantum well laser with graded structure. Which one is functionally better in comparison between single quantum well laser with steplike structure and single quantum well laser with graded structure. **2+2+2**

3. (a) Consider a system of two coupled and identical rectangular shaped quantum wells each of width L and depth V_b centered around $z = -d/2$ and $z = d/2$. Write down the Schrödinger equation for this coupled quantum wells.

The wavefunction of this two coupled quantum well system can be written as

$$\chi(z) = A_i \chi_i(z - d/2) + B_i \chi_i(z + d/2).$$

Find out the expression for energy in terms of overlap integral, shift integral and transfer integral. Now assuming weak penetration of the electronic wave in the barrier region modify the expression for energy. Finally from the modified expression of energy find out the relation between A_i and B_i and hence interpret symmetric and anti-symmetric states of this system. Now explain the situations when an electron can be (i) localized and (ii) de-localized inside one of the quantum wells.

1+4+1+2+2

4. Draw a schematic diagram of Quantum Interference Transistor (QIT) in which size quantization occurs in one direction only. Draw also the energy band diagram and electron path ways for the entire structure of QIT. Write down the expression for energy and the wave function at source for an electron. Compute the wave function at the middle portion and at the drain. Establish the expression for phase shift $(\theta) = (L/v)[e\Phi_{12}/(h/2\pi)]$, where L is the length of the channel, v the velocity from source to drain and Φ_{12} represents the difference between the average potential in the channel.

1+2+1+2+4

5. Explain how an ammonia molecule can make a transition emitting microwaves.
The energy levels of ammonia beam maser are perturbed by a dc electric field E where $\mu E << \hbar (\omega_a - \omega_b)$ ($\mu \rightarrow$ dipole moment of the molecule, $\hbar\omega_a$ and $\hbar\omega_b$ are the unperturbed eigenvalues). Obtain the perturbed eigenvalues and eigenfunctions of the levels.
Explain how this perturbation effect can be utilized to obtain the population inversion in ammonia maser when the electric field is inhomogeneous.

2+5+3

6. (a) Write down the power law profile of refractive index distribution for the graded index waveguides and show the distribution graphically. Obtain the equation of ray path in a parabolic index slab waveguide and calculate the time taken by a ray to propagate through a length z of the waveguide. Explain the advantage of using a parabolic index waveguide than a step index waveguide in respect of pulse dispersion.

2+1+2+3+2