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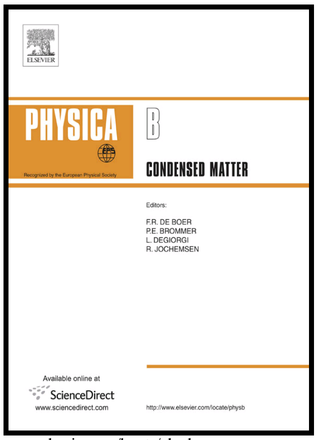

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Donor-impurity-related optical response and electron Raman scattering in GaAs cone-like quantum dots

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The donor-impurity-related optical absorption, relative refractive index changes, and Raman scattering in GaAs cone-like quantum dots are theoretically investigated. Calculations are performed within the effective mass and parabolic band approximations, using the variational procedure to include the electron-impurity correlation effects. The study involves $1s$-like, $2p_x$-like, and $2p_z$-like states. The conical structure is chosen in such a way that the cone height is large enough in comparison with the base radius thus allowing the use a quasi-analytic solution of the uncorrelated Schrödinger-like electron states.

Keywords: Donor impurity; Conical quantum dots; Raman scattering; Optical properties; Electronic structure

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I. INTRODUCTION

Due to decades of studies on quantum dot (QD) systems, there has been a significant development in the nanofabrication technology. Such structures have been considered as important candidates for new electro-optical devices [1–3] mainly due to the discrete energy spectrum resulting from the dimensional confinement. Driven by the technological applications of these low-dimensional structures in optical communications and quantum information processing [4–6], a big amount of research has been focused on the speed of light control in semiconductor nanosystems. Quantum dots of different shapes have been intensively studied since these systems enable confinement and charge carriers motion control in three dimensions by changing the type of geometric confinement. The optical and electronic properties of QDs can be tuned by means of some external and internal factors such as semiconductor composition [7], QD shape [8], impurity presence -and its position- [9–11], hydrostatic pressure [12], as well as the effects of static electric or magnetic fields [13–22].

In recent times, there has been a number of works on semiconductor QDs with conical shape both from the experimental and theoretical points of view (see, for example, the article of interference phonon modes [23]). They have shown remarkable potential for prospective applications in the fields of optoelectronics and quantum information, in devices such as QD LED and single photon sources (see for instance the articles [24–27]).

A subject that has been analyzed in several occasions is the possibility of providing an analytical solution for allowed quantum states in conical QDs [28–30]. The calculation of the energy spectrum of charge carriers in these systems has mostly dealt with numerical solutions of the effective mass differential equations. With the solutions for the carrier states, optical properties such as absorption and refractive index change, can be calculated [31]. It is also interesting the inclusion of impurity atoms into the conical QD, and the corresponding investigation on how it changes its optical properties when the QD size and impurity position are varied [32]. The study of QDs has been performed recently by means of the numerical computation of all the bound state energies and the wavefunctions corresponding to the heterostructure [40–42]. Particulary, the coefficients of second and third-harmonic generation for conical QDs have been obtained [43].

However, for practical use, it is highly desirable to have simple analytical expressions for the wavefunctions and the corresponding eigenvalues of the electronic states in this kind of structures. This is a fact that would greatly simplify the theoretical analysis of many properties of interest. One of such properties is the electron-related Raman scattering, which is a phenomenon that allows for the practical investigation of the spectrum of quantum