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State energies and transition frequency of strong-coupling polaron in an anisotropic quantum dot

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Abstract. We study the ground and the first excited states energies and the transition frequency between the first excited- and the ground-state of strong-coupling polaron in an anisotropic quantum dot. The effects of the electron-phonon coupling strength and the transverse and the longitudinal effective confinement lengths are taken into consideration by using variational method of the Pekar type. It is found that the transition frequency is an increasing function of the electron-phonon coupling strength, whereas the state energies are decreasing one of it. They will increase rapidly with decreasing transverse and longitudinal effective confinement lengths.

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1 Introduction

In recent years, lots of novel effects in systems consisting of quantum dot (QD) have attracted interests from more and more physicists. Because of the wide device applications and many new effects in such structures, understanding their electronic and transport properties is of particular importance. Consequently, there has been a large amount of experimental work [1-3] on QD. Meanwhile, many investigators studied its properties in many aspects by a variety of theoretical methods [4-8]. Using a variational approach with squeezed states, Kervan *et al.* [9] investigated the polaronic effects of an electron confined in a parabolic QD and obtained the polaronic correction to the ground and the first excited states energies in the presence of optical phonons. Li and Xia [10]studied the quantum-confined Stark effects in GaAs/$Al_xGa_{1-x}As$ self-assembled QDs in the framework of the effective-mass envelope-function theory. The electron and hole optical transition energies were calculated in the presence of an electric field in different directions. At

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low temperature, Zaitsev *et al.* [11] studied the magneto-optics and picosecond dynamics of radiative recombination of excitons in self-assembled semi-magnetic CdSe /ZnMnSe QDs. Kaer *et al.* [12] investigated the influence of the electron-phonon interaction on the dynamical properties of a QD-cavity system. Within the spin-density-functional theory, Zhang *et al.*[13] investigated the electronic structure of dynamic QDs formed by surface acoustic waves potential and the confinement potential produced by gate voltage. Based on Huybrechts's strong-coupled polaron model, Tokuda modified the linear-combination operator and the unitary transformation methods. The effective mass of strong-coupled polaron in an asymmetric QD induced by Rashba effect has been studied by us [14]. The properties of the strong-coupling polaron in an anisotropic quantum dot, however, has not been studied so far by employing variational method of the Pekar type. Especially, the properties of the transition frequency of the polaron have never been investigated yet.

In the present paper, we study the effects of the electron-phonon coupling strength and the transverse and longitudinal effective confinement lengths on the ground and the first excited states energies and the transition frequency of a strong-coupling polaron in an anisotropic quantum dot by using variational method of the Pekar type.

2 Theory model and calculations

The electron under consideration is moving in a polar crystal quantum dot with three-dimensional anisotropic harmonic potential, and is interacting with bulk LO phonons. The Hamiltonian of the electron-phonon interaction system can be written as

$$H=\frac{p^2}{2m}+\sum_{\mathbf{q}}\hbar\omega_{LO}a_{\mathbf{q}}^{+}a_{\mathbf{q}}+\frac{1}{2}m\omega_{||}^2\rho^2+\frac{1}{2}m\omega_z^2z^2+\sum_{\mathbf{q}}[V_{\mathbf{q}}a_{\mathbf{q}}\exp(i\mathbf{q}\cdot\mathbf{r})+hc], \tag{1}$$

where m is the band mass, $\omega_{||}$ and ω_z are the measure of the transverse and longitudinal confinement strengths of the potentials in the xy plane and the z direction, respectively. $a_{\mathbf{q}}^{+}(a_{\mathbf{q}})$ denotes the creation (annihilation) operator of the bulk LO phonon with wave vector $\mathbf{q}$, and $\mathbf{r}=(\rho,z)$ is the position vector of the electron. V_q and α in Eq.(1) are

$$\begin{aligned} V_q&=i\left(\frac{\hbar\omega_{LO}}{q}\right)\left(\frac{\hbar}{2m\omega_{LO}}\right)^{\frac{1}{4}}\left(\frac{4\pi\alpha}{v}\right)^{\frac{1}{2}},\\ \alpha&=\left(\frac{e^2}{2\hbar\omega_{LO}}\right)\left(\frac{2m\omega_{LO}}{\hbar}\right)^{\frac{1}{2}}\left(\frac{1}{\varepsilon_\infty}-\frac{1}{\varepsilon_0}\right). \end{aligned} \tag{2}$$

We carry out the well known Lee-Low-Pines [15] transformation to Eq. (1)

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