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Dependence of electromagnetically induced transparency on pressure and temperature in a quantum dot with flat cylindrical geometry

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We demonstrate an electromagnetically induced transparency in a quantum dot having disk geometry under two radiation fields. It is found that electromagnetically induced transparency occurs in the system. Analytical expressions for the complex electric susceptibility, absorption, dispersion and group index are presented. The combined effects of external factors such as magnetic field, hydrostatic pressure, temperature and confinement length on the electromagnetically induced transparency are investigated. Our results may have potential applications in optical communication and quantum information processing.

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1. Introduction

Fast development in the fabrication and control of low dimensional quantum nanostructures such as quantum wells, quantum wires and quantum dots opens an avenue to investigate their optical and electronic properties. Such low dimensional nanostructures especially quantum dots are not only interesting for fundamental research due to their unique structural and physical properties relative to their bulk counterparts, but also offer fascinating potential for the fabrication and subsequent working of electronic and optical devices based on such systems. The nonlinear optical effects in these structures are much stronger than the bulk materials due to the existence of strong quantum

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confinement effects. Many researchers have made flurry of observations on nonlinear optical properties of quantum dots including optical absorption coefficients and refractive index changes [1], Rashba spin orbit coupling [2], nonlinear properties of shallow donor impurities in quantum dots [3], etc. These properties exhibit interesting applications in photo-electronic devices, such as far-infrared photo-detectors, electro-optical modulators, all optical switches, infrared lasers, semiconductor optical amplifiers, optical memories and optical switches [4–11].

External electromagnetic fields have become an interesting probe for studying the nonlinear optical properties of quantum nanostructures, both from the theoretical and technological point of view. Among them, the optical properties of quantum dots can be dramatically modified by using a secondary light beam approximately resonant with an internal process of the system using the effect of electromagnetically induced transparency (EIT). Currently, EIT has become the basic systems for studying optical properties of quantum dots. Over the past years, a lot of researchers have investigated the process of EIT in quantum dot systems [14–16]. EIT has spurred a lot of research activities both due to fundamental interests as well as possible device applications. It was firstly found theoretically and was then experimentally demonstrated by Imamoglu et al. [12,13]. The importance of EIT stems from the fact that it gives rise to greatly enhanced nonlinear susceptibility in the spectral region of induced transparency of the medium and is associated with steep dispersion. This phenomenon can be used to slow down light pulses, or even bring them to a complete stop. External factors such as electric field, magnetic field, laser field, hydrostatic pressure, temperature, and impurity are important parameters for studying the electronic and optical properties of nanostructures and have been extensively investigated. These factors can also have an immense effect on the process of EIT. The hydrostatic pressure modifies the semiconductor band structure and it effectively shifts the energy levels without altering the symmetry of the heterostructure system. The hydrostatic pressure modifications of the physical properties of low dimensional heterostructures are helpful for exploring the new phenomena and have been considered both experimentally and theoretically for many years [17–19]. Recently simultaneous effects of pressure and temperature on the binding energy and diamagnetic susceptibility of a laser dressed donor in a spherical quantum dot have been investigated by Vaseghi and Sajadi [20]. Liang and Xie [21] have investigated the combined effects of hydrostatic pressure and temperature on the optical absorption coefficient and refractive index changes of a hydrogenic impurity in a disc-shaped quantum dot with parabolic confinement in the presence of an external electric field have been investigated by using the perturbation method within the effective-mass approximation. Oyoko et al. [22] have calculated the effect of hydrostatic pressure and temperature on shallow-impurity related optical absorption spectra in single and double quantum wells. Peter et al. [23] have calculated the binding energies of donors in a single quantum well as a function of the pressure and temperature. Sokmen and Kasapoglu [24] have studied the intense laser field dependence of intersubband absorption coefficient in double-graded quantum well in the presence of electric field. The obtained results show that by changing the laser intensity together with the electric field and the well parameters the desired energy range or spectral range of interest for intersubband and also interband absorption peak position may be tuned. Duque et al. [25] have investigated the combined effects of intense laser radiation, hydrostatic pressure, and applied electric field on shallow-donor impurity confined in cylindrical-shaped single and double quantum dot using the effective mass and parabolic band approximations and a variational procedure. Very recently, a systematic experimental study on the optical properties of colloidal semiconductor nanocrystals as a function of temperature and pressure has been carried out by Pedrueza et al. [26]. The effect of temperature on the energy states of confined charge carriers in a semiconductor quantum dot were reported in many papers [27,28].

In the current work, we report computation of the nonlinear response of magnetic field, pressure and temperature on the electromagnetically induced transparency in a quantum dot having flat quantum disk geometry (QDG). Many researchers have paid more attention to the optical properties of low-dimensional structures; however, the effects of pressure and temperature on EIT have not been discussed in such a system. In this paper the detailed studies of the effects of variation of static magnetic field, hydrostatic pressure and temperature are made on the absorption, dispersion and group velocity of the probe light pulse. The paper is organized as follows: In Section 2, we describe the model and theoretical framework. The Hamiltonian and the relevant eigenenergies and eigenfunctions in a QDG, obtained using the effective mass approximation are presented analytically. The combined

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