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Nonlinear optical absorption via two-photon process in asymmetrical Gaussian potential quantum wells

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In this paper, linear and nonlinear optical absorption spectrum in asymmetrical Gaussian potential quantum wells under the applied magnetic and electric fields are studied via investigating the phonon-assisted cyclotron resonance (PACR) effect. The results are calculated for GaAs and $Ga_{1-x}Al_xAs$ materials. Our results show that the optical absorption behaviors and the half-width are significantly dependent on the height of the Gaussian potential, the well width, the magnetic field, and the temperature. It is also found that there is a clear monotonic behavior of the resonant peaks and the half-width as functions of the factors mentioned above in both one and two-photon absorption processes.

1. Introduction

Nonlinear optical properties in low-dimensional semiconductor structures have been intensively studied in recent decades because of their novel physical characteristics and possibility of applications in micro-electronic and opto-electronic devices. Therefore, the linear and nonlinear optical absorption effects in these structures have been investigated by a number of researchers [1–21]. Based on the effective mass approximation, the simultaneous effects of the hydrostatic pressure, and temperature on the optical absorption spectrum have been investigated in several systems, such as spherical

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quantum dots [1,2], quantum wells [3–8], concentric double quantum rings [9,10], and quantum wire [11]. In these works, the authors have found that the energy levels and inter-subband properties can be modified and controlled by the hydrostatic pressure and temperature. In the other hand, with the applied electric and magnetic fields, the linear and nonlinear optical absorption coefficients have been investigated in a square quantum well [12], V-shaped quantum well [13], double inverse parabolic quantum well [14], parabolic quantum well [15], GaAs/GaAlAs asymmetric double quantum wells [16], cylindrical quantum wires [17], quantum disk with flat cylindrical geometry [18], quantum dot [19,20], and in parabolic two-dimensional quantum rings [21]. These works results showed that the optical absorption coefficients depend not only on the structure of the system but also on the strength of the static magnetic and/or electric fields.

The confined potential used in this paper is Gaussian potential. It is known that although the parabolic potential are often used to display the confined potential in low-dimensional semiconductor structures [14,15,22–25], it is not perfectly suitable to describe the experimental results [26,27]. Therefore, the parabolic potential should be replaced by Gaussian potential [28]. Based on the Gaussian potential, there are a number of works have been reported to investigate the optical properties [27,29–32]. However, in most of these studies, the optical absorption has been only investigated by one-photon absorption, while the two-photon absorption process has not been done. In this paper, we use the Gaussian potential to investigate the linear and nonlinear optical absorption via two-photon absorption process in GaAs and $Ga_{1-x}Al_xAs$ quantum wells. Our results show that the optical absorption behaviors and the half-width are significantly dependent on the height of the Gaussian potential, the well width, the magnetic field, and the temperature. We also found that there is a clear monotonic behavior of the resonant peaks and the half-width as functions of the factors mentioned above in both one and two-photon absorption processes. The paper is organized as follows: In Section 2, the theoretical framework and analytical results are presented. Section 3 is dedicated the numerical results and discussion. Finally, our conclusion is given in Section 4.

2. Theoretical framework and analytical results

We consider a quantum well where electron is confined in z-direction by an asymmetric Gaussian potential, which is given by [27,31,32]

$$U(z) = \begin{cases} -U_0 \exp(-z^2/2L^2) & z \geqslant 0, \\ \infty & z < 0, \end{cases} \tag{1}$$

where U_0 is the height of the Gaussian potential, and L is the range of the confinement potential (well width). When the static magnetic $\mathbf{B}$, and electric $\mathbf{F}$ fields are applied simultaneously to the z-direction, in the Landau gauge for the vector potential $\mathbf{A} = (0, Bx, 0)$, the one electron Hamiltonian reads

$$H = \frac{1}{2m^*}(\mathbf{p} + e\mathbf{A})^2 + U(z) - eFz, \tag{2}$$

where $\mathbf{p}$ and m^* are the momentum operator and the effective mass of a conduction electron, respectively. The eigenfunction and eigenvalue corresponding to the Hamiltonian in Eq. (2) are

$$\Psi_{N,n,k_y}(\mathbf{r}) = \frac{1}{\sqrt{L_y}} \exp(ik_y y)\psi_N(x - x_0)\phi_n(z), \tag{3}$$

$$E_{N,n,k_y} = \left(N + \frac{1}{2}\right)\hbar\omega_c + \varepsilon_n, \quad N = 0, 1, 2, \ldots, \tag{4}$$

where N is the Landau level index, $\omega_c = eB/m^*$ is the cyclotron frequency, $\psi_N(x - x_0)$ is the harmonic oscillator wave functions, centered at $x_0 = -a_c^2 k_y$, L_y and k_y are the normalization length and the electron wave vector in the y-direction, respectively, and $a_c = (\hbar/m^*\omega_c)^{1/2}$ is the radius of the orbit in the (x, y) plane. The component eigenfunction and eigenvalue in z-direction in Eqs. (3) and (4) are given by [27,31,32]