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# Electric field and shape effect on the linear and nonlinear optical properties of ellipsoidal finite-potential quantum dots

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In this work, the optical properties of ellipsoidal finite-potential quantum dot with an on-center shallow hydrogenic impurity in the presence of an external electric field have been studied. A variational procedure in the framework of perturbation theory was employed within the effective-mass approximation. Numerical results on typical $GaAs/Al_xGa_{1-x}As$ materials show that, besides incident light intensity, the electric field and dot shape have an important influence on the peak positions and magnitudes of linear and third-order nonlinear absorption coefficients and refractive index changes.



## 1. Introduction

There is no doubt that linear and nonlinear optical properties such as optical absorptions (ACs), refractive index changes (RICs) and oscillator strength [1–6] have the potential for luminescent device applications. Furthermore, it is well known that the zero-dimensional quantum dots (QDs) with well-controlled shape and size have became one of the hottest topics in the area of the condensed matter and materials physics due to their distinctive electronic and optical properties, which shows a potential application in the electronic and optoelectronic devices [7–9]. Therefore, the optical properties of QDs have attracted the considerable attention in the experimental and theoretical studies in recent years.

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Due to the shape of QDs lead to the formation of discrete energy levels, the optical properties of semiconductor QDs depend on the shape of QDs. In the theoretical works, it is customary to assume a spherical shape for the QDs, and many studies were focused on the optical properties of the spherical QDs [2,4,10,11]. But from physical point of view the consideration of ellipsoidal shape is actual due to unavoidable small deviations from spherical shape because of deformations during QD growth [12–14]. It should be mentioned that besides the shape of QDs under investigation the choice of confinement potential is also very important. The correct choice of confinement potential on QD border allows the results to come closer to the real situation. Generally speaking, if the QD is weakly prolate (oblate), the problem can be solved within the frame work of perturbation theory [12–15], of course, the spherical part plays the role of unperturbed part.

In order to modulate the properties of devices, the effect of applied electric field on the impurity sates in QDs has been studied extensively by many authors [16,17]. It is well known that the applied electric field induces an energy shift of the quantum states to introduce a considerable change in the energy spectra of carriers, and this property is very useful for optoelectronic devices. Therefore, the optical properties of QDs with an applied electric field have been theoretically studied [2,3,11,18]. Due to the special shape for the ellipsoidal QDs, there are fewer works related to the effect of the applied electric field on the optical properties of the ellipsoidal QDs, even though for a weakly prolate (oblate) ellipsoidal QD. Therefore, it is necessary to study the influences of shape and electric field on the optical properties of the ellipsoidal QDs.

In the present work, the effects of shape and applied electric field on the linear and third-order nonlinear ACs and RICs for an on-center impurity in a weakly prolate (oblate) ellipsoidal QD is studied. In calculations, the variational method in the framework of perturbation within the effective mass approximation theory has been used to determine the energy levels and their wave functions. To come closer to the real situation, the electronic confinement is modeled by a finite potential well.

## 2. Theory

Let us consider an ellipsoidal QD denoted by $\Omega$, and indicate with $a$ and $c$ its semi-axis in the $x-y$ plane and along the $z$ axis respectively. The equation of the QD surface is:

$$\frac{X^2+Y^2}{a^2}+\frac{Z^2}{c^2}=1. \tag{1}$$

In the effective mass approximation, the Hamiltonian of an electron bound to an on-center donor impurity under the influence of electric field with finite potential is given as:

$$H=\frac{p^2}{2m}-\frac{e^2}{4\pi\varepsilon_0\varepsilon r}+U\left(\vec{r}\right)+|e|Fr\cos\alpha, \tag{2}$$

with

$$m=\begin{cases} m_i & r\in\Omega \\ m_o & r\notin\Omega \end{cases}, \tag{3}$$

$$\varepsilon=\begin{cases} \varepsilon_i & r\in\Omega \\ (\varepsilon_i+\varepsilon_o)/2 & r\notin\Omega \end{cases}, \tag{4}$$

$$U\left(\vec{r}\right)=\begin{cases} 0, & \frac{X^2+Y^2}{a^2}+\frac{Z^2}{c^2}<1 \\ U_0, & \frac{X^2+Y^2}{a^2}+\frac{Z^2}{c^2}\geqslant 1 \end{cases}, \tag{5}$$

where $m_i(m_o)$ and $\varepsilon_i(\varepsilon_o)$ are the effective mass and static dielectric constant in dot(barrier) material respectively. $U\left(\vec{r}\right)$ is the confinement potential of ellipsoidal QD, $F$ is the strength of the electric field along the $z$ direction, $\alpha$ is the angle between the electronic position vector $\vec{r}$ and the electric field direction. For the weakly prolate or oblate ellipsoid QD (ellipsoid is only slightly different from sphere) the problem may be solved within the framework of perturbation theory.

It is useful to change the variables as follows [12,15,19]: