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The properties of the polaron in semiconductor quantum dots induced by influence of Rashba spin-orbit interaction

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Abstract. The properties of the effective mass of polaron in semiconductor quantum dots by influence of Rashba spin-orbit (SO) interaction are studied. The relations of the strength of confinement ω_0, the interaction energy and the effective mass of the polaron in the electron-LO phonon strong coupling region in a parabolic quantum dot on the vibration frequency is derived by using improved liner combination operator method. Numerical calculations for RbCl crystal are performed and the results show that the Rashba SO interaction makes the ground state energy and the effective mass of polaron split into two branches; the ground splitting energy and the effective mass will increase with the vibration frequency increasing. Whereas the interaction energy is sharply increased until the confinement strength reaches a certain value, then it will sharply decrease.

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Key words: semiconductor quantum dot, polaron, Rashba spin-orbit interaction, effective mass

1 Introduction

In recent years there has attracted great attention in spin physics in semiconductors. Most of it is focused on spin-related optical and transport properties of low-dimensional semiconductor structures [1-3]. In particular, the spin-orbit (SO) interaction has attracted a lot of interest as it plays an important role in the field of semiconductor spintronics. SO interaction can arise in quantum dots (QDs) by various mechanisms related to electron confinement and symmetry breaking and are generally introduced in the Hamiltonian via the Rashba [4] and Dresselhaus terms [5]. Dresselhaus term is obtained from the electric field produced by the bulk inversion asymmetry of the material and Rashba term is

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generated due to the structural asymmetry of the heterostructure. Rashba splitting has been observed in many experiments and it constitutes the basis of the proposed electronic nanostructures. The strength of these interactions not only depends on the characteristics of the material but can be controlled by an external electric field.

In the literature, most of the theoretical studies about the solution of the SO effects in QDs are carried out by means of perturbative schemes or numerical simulations [6, 7]. Analytical solution of the problem has recently been treated by employing various techniques [8-11]. For zero-magnetic field and a hard-wall confining potential the exact analytical results have been obtained by Boulgakov and Sadreev[12]. Tsitsishvili et al present an analytic solution to Rashba coupling in a quantum dots [13]. Tapash Chakraborty report on a theoretical approach developed to investigate the influence of the Bychkov-Rashba interaction on a few interacting electrons confined in a quantum dot [14].

There have been much work about the influence of the Rashba SO interaction on the electron system, the study of the effect of the Rashba SO interaction on the polaron, however, is quite rare so far. In this paper, we find the Rashba SO will induce the splitting of the ground state energy and the effective mass of the polaron.

2 Theoretical model

We consider a quasi-two-dimensional quantum dot normal to the z axis. Therefore, we confine ourselves to considering only the motion of the electron in the x-y plane. The Hamiltonian of the electron-phonon system is given by

$$H=\frac{p^2}{2m}+V(\rho)+H_{ph}+H_{ph-e}+H_{SO}, \tag{1}$$

where the first term denotes the kinetic energy of the electron and the second term represents the confining potential in a single QD that is

$$V(\rho)=\frac{1}{2}m\omega_0^2\rho^2, \tag{2}$$

where m is the bare band mass of the electron and ω_0 is the confinement strength of the quantum dot.

The Hamiltonian of the phonons H_{ph} is given by

$$H_{ph}=\sum_{\mathbf{q}}\hbar\omega_{LO}b_{\mathbf{q}}^{+}b_{\mathbf{q}}, \tag{3}$$

where $b_{\mathbf{q}}^{+}(b_{\mathbf{q}})$ is the creation (annihilation) operator of a bulk LO phonon with wave vector $q_1,\mathbf{q}=(\mathbf{q}_{//},q_z)$.

The electron-phonon interaction term H_{ph-e} is expressed as

$$H_{ph-e}=\sum_{\mathbf{q}}[V_{\mathbf{q}}\exp(i\mathbf{q}\cdot\mathbf{r})b_{\mathbf{q}}+h.c.], \tag{4}$$