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Temperature effect on vibrational frequency and ground state energy of strong-coupling polaron in symmetry RbCl quantum dots

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Abstract. By employing the linear combination operator and the unitary transformation methods, we study the vibrational frequency and the ground state energy of a strong-coupling polaron in symmetric RbCl quantum dots (SRQDs). The effects of the temperature and the confinement strength are taken into account. It is found that the vibrational frequency and the ground state energy are increasing functions of the temperature and the confinement strength. We find two ways of tuning the vibrational frequency and the ground state energy via adjusting the temperature and the confinement strength.

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Key words: vibrational frequency, linear combination operator, temperature effect, unitary transformation methods, Polaron.

1 Introduction

In recent years, there has been an active research subject in the experimental and theoretical physicists study of low-dimensional nanostructures. This low-dimensional nanostructures are not only advantageous to the point view of fundamental physics but also electronic and optoelectronic devices [1,2]. Consequently, there has been a large amount of experimental work [3-5] on QD. Meanwhile, many investigators studied its properties in many aspects by a variety of theoretical methods [6-8]. Using the framework of effective mass theory, Wang and Li [9] theoretically investigated the center-of-mass motion of quasi-two-dimensional excitons with spin-orbit coupling. Using a variational method of the Pekar type, Xiao [10] study the ground and first excited states energies and the corresponding transition frequency of a strong-coupling polaron in an asymmetric quantum

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dot (AQD). Beard [11] uses a way to enhance solar energy conversion by utilizing the excess energy in the absorbed photons to study Multiple exciton generation in quantum dots. Based on the variational method of Pekar type, state energies and transition frequency of strong-coupling polaron in an anisotropic quantum dot had been calculated by us [12].

In this paper, by using the linear combination operator and unitary transformation methods, we study the temperature effect on vibrational frequency and ground state energy of a strong-coupling polaron in a SRQD.

2 Theory model calculations

The electron under consideration is moving in a crystal RbCl quantum dot with the parabolic potential which is much more confined in z direction than in the x–y directions, and interacting with bulk LO phonons. The Hamiltonian of the electron-phonon interaction system can be written as

$$H=\frac{p^2}{2m}+\sum_{\mathbf{q}}\hbar\omega_{LO}\alpha_q^+\alpha_q+\frac{1}{2}m\omega_{\|}^2\rho^2+\frac{1}{2}m\omega_z^2z^2+\sum_q[V_q\alpha_q\exp(i\mathbf{q}\cdot\mathbf{r})+h.c.] \tag{1}$$

where m is the band mass, ω_o is the magnitude of the confinement strengths of the potentials in the x-y plane, respectively. $a_{\mathbf{q}}^+(a_{\mathbf{q}})$ denotes the creation (annihilation) operator of the bulk LO phonon with wave vector $\mathbf{q}$, P and $\mathbf{r}$=($\mathbf{p}$,z) is the momentum and position vector of the electron. V_q and α in Eq. (1) are

$$V_q=i\left(\frac{\hbar\omega_{LO}}{q}\right)\left(\frac{\hbar}{2m\omega_{LO}}\right)^{\frac{1}{4}}\left(\frac{4\pi\alpha}{V}\right)^{\frac{1}{2}},\quad \alpha=\left(\frac{e^2}{2\hbar\omega_{LO}}\right)\left(\frac{2m\omega_{LO}}{\hbar}\right)^{\frac{1}{2}}\left(\frac{1}{\varepsilon_\infty}-\frac{1}{\varepsilon_o}\right) \tag{2}$$

Then, we carry out the unitary transformation to Eq. (1):

$$U=\exp\left[\sum_{\mathbf{q}}\left(f_q\alpha_{\mathbf{q}}^+-f_q^*\alpha_{\mathbf{q}}\right)\right], \tag{3}$$

where f_q and f_q are the variation functions, we introduce a linear combination operator:

$$\begin{matrix} p_j=\left[\frac{m\hbar\lambda}{2}\right]^{\frac{1}{2}}\left(b_j+b_j^+\right) \\ r_j=i\left[\frac{\hbar}{2m\lambda}\right]^{\frac{1}{2}}\left(b_j-b_j^+\right)\end{matrix}\quad,\quad j=x,y \tag{4}$$

where λ is the variation parameter which describing the vibrational frequency of polaron. The ground state wave function of the system is chosen as

$$|\psi_0\rangle=|\varphi(z)\rangle|0\rangle_a|0\rangle_b, \tag{5}$$