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Studies on the third-harmonic generation coefficients in asymmetrical semi-exponential quantum wells

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ABSTRACT

Third-harmonic generation (THG) coefficients in asymmetrical semi-exponential quantum wells (ASEQW) are studied theoretically. We obtain the eigenfunctions and the energy eigenvalues by means of solving Schrödinger equation within the framework of effective mass approximation. Besides, the analytic expression of THG coefficients is acquired through using compact-density-matrix approach and iterative method. The results show that both the amount of peaks of THG coefficients and the magnitude of peaks are significantly affected by σ and U_0, which are parameters refer to the intensity of confinement potential in the growth direction of ASEQW.

1. Introduction

Owning to the advances of nanofabrication techniques in the past several decades, it is feasible to produce low-dimensional semiconductor structures such as quantum wells, quantum wires, quantum dots and superlattices. In these low-dimensional semiconductor structures, quantum confinement of carriers is enhanced because of decreasing dimensionality. The enhancement of quantum confinement of carriers can result in discrete energy levels and can also lead to novel electronic and optical properties in low-dimensional semiconductor structures. Consequently, many attentions are attracted to study the nonlinear optical properties experimentally and theoretically [1–20].

In fact, various types of nonlinear optical properties have been widely surveyed by different researchers. These nonlinear optical properties include second-harmonic generation coefficients

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[2,4], third-harmonic generation (THG) coefficients [8–20], optical rectification [3,4], optical absorption coefficients [5–7], refractive index changes [5,6] and so forth. In 2003, Zhang studied the electric field effect on the second-harmonic generation coefficients in parabolic and semi-parabolic quantum wells [2]. In 2013, Liu et al. investigated the polaron effects on the optical rectification in cylindrical quantum with consideration of the influences of the electric and magnetic fields [3]. In 2011, Karimi et al. researched the linear and nonlinear intersubband optical absorption and refractive index changes in double semi-parabolic quantum wells [6].

Among the nonlinear optical properties, THG coefficients appeal to many researchers. In 2005, Wang discussed third-harmonic generation coefficients in cylindrical parabolic quantum wires with an applied electric field [8]. In his study, he found that the parabolic confinement potential and the applied electric field have great influence on the THG susceptibilities in the system. In 2005, Yu et al. surveyed the polaron effects on third-harmonic generation coefficients in cylindrical quantum well wires [9]. Their results revealed that the THG coefficients are greatly enhanced and the peak shifts to the aspect of high energy when the influence of electron–phonon interaction is taken into consideration. In 2009, Wang et al. researched third-harmonic generation coefficients in asymmetric coupled quantum wells [10]. In their work, they found that the THG coefficients in the asymmetric coupled quantum wells can be significantly modified by the width difference between the left well and the right well and the width of barrier. Moreover, third-harmonic generation coefficients are affected by the relaxation rate of the asymmetric coupled quantum wells. In 2012, Rezaei and Karimi reported third-harmonic generation coefficients under the influence of an external magnetic field in coaxial cylindrical quantum well wires. In their report, they obtained energy eigenvalues and eigenvectors of the system through fourth-order Runge–Kutta method and they discovered the maximum values of the THG coefficients increase with the increment of the wire radius and magnetic field [11]. In 2012, Li et al. investigated the polaron effects on third-harmonic generation coefficients in a two-dimensional quantum pseudodot system [12]. In their investigation, they found that the THG coefficients are strongly affected by both external magnetic field and the geometrical size of the pseudodot system. In addition, their results showed that the theoretical values of the THG coefficients obviously increase when the electron-LO-phonon interaction is taken into account.

In this paper, we theoretically research the THG coefficients in asymmetrical semi-exponential quantum wells (ASEQW). The paper is organized as follows. In Section 2, through solving Schrödinger equation, the eigenfunctions and energy eigenvalues are acquired. Then we obtain the analytical expression of the THG coefficients with the compact-density-matrix approach and iterative method. In Section 3, we present numerical results and some discussions. In the end, a brief conclusion is exhibited in Section 4.

2. Theory

2.1. Energy eigenvalues and eigenfunctions

In this paper, we take account of an electron confined in ASEQW. The Hamiltonian of the system can be expressed as follow when the framework of effective mass approximation is considered.

$$H = -\frac{\hbar^2}{2m^*}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right) + U(z), \tag{1}$$

where

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

In the equations above, z indicates the growth direction of the quantum well, $\hbar$ represents Planck constant, m^* is the effective mass of electron in conduction band. In addition, both U_0 and σ are parameters which are related to the property of the ASQW.