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Effect of hydrogenic impurity on the third-harmonic generation in a quantum well

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ABSTRACT

The third-harmonic generation (THG) coefficients in a quantum well with hydrogenic impurity are theoretically investigated with the compact-density-matrix approach and iterative method. The wave functions and the energy levels can be obtained by using variational method and numerical method. Numerical results show that the THG coefficients are strongly affected by the hydrogenic impurity.

1. Introduction

It is well known that the low-dimensional quantum systems can cause more obvious nonlinear optical properties than bulk materials. Owning to the advances of nanofabrication techniques in the past several years, it is feasible to produce low-dimensional semiconductor structures such as quantum wells, quantum wires, quantum dots and superlattices [1–7]. Nonlinear optical properties such as optical rectification [13], second harmonic generation [8], refractive index change [4,9], optical absorption [6,9], and third harmonic generation [14–24] have widely aroused people interest and various types of nonlinear optical properties have been surveyed by different researchers. In 2003, Zhang et al. studied the electric field effect on the second-harmonic generation coefficients in parabolic and semiparabolic quantum wells [10]. Their results showed that the second harmonic generation susceptibility in semiparabolic quantum well is larger than that in parabolic quantum well for the same effective widths. In 2009, Chen et al. reported the linear and nonlinear intersubband optical absorption in double triangular quantum wells with applying an electric field [11]. Their results revealed that

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applying an electric field to the double triangular quantum wells with a thinner right-well can enhance the linear optical absorption but has no prominent influence on the nonlinear optical absorption. In 2012, Liu et al. investigated the linear and nonlinear intersubband optical absorption and refractive index change in asymmetrical semi-exponential quantum wells [12]. Their results showed that the optical absorption coefficients and the refractive index changes are strongly affected not only by σ and U_0, but also by the incident optical intensity. In 2014, Xiao et al. discussed the polaron effects on the optical rectification in asymmetrical semi-exponential quantum wells [13]. Their results revealed that when considering the electron-Lo-phonon, the resonant peak of the optical rectification is enhanced, and the blue shifts are also observed.

Among the nonlinear optical properties, more attention has been paid to the THG coefficients. Several researchers have been doing a lot of work on the THG coefficients. In 2005, Yu et al. surveyed the polaron effects on the THG coefficients in cylindrical quantum-well wires [14]. 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 the THG coefficients in asymmetric coupled quantum wells [15]. In their work, they found that the THG coefficients in the asymmetric coupled quantum wells can be significantly modified by the different widths between the left well and the right well and the width of barrier. Moreover, the THG coefficients are affected by the relaxation rate of the asymmetric coupled quantum wells. In 2012, Li et al. investigated the polaron effects on the THG coefficients in a two-dimensional quantum pseudodot system [16]. 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 2014, Mou et al. studied the THG coefficients in asymmetrical semi-exponential quantum wells [17], their results showed that both the amount of peaks of THG coefficients and the magnitude of peaks are significantly affected by σ and U_0.

As we know, impurity states play an important role in semiconductor devices, however, the nonlinear optical properties in a quantum well with a hydrogenic impurity have not been theoretically investigated. In this paper, a detailed study will be given about the current problem.

In this paper, we will theoretically study the THG coefficients in a quantum well with a hydrogenic impurity. This paper is organized as follows. In Section 2, we obtain the eigenfunctions and the energy eigenvalues through solving Schrödinger equation using variational method. Then we get the analytical expression of the THG coefficients with 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

2.1. Energy eigenvalues and eigenfunctions

In this paper, we take account of an electron confined in a quantum well with a hydrogenic impurity. Within the framework of effective-mass approximation, The Hamiltonian for a hydrogenic impurity in the system can be expressed as follows:

$$\widehat{H} = \widehat{H}_0 - \frac{e^2}{4\pi\varepsilon_0\varepsilon r}, \tag{1}$$

with

$$\widehat{H}_0 = -\frac{\hbar^2}{2m^*}\frac{\partial^2}{\partial z^2} + V(z), \tag{2}$$

where

$$V(z) = \begin{cases} \infty & |z| \geqslant d/2 \\ 0 & |z| < d/2. \end{cases} \tag{3}$$