Absorption Coefficients for Intersubband Transition in A II-VI Semiconductor Nanodot

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***Abstract*— Wide band gap II-VI semiconductors are quite interesting due to the tuning of the band gap with the proper incorporation of suitable materials, the application of external perturbations and the geometrical confinement. Among low dimensional semiconductor systems, quantum dots, in which the charge carriers are confined in all the directions, show atomic like discrete energy levels. And they exhibit some exotic optical properties in these systems. The interesting aspect in the quantum dots is the investigation of intersubband optical transitions. In the present work, the electronic states of a hydrogenic donor in a CdZnSe/ZnSe quantum dot are investigated taking into consideration of the effects of geometrical confinement. Numerical calculations are performed variationally within the single band effective mass approximation. The absorption spectra, with the photon energy, for the intersubband optical transitions in a CdZnSe/ZnSe quantum dot are discussed. And eventually, the optical gain as a function of incident photon energy is found with the spatial confinement [2]. Incident photons having energies comparable with the intersubband energies are the main cause for the alternation of nonlinear optical properties such as absorption coefficients and changes of refractive index. It is hoped that the development of this heterostructures in II-VI low-dimensional structures suggest the application of materials in the mid- or near-IR spectral region**.

Keywords- semiconductors; band gap; CdZnSe/ZnSe; quantum dot; mid- or near-IR spectral region.

I. INTRODUCTION

Intersubband optical transitions within the conduction (valence) band of semiconductor quantum nanodots are given interests from both physical point of view leading to some novel optical device fabrications. The optical properties of the nano-dots in a semiconductor structure are studied extensively in both theoretical and experimental aspects [1]. A number of optical device applications based on the intraband optical transition include far-infrared photodetectors, electro-optical modulators, all-optical switches and infrared lasers [2].

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II. THEORY AND CALCULATION

The Hamiltonian associated with the hydrogenic impurity in a $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot, within the single band effective mass approximation, can be written as

$$H = -\frac{\hbar^2}{2m_e^*(E)}\nabla^2 - \frac{e^2}{£r} + V(r) \qquad (1)$$

where r is the distance between the electron and the impurity, $m_e^*(E)$ is the energy dependent effective mass of the electron, £ is the dielectric constant of the inner dot, $V = \frac{V_{0B}r^2}{R^2}$ *for* $|r| \le R$ *and* $V = V_{0B}$ *for* $|r| > R$ with R is the radius of the quantum dot and V_{0B} is the barrier height of the parabolic dot. The ratio of the conduction-band offset to the bandgap difference between $Cd_{1-x}Zn_xSe$ and ZnSe semiconducting materials is considered as 70% [3].

The Schrödinger wave equation, time independent, is given by

$$H \cdot_{nlm} = E \cdot_{nlm} \qquad (2)$$

where H is the Hamiltonian of the system as given in Eq.(1), E_i and $\cdot_i$ are the eigen energies and the assumed trial wave functions of the impurity for the 1s state are given as

$$\cdot_{nlm}(r) = A_1 \frac{\sin k_1 r}{r} e^{-\phi r^2} e^{-\sim_{1s} r}, \quad n=1, l=0, m=0 \qquad r < R \tag{3}$$

The binding energy is obtained as

$$E_b = E_s - \langle \cdot | H | \cdot \rangle_{\min} \tag{4}$$

where E_s is the lowest binding energy which is obtained without adding the impurity.The expression for linear optical absorption coefficient for the intersubband transitions in the conduction band is given by [4]

$$\sim(\mu) = \frac{\mu \ll c e^2}{\text{¦}} |M_{fi}|^2 \frac{m^* k_B T}{R\circledR\hbar^2} \times \ln\left[\frac{1+\exp[(E_F - E_i)/k_B T]}{1+\exp[(E_F - E_f)/k_B T]}\right] \times \frac{\hbar/\Gamma_{in}}{(E_f - E_i - \hbar\mu)^2 + (\hbar/\Gamma_{in})^2} \tag{5}$$

where e is the absolute value of the electron charge, « is the permeability of the dot 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, μ is the angular frequency of optical radiation, ¦ is the refractive index, M_{fi} is the matrix element.

III. Results and discussion

The lowest subband energy of the electron in the conduction band in the $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot is solved numerically and thereby the linear intersubband optical absorption coefficient of the strained quantum dot is calculated. Any group-III material acts as hydrogenic impurity (A center). The optical gain is calculated using the compact density matrix approach and iterative procedure. Fig. 1 displays the variation of optical gain spectra as function of photon energy for various values of Zn alloy composition in a $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot. The transition matrix elements and thereby the optical gain are computed for the electron density, 2×10^{18} cm^{-3}. It is noticed that the resonant peak shows the higher amplitude when the Zn content is increased in the heterostructure and it moves towards the higher photon energy with the Zn composition. The electron confinement increases with the Zn alloy composition. It is because the larger matrix element has been obtained when the Zn alloy content is increased [5] and the increase in Fermi level with the electron density. It is observed that the intersubband optical absorption resonant peak shows a blue shift with the increase in the Zn alloy content in the $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot and it refers the increase in transition energies between the levels. In conclusion, the confined energies, electrical and optical properties and the absorption coefficient for intersubband transition have been investigated for photon energies around the band gap taking into account the geometrical confinement and the Zn alloy content in a $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot. The optical gain as a function of incident photon energy has been computed. These materials are attracted much for their potential applications in fabricating novel opto-electronic devices. Their excitonic recombination is dominant at room temperature because they posses higher exciton binding energies [6].

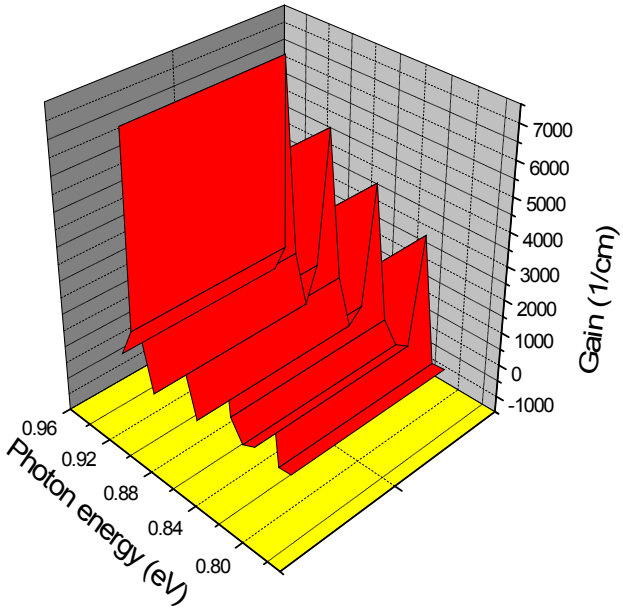

Fig. 1 displays the variation of optical gain spectra as function of photon energy for various values of Zn alloy composition in a $Cd_{1-x}Zn_xSe/ZnSe$ quantum dot.

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