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Non-linear optical processes involving excited subbands in laser-dressed quantum wires with triangular cross-section

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HIGHLIGHTS

- A quantum wire with triangle cross section under intense laser field is studied.
- The effective mass approximation and the finite element method are used.
- Conduction subbands strongly depend on the laser field parameter.
- THG, DC Kerr effect, and EA susceptibilities are changed by the laser field.
- Two polarizations of the pump light with respect to the laser field are discussed.

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ABSTRACT

The conduction subband structure of a triangular cross-section GaAs/AlGaAs quantum well wire under intense laser field is theoretically investigated by taking into account a finite confining potential. The calculation of the subband energy levels is based on a two-dimensional finite element method within the effective mass approximation. It is shown that a transversally polarized laser field non-uniformly shifts the subband energy levels and could be used for tuning the intersubband transitions and altering the related optical susceptibilities. We found that the non-resonant laser field allows the magnification and the red- or blueshift of the third-order non-linear susceptibility peaks for particular polarizations of the pump light and proper laser parameter values. The effects of the laser dressing field on the intersubband third harmonic generation and quadratic electro-optical process are discussed.

1. Introduction

Since the eighties progress in the physics of semiconductor quantum wells (QWs) and their applications has encouraged many scientists to study heterostructures of even lower dimensionality [1]. The development of diverse methods for engineering low-dimensional nanostructures has allowed studying quantum well wires (QWWs) of various compositions, sizes, and shapes [2–8]. The theoretical study of the electromagnetic field effects on the electronic and optical properties of low-dimensional systems may be very important for potential technical applications. It was demonstrated that for an electron confined in a quantum structure and subjected to a non-resonant intense laser field (ILF), the energy levels and wave functions are considerably modified [9–18]. The dressing effects of a THz ILF on the confinement potential of QWWs may be significant for designing new tunable QW lasers, optical modulators and ultra-fast infrared detectors. Relevant experiments have been conducted on the optoelectronic properties of both bulk semiconductors and low-dimensional heterostructures under intense dynamic fields [19–22]. The first observation of the exciton Stark shift under non-resonant ILF has been reported by Peyghambarian et al. [19]. Knox et al. have investigated the femtosecond dynamic Stark effect in GaAs QWs in extreme-low and high-intensity electric field limit [20]. Asmar et al. have studied quasi-two-dimensional electron gases in $GaAs/Al_xGa_{1-x}As$ heterostructures dressed by ILFs in a frequency range from 0.2 to 3.5 THz [21]. The band-gap luminescence from doped GaAs under mid-infra-red radiation has been observed by Mori et al. [22].

The tunability of the intraband transitions is one of the

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fundamental but not yet sufficiently explored properties of the quantum structures under laser fields. Since it can be used experimentally in a controlled way, the laser field becomes a possible mean of controlling the optoelectronic devices. These aspects motivate the realization of further studies focused on the subband structure and the electronic properties of one-dimensional systems under ILFs, as well as on the various optical processes in QWWs. Non-linear optical process in general may be very useful for designing higher-frequency coherent light sources. Combining the nonlinear techniques with the relatively low-cost, compactness, conceptual simplicity and optical integrability of semicondcuctor quantum structures is a good motivation for theoretical investigations in this field.

Polaron effects on third-harmonic generation (THG) in cylindrical QWWs with a finite [23] and infinite [24] confining potential have been studied by Yu et al. They found that the THG coefficient is greatly enhanced and its peak shifts to the higher photon energy when the influence of electron–phonon interaction is taken into account. The THG in cylindrical parabolic QWWs with applied electric [25] and magnetic [26] fields have been also theoretically investigated.

Recently, the study of optical properties has been extended to QWWs with particular geometries. There are-for instance-reports on the influence of the electron–hole interaction on the electro-optical properties of hyperbolic QWWs [27], the hydrostatic pressure effect on the intersubband (ISB) optical absorption and refractive index changes in V-groove QWWs [28], and the optical absorption in asymmetric graded ridge QWWs [29]. Using the infinite confining potential model, Khordad et al. have investigated the optical properties of the QWW with equilateral triangle cross section [30] and the second- and third-harmonic generation in GaAs QWWs with triangular cross-section [31]. They found that, by optimizing the confinement potential, a maximum THG can be obtained and the corresponding resonant peaks shift towards lower energies by increasing the size of the triangle side. Very recently, Duque and collaborators [32] presented the results of the calculation of the linear and nonlinear optical absorption and relative change of the refractive index associated with $1s \rightarrow 2p$ transitions between donor states in a QWW of triangular cross-section. Niculescu et al. have reported a study of the magnetic field effect on the THG in triangular cross section QWWs [33]. Recently, we have presented a study on the ILF effects on the linear and nonlinear optical properties in a semiconductor QWW with triangle cross section [34].

