UNITECH 2018 GABROVO

INTERNATIONAL SCIENTIFIC CONFERENCE
16-17 November 2018, GABROVO

THE EFFECT OF POLARIZATION A DONOR IMPURITY IN A GAAS/ALAS TETRAGONAL QUANTUM DOT UNDER APPLIED SPATIAL ELECTRIC FIELD

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Abstract
The polarization of donor impurity in a tetragonal quantum dot is investigated with infinite confinement is presented by using the variational procedure with effective mass approximation. The polarization is calculated as a function of (Lz/L) ratio. It is found that polarization of a donor impurity in tetragonal quantum dot depends strongly on the Lz/L ratio, applied spatial electric field strength and impurity position.

Keywords: Binding Energy, Donor Impurity, Quantum Dot

INTRODUCTION

In the past decades low dimensional semiconductor structures, such as quantum dots (QDs), quantum well wires (QWWs) and quantum wells (QWs)have been investigated theoretical and experimental studies of optical and transport properties[1-7]. Impurity states play an important role in semiconductors devices. Many researchers have studied the polarization, the binding energy of donor impurities in these structures.

EXPOSITION

Within the framework of effective-mass approximation, the Hamiltonian for the ground state energy of a donor impurity in a TQD under an external electric field is given by

$$H = -\frac{\hbar^2}{2m^*}\nabla^2 - \frac{e^2}{\varepsilon\left|\vec{r}-\vec{r}_i\right|} + e\vec{F}.\vec{r} + V(x,y,z) \quad (1)$$

where m^*, e and ε are the electron effective mass, charge and the static dielectric constant, respectively.
$\left|\vec{r}-\vec{r}_i\right| = \sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}$ is the distance between the electron and the impurity site. $e\vec{F}.\vec{r}$ is the effective potential energy induced by the external static electric field. V(x,y,z) is the confining potential

$$V(x,y,z) = \begin{cases} 0; & |x|,|y| \le \frac{L}{2} \text{ and } |z| \le \frac{L_z}{2} \\ \infty; & \text{elsewhere,} \end{cases} \quad (2)$$

L and L_z are dimensions of the TQD. The center of the TQD is chosen as the origin of the system. The external spatial electric field is $\vec{F} = F\,(\sin\theta\cos\varphi\,\vec{e}_1 + \sin\theta\sin\varphi\,\vec{e}_2 + \cos\theta\,\vec{e}_3)$, where θ and φ are the angles in spherical coordinates. Effective Rydberg constant $R^* = \frac{m^* e^4}{2\hbar^2\varepsilon^2}$ as the unit of energy and the effective Bohr radius $a^* = \hbar^2\varepsilon / m^* e^2$ as the length unit, the Hamiltonian becomes

$$H_{T,D} = -\nabla^2 - T\frac{2}{\left|\vec{r}-\vec{r}_i\right|} + \quad (3)$$
$$D\,\eta\,(x\sin\theta\cos\varphi + y\sin\theta\sin\varphi + z\cos\theta) + V(x,y,z),$$

where $\eta = |e| a^* F / R^*$ is the dimensionless measure of the electric field. The trial wave function given in Ref. [8] is chosen as

$$\Psi_{T,D} = N_{T,D} f(x,y,z) \exp \left[-T \left(\frac{(x-x_i)^2 + (y-y_i)^2}{8a^2} + \frac{(z-z_i)^2}{8b^2} \right) \right] \times$$

$$\exp \left[-D \left(x \sin\theta \cos\varphi + y \sin\theta \sin\varphi + z \cos\theta \right) . \beta \right], \qquad (4)$$

where a, b and β are the variational parameters. $N_{T,D}$ is the normalization constant of the wave function. The coefficients T and D take the values zero and unity depending on the quantity to be calculated. $f(x,y,z) = \cos\left(\frac{\pi x}{L}\right) \cos\left(\frac{\pi y}{L}\right) \cos\left(\frac{\pi z}{L_z}\right)$ is the ground-state wave function in the TQD with a square base $(L \, by \, L)$ and height (L_z).

The polarization of a donor electron due to the spatial electric field can be written by equation

$$\frac{P_i}{e} = -\left\langle \Psi_{1,1} \right| \left[(x-x_i)\sin\theta\cos\varphi + (y-y_i)\sin\theta\sin\varphi + (z-z_i)\cos\theta \right] \left| \Psi_{1,1} \right\rangle$$

$$+ \left\langle \Psi_{1,0} \right| \left[(x-x_i)\sin\theta\cos\varphi + (y-y_i)\sin\theta\sin\varphi + (z-z_i)\cos\theta \right] \left| \Psi_{1,0} \right\rangle . \quad (5)$$

Figure plots the polarization as a function of the L_z/L ratio for different impurity positions and spatial electric field strengths. Although the volume of the tetragonal quantum dot is constant, the characteristic behavior of the polarization is functionally different, which is evident from the fact that the polarization values are close for the $\frac{L_z}{L} = 1$ ratio while the large polarization differences are observed for the smaller or larger L_z/L ratios. In this Figure, from a comparison of electric field strengths $F = 50\,kV/cm$ and $F = 100\,kV/cm$, it is seen that symmetry is more broken with increasing electric field strength with respect to the cubic case, $\frac{L_z}{L} = 1$.

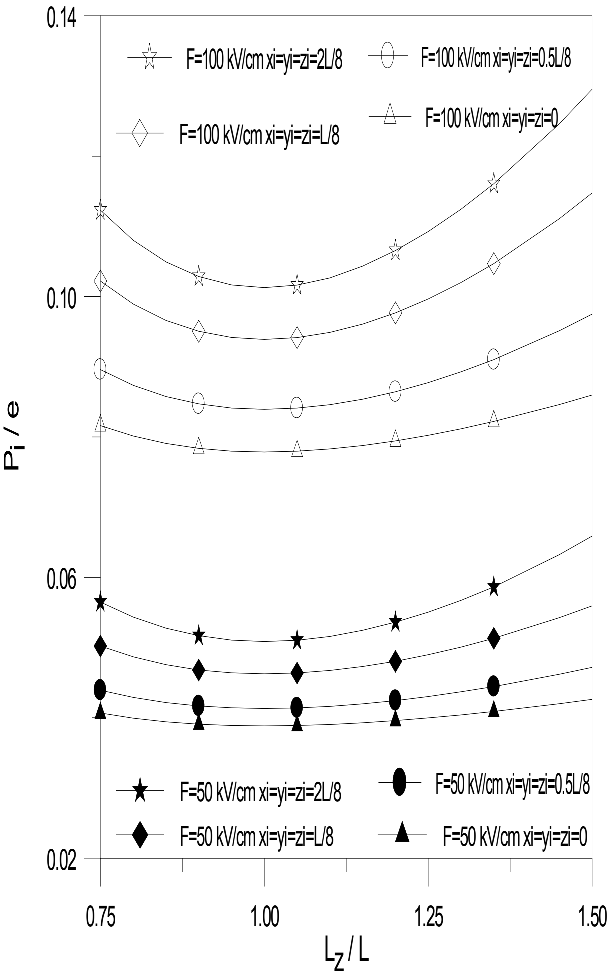

Fig. 1. *The variation of the polarization of a donor impurity as a function of the L_z/L ratio in the tetragonal quantum dot for different values of electric field strength and impurity position*

CONCLUSION

It is found that polarization in tetragonal quantum dot depends on the L_z/L ratio, impurity position and applied spatial electric field strength.

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