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Transverse Stark effect of electrons in GaAs semiconducting quantum boxes

Sheng Wang [a,*], Yun Kang[a], and Yu Han[b]

[a] *College of Electronic Science, Northeastern Petroleum University, Daqing 163318, China*
[b] *College of Sciences, Liaoning University, Shenyang 110036, China*

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Abstract. The transverse Stark shift of the electronic energy levels in GaAs semiconducting quantum box is investigated by the use of variational solutions to the effective-mass approximation. It is found an interesting phenomenon that the largest Stark shift is obtained for the electric field directed along the diagonal in cross section of a quantum box, while for a rectangular one, the shift reaches peak value for the low field directed along a side of cross section and for the high field along the diagonal. Likewise, the conclusion is shown that the transverse Stark shift in a quantum box depends highly on the ratio of cross sectional sides while is irrelevant to itsheight. The large Stark shift of the electron and hole trapped in a quantum box leads to an obvious reduction of the interband recombination and wide irradiance spectrum.

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Key words: Stark effect, quantum boxes, electric field, variational method, quantum sizes

1 Introduction

In recent several decades, low-dimensional semiconductor quantum dots (QDs), with zero-dimensional electronic properties, have stimulated great interest due to their important roles in fundamental physical research and for developing novel devices, and has potential applications in the 21st century nanoelectronics. It has been one of frontier topics of materials science to study the characterization of self-organized quantum dots and device applications. The study of energy shifts of particles in semiconductor nanostructures of different geometries turns out to be a very important task since the shifts are associated with the spatial separation between electrons and holes in these structures which induces a reduction of interbandrecombination.The Stark effect significantly changes the optical absorption, reflection,

*Corresponding author. *Email address:* `wangsheng10@126.com` (S. Wang)

and photoluminescence properties. It is useful to understand quantum lasers and application of quantum dot fluorescence in the biology field. Consequently, the quantum confined Stark effect of low-dimensional system has attracted considerable attention recently. There has been quite a bit of work on the Stark effect in quantum wells, quantum wires, and spherical quantum dots when an electric field is applied along the direction of carrier confinement in the system [1–10]. There has been less work concerning the Stark effect in quantum boxes. Mendoza *et al.* [11] have calculated the Stark shift of the energies of impurities in a cubical quantum box. Spector *et al.* [12] have calculated the effect of a transverse electric field on the ground and the first few excited states of the electrons confined in a cubical quantum box. Li *et al.* [13] have calculated the Stark effect of the energy of a hydrogenic donor impurity in a rectangular parallelepiped-shaped quantum dot in the framework of effective-mass envelope-function theory using the plane wave basis.

In previous paper [14], we have given the Stark effect in a rectangular quantum boxes in the present of spatial electric field by means of variational calculation method and effective-mass approximation. In this paper, we use the same method to calculate the energy shift in a quantum box in the presence of a transverse electric field. The dependences of the shift in a quantum box upon the ratio of cross sectional sides and the transverse electric field directions are studied. It is necessary to investigate the transverse Stark effect in a quantum box which is very promising for the realization of fast optical switches and modulators. These results are relevant to any optical processes, such as emission and absorption. This feature is important for application of the nanostructures to optical modulators with lower voltage operation and quantum dot fluorescence in the biology field.

2 Theory

The Hamiltonian of a charged particle in a quantum box in the presence of a transverser electric field applied to the center axis of the box is

$$H=\frac{\vec{p}^2}{2m^*}+V(\vec{r})-q(Fx\cos\phi+Fy\sin\phi), \tag{1}$$

where $F>0$ is electric field, $\vec{p}$ is the carrier momentum, m^* and q are the carrier effective mass and charge respectively, the orientations of the transverser electric field $\vec{F}$ in cross section is specified by the angle ϕ between the positive direction of x-axis and the electric field direction. $\vec{r}$ is the position vector of the carrier. Confining potential $V(r)$ is given by

$$V(\vec{r})=\begin{cases} -\frac{L}{2}<x<\frac{L}{2}, \quad -\frac{W}{2}<y<\frac{W}{2}, \quad \text{and} \quad -\frac{H}{2}<z<\frac{H}{2}, \\ \text{elsewhere,} \end{cases} \tag{2}$$

using the infinite well model. Here, L, W and H are the length, width and height of the quantum box in the x, y and z directions respectively. We take the variational wave function