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Nonlinear phonon-assisted cyclotron resonance via two-photon process in parabolic quantum well

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ABSTRACT

In this work, the combined effect of aluminum concentration, hydrostatic pressure, temperature, and confinement frequency of a parabolic quantum well (PQW) on the phonon-assisted cyclotron resonance (PACR) via two-photon absorption process under applied electric field is investigated theoretically. The analytical expression of the magneto-optical absorption coefficient (MOAC) is obtained by relating it to the transition probability for the absorption of photons. The numerical results are calculated for typical GaAs/GaAlAs quantum well. The obtained results show that the hydrostatic pressure, aluminum concentration, temperature, and confinement frequency have a significant effect on the MOAC as well as on the half-width. Moreover, it has been found that the optical properties of the GaAs/GaAlAs PQW can be modified by changing these parameters. This gives a new capacity for optical device applications.

1. Introduction

With the applied hydrostatic pressure and aluminum concentration, the electron effective mass and dielectric constants have been modified [1,2]. This leads to the changes of the band structures as well as the optoelectronic properties of heterostructures. Besides, the nonlinear optical properties in low-dimensional systems can be useful in many potential applications in micro-electronic and

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optoelectronic devices [3–7]. Therefore, the combined effects of Al-doped concentration and hydrostatic pressure on the optical absorption properties, including the nonlinear optical absorption coefficient, in low-dimensional systems have been investigated intensively in recent years. Based on the effective mass approximation, the simultaneous effects of the Al-doped concentration, the temperature, and the hydrostatic pressure on the optical absorption properties have been investigated in several systems, such as quantum wells [8–13], quantum rings [14–16], quantum wires [17], and quantum dots [18–22]. The results have shown that the energy levels and the optical properties can be modified and controlled by the concentration, the pressure and temperature. Moreover, the concentration and the pressure make the strong effect on the optical absorption coefficients.

Because of the interest in understanding the electron–phonon interaction as well as the optical properties of low-dimensional systems, the linear and nonlinear optical absorption coefficients in the presence of the electric and magnetic fields have also been investigated. Karabulut and co-authors studied the nonlinear optical properties of a square quantum well [23], a GaAs/$Ga_{1-x}Al_xAs$ double quantum well [24], and a spherical quantum dot [25]. The linear and nonlinear optical properties have also been reported in V-shaped quantum well [26], in double inverse parabolic quantum well [27], and in parabolic quantum well [28]. In another work, Gambhir et al. investigated the linear and nonlinear optical absorption coefficients and refractive index changes in a quantum disk with flat cylindrical geometry [29]. Duque et al. studied the optical nonlinearities associated to applied electric fields in parabolic two-dimensional quantum rings [30]. The results showed that the optical absorption properties depend not only on the structure of the system but also on the external static magnetic or electric fields.

According to our knowledge, the influence of hydrostatic pressure, aluminum concentration, and temperature on the linear and nonlinear optical absorption has been only investigated by the one-photon absorption process while the two-photon one has not been done. In this work, we investigate the combined effect of these quantities on the nonlinear phonon assisted-cyclotron resonance in GaAs/$Ga_{1-x}Al_xAs$ parabolic quantum well via two-photon absorption process in the presence of the electric and magnetic fields. Our result shows that the magneto-optical absorption properties and the half-width are significantly dependent on these parameters, and it is necessary to investigate the magneto-optical properties of the GaAs/$Ga_{1-x}Al_xAs$ heterostructure systems nearby the traditional (GaAs) materials. Moreover, the two-photon absorption process is demonstrated to give a significant contribution to the total process and should be included in studying the magneto-optical absorption properties.

2. Theoretical framework and analytical results

2.1. Electron eigenfunctions and eigenvalues

We consider a GaAs/$Ga_{1-x}Al_xAs$ quantum well where electron is confined in z-direction by a parabolic potential, which is given by $U(z) = m^*\omega_z^2 z^2/2$, with ω_z the confinement frequency. When the static magnetic $\mathbf{B} = (0, 0, B)$ and electric $\mathbf{F} = (F, 0, 0)$ fields are simultaneously applied to the system, the one electron Hamiltonian under applied hydrostatic pressure, temperature, and aluminum concentration, reads

$$\mathcal{H} = \frac{(\mathbf{p} + e\mathbf{A})^2}{2m^*(x, P, T)} + eFx + U(z), \tag{1}$$

where $\mathbf{p}$ is the momentum operator of a conduction electron. The expression for the aluminum concentration x, temperature T, and hydrostatic pressure P dependent electron effective mass, $m^*(x, P, T)$, is [31–33]

$$m^*(x, P, T) = m_0 \left\{ \frac{1}{1 + E_P^{\Gamma}\left[\frac{2}{E_g^{\Gamma}(P,T)} + \frac{1}{E_g^{\Gamma}(P,T)+\Delta_0}\right]} + 0.083x \right\}. \tag{2}$$