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Influence of damping on the frequency-dependent polarizabilities of doped quantum dot

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ABSTRACT

We investigate the profiles of diagonal components of frequency-dependent linear (α_{xx} and α_{yy}), and first nonlinear (β_{xxx} and β_{yyy}) optical response of repulsive impurity doped quantum dots. The dopant impurity potential chosen assumes Gaussian form. The study principally focuses on investigating the role of damping on the polarizability components. In view of this the dopant is considered to be propagating under damped condition which is otherwise linear inherently. The frequency-dependent polarizabilities are then analyzed by placing the doped dot to a periodically oscillating external electric field of given intensity. The damping strength, in conjunction with external oscillation frequency and confinement potentials, fabricate the polarizability components in a fascinating manner which is adorned with emergence of maximization, minimization, and saturation. The discrimination in the values of the polarizability components in x and y-directions has also been addressed in the present context.

1. Introduction

Modern nanotechnology is cruising towards development of new high-performance devices with improved parameters. It has been found that the low-dimensional quantum systems exhibit more prominent nonlinear optical effects than the bulk materials, and possess widespread application in

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high-speed electro-optical modulators, far infrared photodetectors, semiconductor optical amplifiers and so on. Moreover, investigations of optical properties of these systems provide important information about the energy spectrum, the Fermi surface of electrons, and the value of electronic effective mass. In this context quantum dot has exhibited enough promises to be reckoned as a high performance semiconductor optoelectronic device. In view of this, the understanding of optical properties of impurity doped QD is important since the said properties of devices made from these materials are strongly affected by the presence of impurities. In practice, with QDs, the subtle interplay between new confinement sources and impurity potentials has set up new areas of research in this field [1–7]. Although the current technology has opened up opportunity to manufacture high purity QDs, the probability of impurity contamination still persists. In fact, during the fabrication of QDs on the basis of colloidal solution, the impurity can populate the QD surface. However, while the binding energy of impurity states in QDs have been extensively studied, the problem of optical properties has been bit less thoroughly investigated in presence of impurities.

The impurity potential modifies the dot confinement and thus provides a means of engineering the electronic structure of these materials by tailoring the shape and size. Such tailoring in turn tunes the energy spectrum toward producing desirable optical transitions. Moreover, in the optical transitions of QDs, the analysis of impurity states is essential since the confinement of quasiparticles in such structures enhances the oscillator strength of electron-impurity excitation. Added to this, the optical transition energy depends on the confinement strength (i.e. the quantum size) and makes the resonance frequency more tunable. These features are essential for the manufacture of optoelectronic devices with controllable emission and transmission properties and ultra-narrow spectral linewidths. As a consequence, impurity guided modulation of linear and nonlinear optical properties assumes importance because of practical applications in photodetectors and high-speed electro-optical devices [8,9]. The unique optical properties of doped QDs have made them fascinating candidates for various optoelectronic applications leading to important theoretical and experimental works on both linear and nonlinear optical properties of these structures [8,10–20].

Pursuing the advancement of science and technology, external probes have often been utilized to gain important information about the system. The external probes include, for example, the applied electric field, magnetic field, hydrostatic pressure, temperature, etc. The application of electric field is able to provide much valuable information about the confined impurities [21–23]. The electric field causes polarization of the carrier distribution with a consequent energy shift of the quantum states. The change, that occurs in the energy spectrum of the carrier could be used to control and modulate the intensity output of optoelectronic devices. Furthermore, the electric field could destroy the symmetry of the system and gives rise to nonlinear optical properties of the system. Among the nonlinear optical properties the second-order quantity is simplest and produces lowest-order nonlinear effect with magnitude usually stronger than higher-order ones. Thus, the effect of applied electric field on the optical properties of doped QDs is of immense importance for fundamental physics and device applications [8,9,13,24–41].

In view of device applications, engineering the materials by means of magnetic field and confinement strength bears recognizable signature on their nonlinear optical properties. The confinement potential, in particular, has significant effects on the physical properties of doped dots and the form of the confinement potential can be experimentally modulated [13,42–48]. A parabolic confinement potential is often considered to be an appropriate candidate to represent the potential in semiconductor structures [2,12,14,31,34,36] and has been actually exploited in the study of optical properties of doped QDs [17]. The parabolic potential particularly becomes appropriate when the QDs are fabricated by etching process on a quantum well, by ion implantation or by application of electrostatic gates.

The phenomenon of *damping* in QDs bears a lot of importance pertinent to fundamental physics as well as nanoelectronic applications. The manufacture of high quality single electron transistors [49], logic elements (quantum bits) [50], memory cells [51], and lasers based on QD heterostructures [52] maintains close relation with damping. The phenomenon appears more important since nanoelectronic devices are often incorporated into large integral circuits consisting of closely packed structural elements [53]. The characteristic length between the elements of integral circuits generally falls within the range of several tens of nanometers. These nanoelectronic devices mutually influence one another and also get affected by the metallic and doped semiconductor fragments of the heterostructures and