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Interband optical transition energies in InAs/InP semiconductor nanostructure

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Abstract : Group III-V narrow band gap semiconducting materials are considered to be promising candidates for infrared photo-detectors in the long wavelength regions. Especially P based InAs semiconductor is considered to be a promising material for fibre optical communication due to the emission of mid-infrared wavelengths [1]. The heavy hole exciton binding energy in a $InAs_{0.8}P_{0.2}$/InP quantum well wire is studied taking into consideration of strain contributions between the inner and outer material in the presence of magnetic field strength. The energy difference of the ground and the first excited state is computed taking into account the effects of quantum confinement. The effects of geometrical confinement and the magnetic field on the optical band gap are investigated in the $InAs_{0.8}P_{0.2}$/InP quantum well wire. Magnetic field induced optical gain with the incident photon energy is computed in the presence of magnetic field strength and the geometrical confinement. The larger optical gain depends on the optical transition in the optical matrix element and the transition life time [2]. This approach can be used to obtain long wavelength emission of 1.55 μm for optical fiber telecommunication applications. The optical, electrical and transport properties are found to enhance with the effects of external perturbations and the spatial confinement effects with respect to bulk values due to their reduction of dimensionality of nano-heterostructures[3]. The studies of optical transitions between two energy levels are recognized to be important for the understanding of electronic properties in order to model any suitable optical devices. The higher optical transition energies are observed in any low dimensional semiconductor system. The wide applications of this system are solar cells, photo-detectors, semiconductor light-emitting diodes, laser diodes and optical modulators.

Keywords.. Quantum confinement, optical transition energy, optical gain, exciton binding energy, external perturbations.

Introduction

Narrow band gap materials are more suitable for high speed quantum information process, telecommunication and fibre optical networks. Optical and electrical properties are significantly modified when a suitable material is doped with the inner material. InAs/InP semiconductors show smaller lattice mismatch around 3% exhibiting near infrared emission[4]. This property can be used for optical fiber telecommunication wavelength. In the present work, the magnetic field induced exciton binding energy in a $InAs_{0.8}P_{0.2}$/InP quantum well wire is discussed using variational approach within the single band effective mass approximation and the optical properties are computed using density matrix approach.

Model

A cylindrical quantum wire of $InAs_{1-x}P_x$ material is considered with the radius R and length L surrounded by a larger band gap energy, InP. Within the framework of a single band effective mass-approximation, the Hamiltonian of an exciton, consisting of single electron, single hole and the Coulomb interaction between them in a $InAs_{1-x}P_x/InP$ quantum wire, in the presence of magnetic field. The Schrödinger wave equation for the exciton as per the effective mass approach can be given as -

$$H\psi(r_e, r_h) = E\psi(r_e, r_h). \quad (1)$$

The charge carriers in any state in any low dimensional semiconductor system can be investigated from the interband optical absorption. Hence, the optical transitions between these energy levels are possible. The strength of the interband optical transition energy is associated with the Fermi Golden rule. It shows the transition probability of the exciton taking place from an initial state to the final state. The expression for linear optical absorption coefficient for the interband transitions is given by eqn.(2)

$$\alpha(\omega) = \frac{\omega\mu c e^2}{\eta}\left|M_{fi}\right|^2 \frac{m^* k_B T}{R\pi\hbar^2} \times \ln\left[\frac{1+\exp\left[(E_F - E_i)/k_B T\right]}{1+\exp\left[(E_F - E_f)/k_B T\right]}\right] \times \frac{\hbar/\Gamma_{in}}{(E_f - E_i - \hbar\omega)^2 + (\hbar/\Gamma_{in})^2} \quad (2)$$

where e is the absolute value of the electron charge, μ is the permeability of the inner wire material, refractive index, c is the speed of light in free space, Γ_{in} is the relaxation time, $E_{f(i)}$ is the final and initial state energy, ω is the angular frequency of optical radiation, k_B is the Boltzmann constant, T is the temperature, E_F represents the Fermi energy, M_{fi} is the matrix element given by the expression as-

$$M_{fi} = \int \psi_f^*(r) r \psi_i^* dr \quad (3)$$

where ψ_f and ψ_r refer the initial and final state wave functions of the optical transition.

