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Intersubband optical properties of a two electron GaN/AlN constant total effective radius multi-shells quantum rings

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ABSTRACT

In this study, we have investigated the effect of the number of wells and quantum ring thickness on optical properties of a GaN/AlN two electron constant total effective radius multi-shells quantum rings (2e-CTER-MSQRs). We found that by using the number of wells and inner quantum ring radius complete wavefunction engineering is possible (localization of the wavefunction within a special region in the system). When inner quantum ring radius R_0 or number of wells changes resonant energies of linear absorption coefficient do not undertake any red or blue shift. Thus, CTER-MSQRs are suitable systems when we want to manipulate the amplitude of the linear absorption coefficient or absolute value of the linear refractive index changes without any red or blue shift in the resonant energies. When number of wells increases the from 2 to 6, linear absorption coefficient and absolute value of the linear refractive index changes monotonically decreases by a factor close to two. Further increasing of the number of wells, from 6 to 12, leads to increasing of the linear absorption coefficient amplitude and absolute value of the linear refractive index changes by a factor close to three. Single quantum well 2e-CTER-MSQRs has maximum absorption among the studied systems. Finally, when inner ring radius R_0 increases, linear absorption coefficient and absolute value of the linear refractive index changes monotonically decreases.

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1. Introduction

With advances in lithography and epitaxial techniques, fabrication of a variety of quantum structures became possible in which carriers can be confined quantum-mechanically [1–4]. In quantum dots (QDs) and quantum rings (QRs), the electrons are confined in all three dimensions. QDs and QRs have usually been regarded as artificial atoms. Number of electrons in these artificial atoms can be tuned by altering experimental conditions. Nowadays, single electron charging of QDs is also possible [5]. The resulting few-electron problems have been extensively studied theoretically for QDs [6–8] and QRs [9–11]. Some optical properties of QRs have been also investigated in recent times. While studding the optical properties of two-electron QRs [12], it was revealed that intersubband optical absorptions strongly depend on the ring radius, electron–electron interaction, and the incident optical intensity. Study of the optical properties of a donor impurity in QRs by the same research group [13] show that, the confinement strength, the incident optical density and the ring radius have a great effect on the linear, the third-order nonlinear and total absorption spectra. When they investigated the optical rectification coefficient in a quantum ring [14], they found that, the second-order nonlinear optical rectification coefficient of a hydrogenic QR are strongly affected by the geometrical size and chemical potential of the pseudopential, the hydrogenic impurity and the external magnetic field. Finally, investigation of the second and third harmonics generation in a quantum disc with inverse square potential harmonics generation [15] proved that due to the electric dipole selection rules, the system have second harmonic generation coefficient identically zero for all the values of incident frequency while the generation of third optical harmonics was significantly dependent on the values of the different input parameters such as magnitudes of the parabolic confinement and the applied magnetic field. Based on these optical properties, optoelectronic devices can also been fabricated. Device fabrications are a strong motivation of the researchers in this field of study. There are different reasons to use QRs as a photo-detector : (A) Quantum ring inter-subband photo-detectors (QRIPs) can detect a wide range of electromagnetic frequencies from IR to THZ [16,17]. (B) High performance QR detector for terahertz range can be achieved [18]. (C) Because of more confinement in QRs, the energy levels are closer to conduction band edge and thus it is expected to have higher dark current for a QRIP in comparison to other types of low dimensional semiconductor photodetectors. Dark current can affect the performance of any detector, and it must be very small to attain high operation temperature and enhance specific detectivity [19]. In the meantime, by means of Raman spectroscopy the strain state of GaN/AlN QDs has been obtained previously [20]. Its influence on the internal electrostatic potential has been analyzed and found that the piezoelectric and spontaneous contributions have opposite sign, partially canceling each other (see conclusion part of Ref. [20]). Thus, we did not include the strain effect.

In our previous works [21–25], we have started to investigate some properties of GaN/AlN Constant Total Effective Length Multiple Quantum Wells (CTEL-MQWs) based on III–V semiconductors. Our motivation for these studies was a technological point of view to have smaller device sizes. For this purpose we have retained total length of the system constant. We have investigated the effect of the number of wells [21] and the external magnetic field [22–24], external electric field [25] and electronics structure of the system [24] and in the meantime proved the validity of our calculations procedure. According to the importance of the QDs and QRs optical properties which we have described above, we have changed our system and studied the effect of the number of wells and quantum ring thickness on optical properties of a Two Electron GaN/AlN Constant Total Effective Radius Multi-Shells Quantum Ring system (2e-CTER-MSQRs).

2. Formalism

In the framework of the effective mass approximation, by considering two electrons moving in a constant total effective radius multi-shells quantum rings (CTER-MWQRs), Hamiltonian is given by [26,27]: