Optik - International Journal for Light and Electron Optics 173 (2018) 263–270

Contents lists available at ScienceDirect

Optik

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

Original research article

Magneto-optical absorption in quantum dot via two-photon absorption process

Doan Q. Khoa[a,b], Nguyen N. Hieu[c], Tran N. Bich[d], Le T.T. Phuong[e], Bui D. Hoi[e], Tran P.T. Linh[f], Quach K. Quang[g], Chuong V. Nguyen[h,*], Huynh V. Phuc[i,*]

[a] *Division of Computational Physics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[b] *Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[c] *Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam*
[d] *Division of Physics, Quang Binh University, Quang Binh 510000, Viet Nam*
[e] *Center for Theoretical and Computational Physics, University of Education, Hue University, Hue 530000, Viet Nam*
[f] *Faculty of Physics, Hanoi National University of Education, 136 Xuan Thuy, Cau Giay, Ha Noi 100000, Viet Nam*
[g] *International Cooperation Department, Dong Thap University, Dong Thap 870000, Viet Nam*
[h] *Department of Materials Science and Engineering, Le Quy Don Technical University, Ha Noi 100000, Viet Nam*
[i] *Division of Theoretical Physics, Dong Thap University, Dong Thap 870000, Viet Nam*

A R T I C L E I N F O

Keywords:
Magneto-optical absorption
Quantum dot
Two-photon process
E–p interaction
FWHM

A B S T R A C T

The magneto-optical absorption coefficients (MOAC) and the full-width at half-maximum (FWHM) in a quasi-zero-dimensional quantum dot (QD) via two-photon process are theoretically studied in which the electron–phonon (e–p) interaction is involved. It is found that the best range of the magnetic field to observe the MOAC is from $B = 3.49$ T to $B = 15.77$ T. As the magnetic field enhances, the peaks intensities firstly enhance, reach the maximum value at $B = 5.38$ T, and then start reducing if the magnetic field continues increases further, while the peaks positions give a blue-shift. Besides, the magneto-optical absorption properties are found to be significantly affected not only by the quantum dot parameter but also by the temperature. The FWHM rises nonlinearly with the enhance of the magnetic field, the confinement frequency, and the temperature. The two-photon process makes an appreciable amount of the total absorption process.

1. Introduction

Because of its high potentials in optoelectronic device applications [1–4], the linear and nonlinear optical properties in low-dimensional semiconductors systems have attracted considerable interest by many scientists in recent years. Among these properties, researches have paid attention to the nonlinear optical rectification [5–8], the second and third-order nonlinear susceptibility [9–11], the second (SHG) [12–14], the third-harmonic generation (THG) [15–19], and the optical absorption coefficients (OACs) [8,20–23]. Their reports show that the optical properties of such systems are powerfully affected and therefore can be controlled by changing the characteristics such as the size or the shapes of the systems. Besides, it is indicated that the increase of the number of the confinement dimension, i.e., the transferring from the three dimensional systems to the quasi-zero dimensional system quantum dots increases the quantum confinement effect, and therefore enhanced their optical properties.

To be typical zero-dimensional systems, semiconductor quantum dots (QD) with different potential shapes have been being investigated in recent decades due to their wonderfully potential applications in the areas of electronics and optics. In a report about

* Corresponding author.
E-mail addresses: doanquockhoa@tdtu.edu.vn (D.Q. Khoa), chuong.vnguyen@lqdtu.edu.vn (C.V. Nguyen), hvphuc@dthu.edu.vn (H.V. Phuc).

https://doi.org/10.1016/j.ijleo.2018.08.030
Received 4 June 2018; Accepted 13 August 2018
0030-4026/

the optical absorption in a lens shape QD, Bouzaiene et al. [24] demonstrated that the energy levels as well as the total OAC peaks position are strongly affected not only by the applied hydrostatic pressure, the quantum dot size, and the temperature, but also by the applied electric field. Liu et al. discussed the optical properties of the disk-shaped QD [25], in which the confinement potential is combined by the parabolic and hyperbolic ones. Solving in details the Schrödinger equation, they obtained the electron eigenfunction and its corresponding eigenvalue explicitly. They indicated that the optical properties of QDs are powerfully affected by the adjustable parameters and the magnetic field. In 2015, Guo et al. surveyed the optical properties of a QD under the applied hydrogenic impurity through studying the OACs and refractive index changes [21]. Their results revealed that the hydrogenic impurity affects strongly not only the peaks intensities but also the peaks positions of the OACs. Very recently, Haouari et al. investigated the hydrostatic pressure effects on the optical properties of spherical core/shell QDs [26]. They found that the binding energy, as well as the OACs in QDs are considerably affected by the core/shell radius, the impurity position, and the hydrostatic pressure. The main lack of these studies is that the e–p interaction has not been included.

