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Polaron effects on the linear and nonlinear intersubband optical absorption coefficients in quantum wells with asymmetrical semi-exponential potential

Sen Mou, Kangxian Guo *, Bo Xiao

Department of Physics, College of Physics and Electronic Engineering, Guangzhou University, Guangzhou 510006, PR China

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ABSTRACT

Linear and nonlinear intersubband optical absorption coefficients in quantum wells with asymmetrical semi-exponential potential are studied theoretically. We obtain unperturbed eigenfunctions and the energy eigenvalues by means of solving Schrödinger equation within the framework of effective mass approximation. The wave functions and energies with consideration of polaron are acquired through perturbation method. Besides, the analytic expressions of optical absorption coefficients are obtained using compact-density-matrix approach and iterative method. The results of calculation show that optical absorption is enhanced when effects of polaron are considered. Additionally, the parameters of confinement potential have great influences on optical absorption.

1. Introduction

The advances of nanofabrication technology achieved in the past several decades have triggered researchers' interest in the electronic and optical properties in low dimensional structures. Due to the enhanced confinement of carriers in low dimensional structures, many novel electronic and

* Corresponding author. Tel.: +86 13751777538.
E-mail address: axguo@sohu.com (K. Guo).

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optical properties appear in these structures. These properties are prospective to be applied practically to design advanced electronic and optical devices. Therefore, it is meaningful to research electronic and optical properties in low dimensional structures.

Among the electronic and optical properties in low dimensional structures, nonlinear optical properties are widely investigated. Especially, optical absorption coefficients appeal to many researchers [1–22]. Zhang et al. studied the optical absorption coefficients and refractive index changes in parabolic quantum dots [8]. In their study they took the effects of external electric and magnetic fields into account when calculating the optical absorption coefficients and refractive index changes. Their results showed that the optical absorption coefficients and refractive index changes are affected by incident optical intensity, frequencies of the confined potential of the quantum dots and the applied electric and magnetic fields. Yesilgul et al. researched the effect of intense high-frequency laser field on the linear and nonlinear intersubband optical absorption coefficients and refractive index changes in a parabolic quantum well, considering applied electric field [9]. Karim and Keshavarz investigated electric field effects on the linear and nonlinear intersubband optical properties in double semi-parabolic quantum wells [15]. In their investigation they studied refractive index changes, optical absorption coefficients and optical rectification coefficients. They found that the resonant peak values of the total refractive index changes and total optical absorption coefficients reach maximum value for a certain value of the applied electric field because of anti-crossing effect. Furthermore, when the double semi-parabolic quantum wells are symmetric the resonant peak values of these optical properties decrease monotonically with augment of the applied electric field.

Meanwhile, many researchers have concentrated their attentions on the effects of polaron on the electric and optical properties in low dimensional structures [23–29]. Guo and Chen discussed polaron effects on the second harmonic generation coefficients in a quantum well within an electric field [23]. Li et al. surveyed polaron effects on the refractive index changes in cylindrical quantum dots with parabolic potential [25]. Yu et al. studied polaron influence on the third harmonic generation coefficients in cylindrical quantum wires [27]. Liu et al. researched polaron effects on the optical rectification and the second harmonic generation in cylindrical quantum dots within magnetic field [28].

In this paper, we theoretically research linear and nonlinear intersubband optical absorption coefficients in asymmetrical semi-exponential quantum wells (ASEQW) taking polaron effects into account. In Section 2, by solving Schrödinger equation, the the unperturbed eigenfunctions and energy eigenvalues are acquired. We also obtain wave functions and energies of the system through perturbation method. Then the analytical expression of the absorption coefficients is derived with the compact-density-matrix approach and iterative method. In Section 3, we present numerical results and some discussions. At last, a brief conclusion is exhibited in Section 4.

2. Theory

2.1. Energy eigenvalues and eigenfunctions

In this paper, we consider an electron confined in ASEQW. When polaron is taken into account the Hamiltonian of the system can be expressed as follow with the framework of effective mass approximation.

$$H = H_e + H_{ph} + H_{e\text{-}ph}, \tag{1}$$

where H_e is the Hamiltonian of electron, H_{ph} is Hamiltonian of phonon and $H_{e\text{-}ph}$ indicates the interaction between electron and LO-phonon. H_e can be expressed as

$$H_e = -\frac{\hbar^2}{2m^*}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)+U(z), \tag{2}$$

where

$$U(z) = \begin{cases} U_0(e^{z/\sigma}-1) & z \geqslant 0 \\ \infty & z < 0. \end{cases} \tag{3}$$