Superlattices and Microstructures 61 (2013) 124–133

Contents lists available at SciVerse ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Effect of intense laser field on the nonlinear optical susceptibilities in an asymmetric single quantum well

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ARTICLE INFO

Article history:
Received 27 December 2012
Received in revised form 1 May 2013
Accepted 2 June 2013
Available online 14 June 2013

Keywords:
Laser radiation effects
Excitons
Eigenvalues and eigen functions
Fourier series
Optoelectronic devices
Infrared detectors

ABSTRACT

In the present paper, the effect of a high-frequency laser field on a single asymmetric rectangular quantum well is studied in the Fourier series method. The effect of laser field on the confining potential of the quantum well is taken through the laser dressing parameter which depends upon the strength of intensity and the magnitude of frequency of the laser field. The step type confining potential of the rectangular asymmetric well is modified by the laser dressing parameter to a smooth function. In this quantum well, linear, third-order nonlinear, nonlinear optical rectification and second harmonic generation susceptibilities under another laser source with low frequency are calculated using the density matrix method. The linewidths for susceptibilities are estimated taking the electron scattering with the longitudinal optic phonon. Compared to laser undressed well, the nonlinear optical properties in the laser dressed well are blue shifted and enhanced due to larger energy separations and oscillator strengths, respectively.

1. Introduction

In the last two decades, there has been considerable interest in the nonlinear optical properties of the semiconductor quantum well (QW) systems as a result of important advances in both the epitaxial growth of the semiconductor heterojunctions and the laser technologies. Using the molecular beam epitaxy method, the QWs with a variety form of confining potentials have been grown in the

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0749-6036/$ - see front matter
http://dx.doi.org/10.1016/j.spmi.2013.06.002

laboratory. With the availability of intense CO_2 THz laser source in recent years, strongly laser-driven semiconductor heterostructures have received attention [1]. The effect of laser field on the semiconductor QW systems is taken through the renormalization of electron confining potential [2].

With a second low-energy laser source, the optical properties in a QW are usually studied. The carrier confinement in a QW results in several nondegenerate energy levels with narrow intersubband energy separations. The optical properties can be enhanced dramatically in the QW systems compared to bulk semiconductors. This happens as the oscillator strengths in the semiconductor QW structures are larger than those in the bulk semiconductors. Moreover, infrared absorption and emission of photons are possible due to narrow intersubband separations [3]. Based on the intersubband transitions, a number of device applications such as far-infrared photodetectors [4], electro-optical modulators [5] and infrared lasers [6] have been proposed and realized.

The linear and nonlinear intersubband absorption coefficients within the conduction band of a laser dressed square [7], graded [8], inverse V-shaped [9] and compositional asymmetric [10] AlGaAs/GaAs quantum wells have been studied with and without an applied electric field. The absorption coefficients are found to get enhanced in the laser dressed QWs due to the renormalization of confining potentials. When the intensity of the laser source is high, the absorption spectra in an asymmetric QW or in a biased QW are bleached due to strong nonlinear absorption coefficient.

The calculation of second-order susceptibilities requires an asymmetric QW which can be achieved either by using the sophisticated material growth technology or by applying external electric field to the symmetric QW. The structural asymmetry can be grown by the molecular beam epitaxy method through compositional asymmetric QW [11] or asymmetrically coupled quantum wells [12]. The asymmetry in the structurally symmetric QW can be introduced by an applied dc electric field [13,14].

The susceptibility for nonlinear optical rectification (NOR) has been studied in a biased rectangular QW [15–17], an asymmetric double triangular QW under applied electric field [18] and a step QW [19]. The susceptibility for second harmonic generation (SHG) has been calculated in a symmetric QW under applied electric field [20,21] and an asymmetric single QW under hydrostatic pressure [22]. It has been found that the nonlinearities in absorption coefficient, NOR and SHG are much higher in a compositional asymmetric well than in a biased symmetric QW. To the best of our knowledge, the second-order optical nonlinearities for NOR and SHG have not been calculated in a laser dressed single asymmetric rectangular quantum well (ARQW) where it is expected that the nonlinearities in optical properties will be further enhanced due to modification of the confining potential of the QW.

In the present work, the effect of THz laser field on the confining potential of a single ARQW is studied. The energies, envelope functions and intersubband linewidths are calculated in the Fourier series method. The susceptibilities for linear, third-order nonlinear, NOR and SHG due to a low-frequency laser radiation source are calculated in the density matrix approach. The results obtained with laser dressed confining potentials are compared with those obtained in the QW under zero optical field.

2. Theoretical methods

A monochromatic laser radiation field with THz frequency Ω and vector potential $A(z,t)$ is incident along the growth direction (z-direction) of the QW. In the dipole approximation, $\mathbf{A}(z,t) \approx \mathbf{A}(t) = \mathbf{e}_z A_0 \cos \Omega t$, where $\mathbf{e}_z$ is the unit vector of polarization and A_0 is the amplitude of the vector potential. By applying the time-dependent transition $z \to z + \alpha(t)$, the effective mass equation in the momentum gauge describing the interaction dynamics in the laboratory frame of reference is transformed as [23–25]

$$\left[-\frac{\hbar^2}{2}\frac{\partial}{\partial z}\frac{1}{m^*(z)}\frac{\partial}{\partial z} + V[z+\alpha(t)]\right]\phi(z,t) = i\hbar\frac{\partial \phi(z,t)}{\partial t}, \tag{1}$$

where $V[z+\alpha(t)]$ is the laser driven dressed confining potential. The classical quiver motion of an electron in the laser field is given by

$$\alpha(t) = \mathbf{e}_z \alpha_0 \sin \Omega t \qquad \alpha_0 = \frac{eA_0}{m^*(0)c\Omega}, \tag{2}$$