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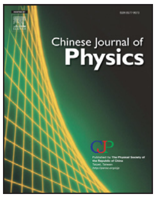

Optical properties of a two-electron system in a double ellipsoidal quantum dot

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ABSTRACT

The present study seeks to scrutinize the optical properties of a double ellipsoidal quantum dot (EQD) containing two electrons. The effect of the electron–electron interaction on the absorption coefficients for different values of the ellipticity constant is investigated. The perturbation method is used and for different values of the ellipticity constant, the absorption coefficients, group velocity and group index are calculated as a function of the incident photon energy. The results show that the absorption coefficients of the double EQD increase with increases in the ellipticity constant and shift to higher energy as β decreases.

1. Introduction

The theoretical and experimental researches on physical properties of quantum dots have attracted much attention in recent years [1–3]. These structures are interesting because charge carrier motions are restricted in all three directions, giving the possibility of the effective control of the physical characteristics of those structures. In theoretical works, it is customary to assume a spherical shape for the quantum dot. Since deformation of the spherical shape during quantum dot growth is unavoidable, quantum dots with other shapes such as an ellipsoid may be a better representation of the actual structures [4,5].

The energy levels of few-electron quantum dots with finite confinement potential were obtained by Fong et al. using the local density approximation [6]. In the infinite confinement potential, the excess electrons in the quantum dots are always bound and possess only discrete energy levels. But in the real quantum dots structures, the confining potential is finite and the number of electrons which can be accumulated in a given quantum state of a quantum dot, the capacity of the dot, can be determined [7]. It has been shown that electron correlation plays a significant role in quantum dots. There have been considerable efforts on the estimation of correlations in few-electron quantum dots. Zhu et al. [8] have pointed out the significance of size and shape effects on electron–electron interactions in a parabolic confinement. The energy spectra of two electrons in low-lying excited states in a spherical QD with different barrier heights has been studied by John Peter and Saravan Kumar [9]. Correlation energies in a triplet state of a two-electron spherical QD with square well potential confinement are estimated in Ref. [10]. Two electronic states and state exchange time control in a multilayered spherical quantum dot with infinite confinement potential were investigated in [11]. The effect of a tilted magnetic field on the energy levels of two-electron quantum dots with harmonic and hard-wall potentials was presented in [12]. The Coulomb

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and exchange energies of two electrons in a double ellipsoidal quantum dot with different ellipticity constants and a finite rectangular potential well model using an appropriate coordinate transformation are calculated in [13].

In recent years, multilayer nanosystems such as quantum dots including a core and various semiconducting layers have been made and extensively investigated [14]. The electronics properties of these structures have attracted many researchers for their experimental applications. The study of the impurity binding energy of a multilayered spherical GaAs/(Ga,Al)As quantum dot by Aktas and Boz [15], three dielectric layers model for the interface between a spherical quantum dot and the surrounding matrix by Deng [16], the binding energy of an impurity located at the centre of a multilayered quantum dot (MSQD) by Boz et al. [17] and the effect of dielectric-constant mismatch and magnetic field in a multilayered SQD by Manaselyan and Kirakosyan [18] are a few examples of some interesting investigations in this field.

The intersubband optical absorptions of low-dimensional systems have attracted enormous interest in recent years [19–22]. The results show that intersubband optical absorptions have very large optical nonlinearity in the semiconductors of nanostructures. Both linear and nonlinear intersubband optical absorptions can be used for practical applications in photodetectors and high-speed electro-optical devices [23].

In this paper, the effect of different ellipticity constants on the absorption coefficients for a two-electron system in a double ellipsoidal quantum dot is considered. In this regards, a suitable change of variable transforms the EQD into a SQD, and thus, the Schrödinger equation for two-electron system is analytically solved. The perturbation method is also used to obtain the energy of the charge carrier for the system. The optical absorption coefficients, group velocity and group index in terms of the photon energy and ellipticity constant are calculated. In Section 2, the Hamiltonian and the calculation method are given. The numerical calculations and discussions on the typical GaAs material are presented in Section 3.

2. Theory

In the effective mass approximation, the Hamiltonian of two electrons in double ellipsoidal quantum dots (EQD) can be written as

$$H = H_1 + H_2 + H^*, \tag{1}$$

where

$$H_{1,2} = \frac{\widehat{P}^2_{1,2}}{2m^*} + V(R) \tag{2}$$

is the single electron Hamiltonian. m^*, and $V(R)$ are the position-dependent effective mass and the confinement potential, respectively. H^* is the Coulomb interaction potential of two electrons and is written as

$$H^* = \frac{e^2}{\varepsilon_d |\vec{R}_1 - \vec{R}_2|}, \tag{3}$$

where ε_d is the dielectric constant of the nanolayer. To transform the ellipsoidal QD to a spherical QD, the ellipticity constant is defined as

$$\beta = 1 - \frac{a}{c}, \tag{4}$$

where a and c are the semi-axes of the ellipsoid. Therefore, the variables change as [24]:

$$X \to \frac{ax}{r_0}, \quad Y \to \frac{ay}{r_0}, \quad Z \to \frac{cz}{r_0}, r_0 = (a^2c)^{1/3}. \tag{5}$$

This change transforms the ellipsoid into a sphere of radius r_0, with the same volume. After these coordinate transformation the Hamiltonian is written as

$$H = h_1 + h_2 + h^* + \Delta h + \Delta V(r), \tag{6}$$

where

$$h_{1,2} = \frac{\hat{p}^2_{1,2}}{2m^*} + V(r), \tag{7}$$

,

$$h^* = \frac{(1-\beta)^{-1/3}e^2}{\varepsilon_d |\vec{r}_1 - \vec{r}_2|} - \frac{\beta(1-\beta)^{-1/3}}{(1-\beta)^2} \frac{e^2(r_1^2\cos^2\theta_1 - r_2^2\cos^2\theta_2)}{\varepsilon_d |\vec{r}_1 - \vec{r}_2|^2}, \tag{8}$$

and

$$\Delta h = \sum_{j=1}^{2} \frac{\beta}{3m^*} (\hat{p_j}^2 - 3\hat{p_{j,z}}^2). \tag{9}$$

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