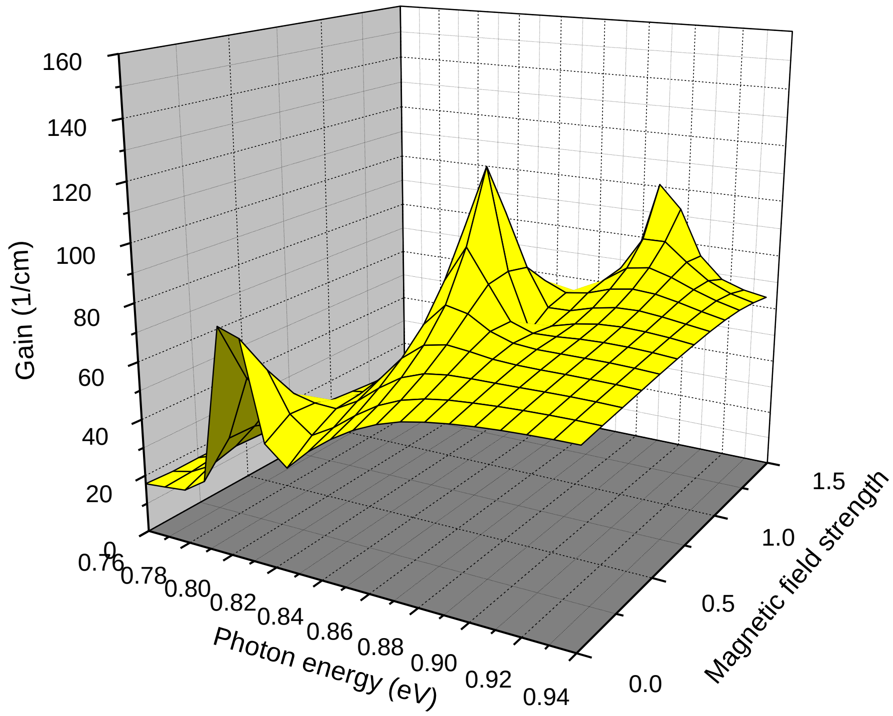

Figure 1. Variation of gain as a function of photon energy for various values of measure of magnetic field strength in a $InAs_{0.8}P_{0.2}/InP$ quantum well wire with the constant electron density

Result and Discussion

Numerical calculations on magnetic field induced exciton binding energy and thereby optical gain are obtained in the $InAs_{1-x}P_x/InP$ (x=0.2) quantum well wire using variational approach within the single band effective mass approximation. The variation of gain as a function of photon energy for various values of measure of magnetic field strengths in a $InAs_{0.8}P_{0.2}/InP$ quantum well wire with the constant electron density is shown in Figure1 The electron density, 2×10^{18} cm^{-3}, is taken in all the calculations. It is observed that the maximum peak occurs at 1.55 µm wavelength for 40 Å quantum dot radius of $InAs_{0.8}P_{0.2}/InP$ quantum well wire. The found wave length is suitable for fibre optical communication using InAs quantum well wire. The results are in good agreement with the previous investigator [4] 5in which the nanowires of InAsP were fabricated by molecular beam epitaxy, the peak emission was observed at 0.8 eV (1.55µm) and demonstrated that the peak emission could be tuned in the telecommunication range with the proper composition of As and P. It is observed that the magnetic field blue shifts the interband optical absorption resonant peak in the $InAs_{1-x}P_x/InP$ quantum wire and it refers the increase in transition energies between the levels and the transition energies increase with the wire radius due to quantum confinement. The results show the dependence of transition energy on the magnetic field strength in the $InAs_{1-x}P_x/InP$ quantum wire. It is hoped that the found results will be useful for the study of optical gain to develop highly efficient micro-lasers emitting at 1.55 µm.

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