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Optical properties of spherical quantum dot in the presence of donor impurity under the magnetic field

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ABSTRACT

In this study, the binding energies of an on-center and off-center hydrogenic donor impurity in a spherical quantum dot with finite confinement potential under an applied external magnetic field are investigated in detail by using the matrix diagonalization method in the effective mass approximation. Depending on the calculated energies and wave functions, the linear, third-order nonlinear and total optical absorption coefficients between the ground and several excited states are examined by the iterative method in the compact density matrix approximation for the two-level system. The combined effect of donor position, magnetic field and dot size on binding energies and optical absorption coefficients is observed. The results show that these effects cause significant changes on donor binding energy and optical absorption coefficients.

1. Introduction

Impressive advances in material growth technologies such as molecular beam epitaxy and metal–organic chemical-vapor deposition have allowed the production of low-dimensional semiconductor systems (LDSSs) such as quantum wells (QWs), quantum well-wires (QWWs) and quantum dots (QDs) with different shapes and sizes [1–6]. QWs, QWWs and QDs confine carriers in one, two, and three spatial dimensions, respectively. As a result of the increased quantum confinement in LDSSs compared to bulk structures, significant changes occur in electronic and optical properties. QDs exhibiting atom-like phenomena with three-dimensional confinement of charge carriers, and therefore commonly called artificial atoms, are a leading member of the community of LDSSs that have an indisputable reputation when it comes to the production of high-performance microelectronic and optoelectronic devices. For this reason, there is a great interest in the investigation of QDs both theoretically and experimentally [7–10]. The main feature of QDs to consider is that their geometric shapes, dimensions, confinement potentials and bound electron numbers are adjustable, since it is possible to produce QDs with different properties by controlling these quantities by experiments.

The working mechanism of most optical devices, consisting of both bulks and nanoscale semiconductors, largely depends on the presence of impurities. Although existing technologies have the possibility to prepare high-purity QDs, the possibility of contamination is still inevitable during production. Studying impurities in QDs not only offers more possibilities to adjust electronic and optical properties, but also diversifies application spectra by inventing new the optoelectronic devices. Therefore, understanding the effects of impurities on the electronic and optical properties of QDs is crucial for the evolution of nanoelectronics, which has emerged as an area of increasing interest due to the possibilities it opens in applied physics [11–15]. Research on impurity states has gained more momentum due to the importance of QDs in physics and technological applications. The presence of impurities changes the energy states of quantum systems and enables the desired optical transitions to be achieved. A controlled optical transition has a great importance in the design of optoelectronic devices with adjustable emission or transmission characteristics and ultra-narrow spectral line width.

A natural effect of nanostructures is the confinement of charge carriers, and this quantum confinement causes increased energy states and dipole transition moments. Therefore, the optical response in nanostructures becomes larger than bulk materials [16]. This motivated researchers to investigate optical phenomena such as optical absorption coefficients (OACs) [17–19], optical rectification (OR) [13,20,21], refractive index changes (RICs) [19,22,23], second harmonic generation (SHG) [24–26] and third harmonic generation (THG) [27–29]. As a result, these nonlinear optical features have become the basis of many advanced optoelectronic devices such as laser amplifier [12], solar cell [30], infrared photodetector [31], optical switching [32], optical

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