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Strain induced optical properties of exciton in a CdTe/ZnTe quantum dot

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ABSTRACT

The influence of strain on the binding energies of heavy and light hole is obtained in a $Zn_xCd_{1-x}Te/ZnTe$ quantum dot taking into account the phonon confinement effect. The band offsets are calculated using model-solid approach. The dielectric mismatch effect is introduced between the dielectric constants of dot and the barrier. The strain induced energies of excitonic transitions in a CdZnTe quantum dot with ZnTe barrier are brought out considering the internal electric field induced by the spontaneous and piezoelectric polarizations. Calculations have been obtained using Bessel function as an orthonormal basis for different confinement potentials of barrier height, strain induced linear and third-order nonlinear optical absorption coefficients and the changes of refractive index with the incident photon energy are observed. Our results show that the exciton binding energy is enhanced with the inclusion of potential taking into account the effects of dielectric mismatch and the geometry of quantum dot with various Zinc alloy content has a great influence on the optical properties of the dot.

1. Introduction

Quantum dots, among low dimensional semiconductors, are shown interests due to their discrete energy levels and the potential applications in fabricating devices such as opto-electronic devices,

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quantum information processing and terahertz devices [1]. Among all the materials, II–VI semiconductors are recently paid attention because they have large direct band gaps throughout the visible spectrum further they have higher exciton binding energies and quantum efficiency which can be applied for opto-electronic devices in the middle regions of spectrum. CdTe/ZnTe material is considered to be an important semiconductor due to the lattice mismatch between its counter constitutes. Higher quality of ZnCdTe/ZnTe quantum dots are grown using latest advances in the growth technology [2–4]. Yellow and green laser diodes based on ZnCdTe materials are fabricated nowadays [5]. Photoluminescence (PL) spectra of various $Zn_{1-x}Cd_xTe/ZnTe$ quantum dots grown by Molecular beam epitaxy were carried out by Bagaev et al. [6] who studied the influence of exciton level energy depth on the temperature dependences of integral PL in the quantum dots. Temperature-dependent photoluminescence measurements have been performed to investigate the optical properties and the enhancement mechanism of the activation energy in CdTe/ZnTe nanostructures [7,8]. The band offsets in strained ZnTe/$Zn_{1-x}Cd_xTe$/ZnTe and ZnSe/$Zn_{1-x}Cd_xSe$/ZnSe square quantum well structures are experimentally determined by the low-temperature cathodoluminescence and electrical current deep-level transient spectroscopy methods [9].

A detailed study of energy gaps, dielectric constants and the composition dependence in zinc-blende $Cd_{1-x}Zn_xTe$ with the Zn alloy composition ranging from 0 to 1, using pseudo potential formalism, have been recently carried out [10]. The influence of strain distribution in CdTe/ZnTe material is taken to be an interesting subject in order to carry out exotic optical and electrical properties. The effect of strain on the electronic energy band structure has been dealt in the strained ZnCdTe/ZnTe heterostructures [11]. Strain induced conduction and valence subband energies were carried out using **k.p** Hamiltonian [12,13]. The composition of quantum dot (Zn in CdTe quantum dot) affects the linear and non-linear optical properties in any low dimensional semiconductor system. The electronic structure and optical properties of some III–V and II–VI semiconductor superlattices were investigated using superlattice-representation formalism on the basis of superlattice **k.p** theory [14]. The wavelength dependence of refractive indices for some II–VI semiconductor alloys at wavelengths below their respective energy gaps were obtained using a combination of optical reflectivity and prism coupler technique [15].

In the present paper, the exciton binding energies of heavy and light holes are investigated in a strained CdTe/ZnTe polar quantum dot nanostructure with the variation of Zn alloy content in the dot. The band offsets and the lattice mismatch effects are introduced between the dot and the barrier. Computations are carried out using Bessel function as an orthonormal basis for different confinement potentials considering the internal fields induced by the spontaneous and piezoelectric polarizations. Some nonlinear optical properties with the photon energies are investigated. The paper is prepared as follows: the band offsets using model-solid theory, the strain induced exciton binding energy and the nonlinear optical properties are briefly discussed in Section 2. In Section 3, we explain the numerical computations and the discussion in detail. Finally, a brief summary of this present work is presented in Section 4.

2. Model and calculations

2.1. Band offsets – model-solid theory

The lattice mismatch (6.2%) between the dot (CdTe) and the barrier (ZnTe) leads a biaxial strain causing a split of the valence band degeneracy. This suggests that the heavy and light holes have different band edge positions. The heavy hole and light hole band offsets are calculated as the difference between the energies at the top of heavy hole and light hole bands in CdTe and ZnTe. Similarly, conduction band offset is calculated as the difference between the energies at the bottom of the conduction bands in CdTe and ZnTe. Thus, the valence band offset related to heavy holes in the CdTe/ZnTe heterostructure interface is given by

$$\Delta E_{v,hh} = \Delta E^{B}_{v,hh}(ZnTe) - \Delta E^{D}_{v,hh}(Cd_{1-x}Zn_xTe) + \delta E_{v,hh} \quad (1)$$