Superlattices and Microstructures 53 (2013) 99–112

Contents lists available at SciVerse ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Linear and nonlinear optical properties of a hydrogenic impurity confined in a two-dimensional quantum dot: Effects of hydrostatic pressure, external electric and magnetic fields

G. Rezaei *, S. Shojaeian Kish

Department of Physics, College of Sciences, Yasouj University, Yasouj 75914-353, Iran

ARTICLE INFO

Article history:
Received 28 August 2012
Accepted 14 September 2012
Available online 17 September 2012

Keywords:
Optical absorption coefficient
Refractive index changes
Hydrogenic impurity
Electric and magnetic fields
Hydrostatic pressure

ABSTRACT

In this work, combined effects of external electric and magnetic fields, and hydrostatic pressure on the refractive index changes and optical absorption coefficients of a hydrogenic impurity confined in a two-dimensional parabolic quantum dot are studied. Energy eigenvalues and eigenvectors are calculated using the direct matrix diagonalization method and optical properties are obtained using the compact density matrix approach. It is found that the confinement potential strength, hydrogenic impurity, hydrostatic pressure, external electric and magnetic fields and the tilt angle θ considerably change the transition energy between the subbands and dipole moment matrix elements. Therefore, these parameters have a great influence on the linear and the third-order nonlinear optical absorption coefficients as well as the refractive index changes of the system.

1. Introduction

Recent developments in crystal growth technique have made it now possible to design semiconductor quantum dots (QDs) whose characteristic dimensions are comparable to the de Broglie wavelengths of free carriers. Due to the possibility of tuning the size, shape, and number of bound electrons, quantum dots (QDs) have developed into one of the major research topics in condensed matter physics. The three-dimensional quantum confinement of carriers in these structures, has led to the

---

* Corresponding author. Tel./fax: +98 741 222 3048.
E-mail address: grezaei@yu.ac.ir (G. Rezaei).

0749-6036/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.spmi.2012.09.014

formation of atomic-like discrete energy levels (subbands) and the drastic changes of the absorption spectra as well as many novel physical properties which had not been observed in the bulk materials. Unique optical properties of QDs, turn them into attractive candidates for many optoelectronic applications [1–4]. So, a great number of theoretical works has been performed on both linear and nonlinear optical properties of these structures [5–17].

Also, impurity states in semiconductor QDs have been of great interest, because of the fact that the optical and transport properties of devices made from these structures are strongly affected by the presence of impurities. Furthermore, external perturbations such as the application of hydrostatic pressure, electric and magnetic fields have become an effective tool for studying the linear and nonlinear optical properties in semiconductor QDs. Thus, there have been many works on studying the influence of hydrogenic impurity, hydrostatic pressure, external electric and magnetic fields on the optical properties of QDs [18–33].

Xie calculated the intersubband optical properties of an off-center hydrogenic impurity in a spherical quantum dot with Gaussian potential [18]. Nonlinear optical properties of a hydrogenic donor in lens-shaped quantum dots are studied by Vahdani and Rezaei [19]. Xie has investigated the nonlinear optical properties of a hydrogenic donor in a disc-like parabolic QD, using the matrix diagonalization method [20]. Nonlinear optical properties of a hydrogenic donor in an ellipsoidal finite potential QD are studied by Rezaei et al. [21]. Çakır et al. [22] also discussed the impurity effects on the linear and nonlinear optical properties of a spherical QD with parabolic potential by using a combination of quantum genetic algorithm and Hartree-Fock Roothaan method. Within the framework of effective mass approximation and using the potential morphing method, Karabulut et al. [23] have studied the effects of hydrogenic impurity and external electric field on the linear and nonlinear optical properties of spherical QDs. Based on the potential morphing method, Baskoutas et al. [24] investigated the effects of impurities and external electric field on the electronic structure and nonlinear optical rectification in a quantum dot. Combined effects of hydrostatic pressure and applied electric field on the nonlinear optical rectification of confined excitons in spherical quantum dots were studied by Duque et al. [25]. Based on the fourth-order Runge–Kutta method and the compact density matrix approach, Karimi and Rezaei [26] have investigated the influence of external electric and magnetic fields on the optical rectification coefficient, the linear and the third-order nonlinear optical absorption coefficients (ACs) as well as refractive index changes (RICs) of finite semi-parabolic quantum dots. Zhang et al. [27] studied the combined effects of external electric and magnetic fields on the optical ACs and RICs in parabolic quantum dots. In the framework of the compact-density-matrix approach and an iterative method Li et al. [28] have investigated the influence of external electric and magnetic fields on the nonlinear optical rectification in parabolic quantum dots.

To our knowledge, linear and nonlinear optical properties of a hydrogenic impurity confined in a two-dimensional parabolic quantum dot (PQD) under the influence of hydrostatic pressure, external electric and magnetic fields have not been investigated so far. The purpose of this paper is to investigate the simultaneous effects of hydrostatic pressure, external electric and magnetic fields on optical properties of a hydrogenic impurity in a two-dimensional PQD by using the matrix diagonalization technique in the framework of effective-mass approximation. Our results are applied to a typical GaAs QD. Then the rest of the paper is organized as follows: In Section 2 we describe the theoretical framework. Our numerical results and a brief summary are presented in Sections 3 and 4, respectively.

2. Theory

Within the framework of effective-mass approximation the Hamiltonian of a system consisting of an electron bound to a donor inside a two-dimensional PQD, under the influence of external electric and magnetic fields is given by

$$\widehat{H} = -\frac{1}{2m^*(P)}\left(\mathbf{p}+\frac{e}{c}\mathbf{A}\right)^2 - \frac{e^2}{\epsilon(P)r} + e\mathbf{F}\cdot\mathbf{r} + \frac{1}{2}m^*(P)\omega^2 r^2, \tag{1}$$

where e is the elementary charge, and c is the speed of light. $\mathbf{A} = (B/2)(-y, x, 0)$ is the vector potential of the magnetic field. $\mathbf{F}$ is the applied electric field with the strength F and a tilt angle θ to the z-axis