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Letter to the Editor

Polaron effects on the optical rectification in asymmetrical semi-exponential quantum wells

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ABSTRACT

Polaron effects on the optical rectification in asymmetrical semi-exponential quantum wells(ASEQWs) are theoretically investigated. The expressions for optical rectification(OR) is obtained with the framework of the compact-density- matrix approach and iterative method. It is founded that with considering the electron–Lo-phonon interaction(ELOPI), the energy levels and the wave functions of an electron confined in ASEQWs are obtained. Numerical results are illustrated for a typical GaAs/AlGaAs. It is founded that when considering the electron–Lo-phonon, the resonant peak of the OR χ_0^2 is enhanced, and the blue shifts are also observed.

1. Introduction

In the past several years, nonlinear optical properties such as optical rectification, second harmonic generation, third harmonic generation, optical absorption and refractive index changes have aroused people widely interest[1–13]. Thanks to the development of molecular beam epitaxial growth technology and metal organic chemical vapor deposition technology, we are able to realize these nonlinear optical properties in the laboratory. We can found the quantum confinement will improve the nonlinear optical properties from the researches. The reason is that the stronger quantum confinement effects, much stronger the susceptibility of these structures than that of materials. And that makes nonlinear optical rectification exhibit interesting applications in photo-electronic devices.

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Polaron effects on the nonlinear optical properties become very important because of the fact that the ELOPI plays an important role in the nonlinear optical properties. Nonlinear optical properties such as absorption, second harmonic generation, third harmonic generation in nanostructures are greatly enhanced after we consider the electron–phonon interaction. The polaron effects on the third harmonic generation in cylindrical quantum-well wires by Yu et al. in 2004 [14]. Also Yu et al. discussed polaron effects on the optical absorption in cylindrical quantum-well wires[2]. In 2012, Wu et al. discussed polaron effects on the linear and nonlinear optical absorption coefficients and refractive index changes in cylindrical quantum dots with applied magnetic field[15]. From these researches we know that nonlinear optical properties are greatly enhanced after consider the electron–phonon interaction. Lacas put forward the polaron concept firstly [16]. He pointed out that the polaron is that an electron moving slowly in a heterostructure of polar crystals may cause a distortion of the lattice, established a polarization filed which acts back on the electron whose properties are when modified.

We will study a special asymmetric quantum well in this paper, and we can change the optical rectification coefficient by adjusting the asymmetry. This paper is organized as follows. In Section 2, we obtain the eigenfunctions and the energy eigenvalues by considering the polaron effects and using the effective mass approximation. We obtain the OR coefficients by adopting the framework of the compact-density-matrix approach and iterative method. In Section 3, we give numerical results and some discussions. In Section 4, a brief conclusion is exhibited.

2. Theory

We consider a polar semiconductor in asymmetrical semi-exponential quantum wells, and in the presence of a uniform magnetic field along the z-direction. In the effective mass approximation, the Hamilton of the system can be written as:

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

where

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

is the electron part, m^* is the effective mass of the conduction band, $\hbar$ is Planck constant, the z presents the growth direction of the quantum well. $U(z)$ is the linear potential, which can be written as follows:

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

where both U_0 and σ are positive parameters. H_{ph} is the phonon part, which can be written as follows:

$$H_{ph} = \sum_q \hbar\omega_{LO} a_q^+ a_q, \tag{4}$$

where a_q^+ and a_q are the creation and annihilation operators of the Lo-phonon, ω_{LO} is the frequency of the optical phonon, respectively. H_{ph} stands for the Hamiltonian of electron–Lo-phonon interaction, and the third term in Eq. (1) representing the electron–Lo-phonon, which is given by :

$$H_{e-ph} = \sum_q (v_q e^{iq\cdot r} a_q + v_q e^{-iq\cdot r} a_q^+), \tag{5}$$

where

$$v_q = -\frac{i\hbar\omega_{LO}}{q}\left(\frac{4\pi\alpha_e}{\Omega}\right)^{\frac{1}{2}}\left(\frac{\hbar}{2m^*\omega_{LO}}\right)^{\frac{1}{4}}, \tag{6}$$

with

$$\alpha_e = \frac{e^2}{2\hbar\omega_{LO}}\left(\frac{2m^*\omega_{LO}}{\hbar}\right)\left(\frac{1}{\varepsilon_\infty} - \frac{1}{\varepsilon_0}\right), \tag{7}$$