It is well-known that the e–p scattering has a strong influence on the optical properties of low-dimensional semiconductor systems. That is the reason why the e-p interaction in such semiconductors has been scrutinized by a large mass of researchers in recent years. Using the compact-density-matrix method, Yu et al. investigated the effect of e–p scattering on the THG [27] and on the OACs [28] in quantum wires. Their results indicated that the e–p scattering led to the blue-shift of both THG and OACs peaks. The e–p interaction has also been demonstrated to make the increase in the intensities of all quantities describing the optical properties include the refractive index changes, the OACs [29], as well as the SHG and the THG [30] in a modified Gaussian QD. When surveying the effect of the e–p scattering on the optical properties of asymmetrical semi-exponential quantum wells, Xiao et al. [31] revealed that the optical rectification coefficient peaks have been enhanced and given blue-shift if the electron–LO-phonon interaction has been taken into account. In all these works, the optical properties have been studied taking account only one-photon process, while the two-photon absorption process has not been concerned.

In recent works [32–35], we have studied the contribution of the two-photon process to the OACs and the FWHM. The two-photon process has been indicated to give a remarkable addition to the total OACs as well as to the FWHM in comparison with the one-photon process. Note that, in the mentioned papers, the e–p interaction has been included in our calculations. However, the role of two-photon process in surveying the optical absorption in QDs is still insufficient, especially in the case of an induced-magnetic field. In this work, we scrutinize the optical absorption properties of QDs when the magnetic field is included, namely magneto-optical absorption. The two-photon process as well as the e–p scattering will also be taken into account in this work. Our paper is organized as follows: In Section 2, we brief the basic formulation for quantum dot model. The analytical expression for the magneto-optical absorption coefficient is presented in Section 3. The numerical results and discussion are performed in Section 4. Finally, conclusions are presented in Section 5.

2. Basic formulation for the QDs model

We examine a model of a QD, where the confinement of electrons in the z-direction is characterized by a triangular potential presented by Fang and Howard [36], where we assume that electron only occupies the lowest subband with energy E_{0z}. For the y-direction, the confinement is modeled by a parabolic potential of frequency ω_y, and the confinement in the x-direction is the infinite square potential, i.e., $V(x) = 0$ when $0 \le x \le L_x$ and $V(x) = \infty$ in other cases. When a static magnetic field of strength B is applied to the z-direction of the system, i.e., $\mathbf{B} = (0, 0, B)$, the Hamiltonian of one-electron reads

$$\mathcal{H} = \frac{1}{2m^*}(\mathbf{p}+|e|\mathbf{A})^2 + \frac{1}{2}m^*\omega_y^2 y^2 + V_0(z). \tag{1}$$

Here, $m^* = 0.067m_0$ [37] is the electron effective mass, $\mathbf{p}$ is the electron momentum operator, e is the electron charge, and $\mathbf{A} = (-By, 0, 0)$ is the vector potential. The eigenfunctions of Eq. (1) are given as

$$|\lambda\rangle = |N, n, 0\rangle = \sqrt{\frac{2}{L_x}}\sin\frac{n\pi x}{L_x}\phi_N(y - y_0)\psi_0(z), \tag{2}$$

where $N(= 0, 1, 2, \ldots)$ denotes the Landau level index, L_x and $n(= 1, 2, \ldots)$ are the normalized length and the electronic subband index in the x-direction, respectively. $\phi_N(y - y_0)$ denotes the harmonic-oscillator wave functions with $y_0 = -\tilde{b}\tilde{\alpha}_c{}^2k_x$, in which, $\tilde{b} = \omega_c/\tilde{\omega}_c$, $\tilde{\alpha}_c = (\hbar/m^*\tilde{\omega}_c)^{1/2}$ being the renormalized magnetic length of the ground-state electron orbit, k_x presents the wave vector in the x-direction, $\tilde{\omega}_c = (\omega_c^2 + \omega_y^2)^{1/2}$ denoting the renormalized cyclotron frequency with $\omega_c = eB/m^*$. The corresponding eigenvalues are given as

$$E_\lambda = E_{N,n,0} = \left(N + \frac{1}{2}\right)\hbar\tilde{\omega}_c + \frac{n^2\pi^2\hbar^2}{2\tilde{m}^*L_x^2} + E_{0z}, \tag{3}$$

where $\tilde{m}^* = m^*\tilde{\omega}_c^2/\omega_y^2$ is the renormalized mass related to the effective mass m^*. According to previous works [38,39], $\psi_0(z)$ in Eq. (2) is taken in the usual form of the variational wave function, i.e.,

$$\psi_0(z) = \xi_0^{3/2}ze^{-\xi_0 z/2} \tag{4}$$

where $\xi_0 = 3/\langle L_z\rangle$, with $\langle L_z\rangle$ being the average thickness in the z-direction.