The main objective of this work is the theoretical study of the laser field effects on the ISB third-order nonlinear susceptibility (NLS) in GaAs/$Al_xGa_{1-x}As$ QWWs with equilateral triangle cross section. In this regard, we consider a finite potential barrier and we calculate the subband states under the action of an ILF which is assumed to be non-resonant with the optical transitions and linearly polarized perpendicularly to the triangle side. The calculation of the subband structure is based on the finite element method (FEM) within the effective mass approximation. The third-order NLSs related with the ISB transitions are calculated within the density-matrix approach using the perturbation theory. We neglect the structural imperfections of the QWWs and also the fact that a monodisperse population of real quantum wires has some inherent size dispersion. Furthermore, in our paper we do not take into account the processes relevant for ISB dephasing (phase-destroying carrier–carrier and carrier–phonon scattering and scattering from the quantum structure disorder potential). Instead we emphasize more the interesting possibilities opened by the use of the laser-dressing effect on the 1D quantum structures: frequency shifting and magnitude changing of the NLS peaks associated with the THG and the quadratic electro-optical effect (QEOE). We discuss the dependence of the DC Kerr effect and the electro-absorption (EA) process on the laser dressing parameter, for all allowed ISB transitions and relevant polarizations of the pump light.

The structure of the work is the following: Section 2 briefly presents the theoretical model. The corresponding results and discussion are given in Section 3. Finally, Section 4 contains the main conclusions of the study.

2. Theory

The quantum structure consists of a GaAs "wire" embedded in an $Al_xGa_{1-x}As$ matrix. The transverse cross section of the QWW is

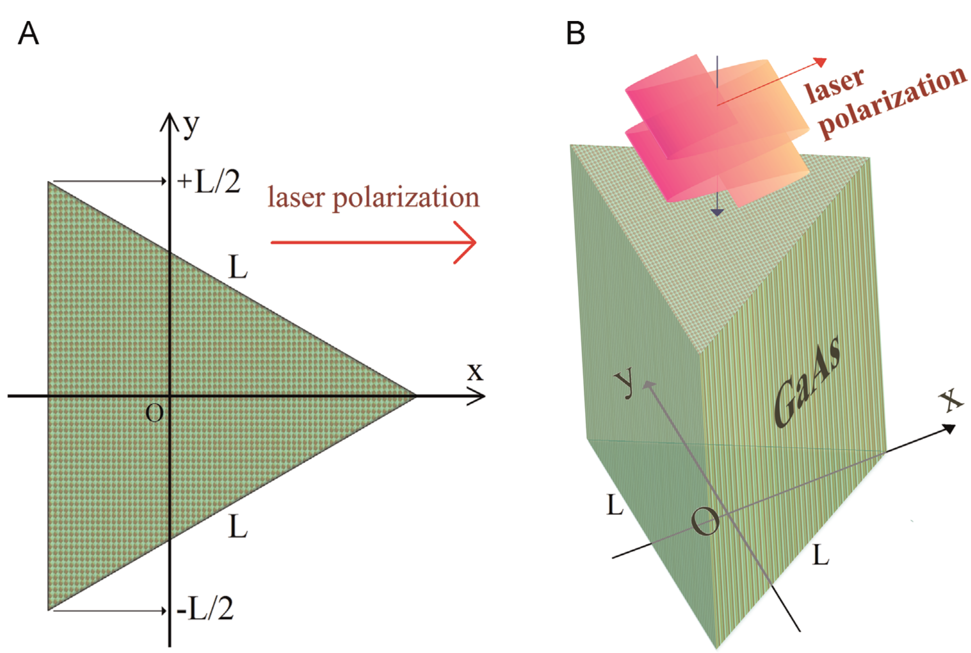

Fig. 1. Schematic of the GaAs quantum well wire under an ILF transversally polarized. (A) Triangular cross-section of the QWW. The origin of the (x, y) plane was chosen at the orthocenter of the triangle. (B) Lateral view of the QWW interacting with the ILF. The $Al_xGa_{1-x}As$ surrounding matrix is not depicted here.