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

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Abstract
The binding energy of donor impurity in tetragonal quantum dot is investigated with two-paramater variational procedure considering the influence of infinite barriers under spatial electric field. It is found that binding energy of a donor impurity in tetragonal quantum dot depends strongly on the Lz/L ratio, applied spatial electric field strength and impurity position.

Keywords: Quantum Dot, Donor Impurity, Binding Energy

INTRODUCTION

In the last years, Low dimension structures (Quantum Dot, Quantum Well Wire, Quantum Well) have let to important development of optoelectronic devices such as quantum transistors, quantum dot lasers, high-speed memory elements, quantum computing. In these systems, electrons are confined to one, two and three dimensions. When the quantum size is reduced, electron moves in smaller space and interaction of electron and hydrogenic impurity increases as size increases. There are several reports on the binding energy of the donor impurity under the electric field [1-10].

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. $\left|\bar{r}-\vec{r}_i\right|=\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}$ 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

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

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. [11] is chosen as

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

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

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 ground state energy of the system without impurity can be written as

$$E_0 = \langle \Psi_{0,1} | H_{0,1} | \Psi_{0,1} \rangle . \qquad (5)$$

The ground state energy of the system with impurity can be defined as

$$E_i = \langle \Psi_{1,1} | H_{1,1} | \Psi_{1,1} \rangle . \qquad (6)$$

The binding energy E_b can be given as

$$E_b = E_0 - E_i . \qquad (7)$$

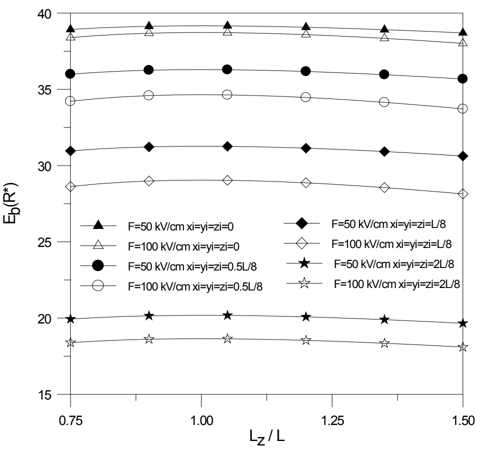

Fig. *The variation of the ground state binding energy of a donor impurity as a function of the* L_z/L *ratio in the TQD for different values of electric field strength and impurity position*

In Fig., the binding energy of a donor impurity has been plotted as a function of the L_z/L ratio for two different spatial electric field strengths and four different impurity positions.

From Fig., as the spatial electric field strength decreases, the binding energy increases for all the impurity position and all values of L_z/L ratios. In this figure, it is observed that the difference in binding energy occurred by two different spatial electric field strength increases with moving impurity from center to $x_i = y_i = z_i = L/8$, as expected. But in contrary to the expectations, this difference in the binding energy decreases for $x_i = y_i = z_i = 2L/8$.

CONCLUSION

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

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