Optik 139 (2017) 256–264

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Comparison of asymmetric double parabolic-inversed parabolic quantum wells for linear optical (1–2) transition

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ARTICLE INFO

Article history:
Received 2 January 2017
Accepted 2 April 2017

PACS:
73.21.Fg
78.67.De
78.67.-n

Keywords:
Asymmetric double parabolic and inverse parabolic quantum wells
Electronic and optical properties
Linear optical absorption
Linear optical rectification
Refractive index change
Resonant peak
Barrier width

ABSTRACT

In present study, for asymmetric double parabolic quantum well (ADPQW) and asymmetric double inverse parabolic quantum well (ADIPQW) the linear optical absorption (OA) coefficient, the linear refractive index change (RIC), resonant peaks of the linear OA and the optical rectification (OR) coefficients are examined as dependent on the structural parameters (barrier width (b) and Al concentration at the well center (σ)). The results display that the variation of all OA and OR coefficients and RIC depend on b and σ-parameter. I have also shown that the σ-parameter has a significant effect on the electronic and optical properties of ADPQW and ADIPQW, and that the energy levels and the dipole moment matrix elements vary depending on the shape of the limiting potential. The intersubband absorption spectrum in the ADPQW shows the blue shift by increasing the b and σ values. Whereas the absorption spectrum for ADIPQW shows blue shift for $\sigma = 1$ with increasing b-values, this spectrum shows red shifts for $\sigma = 5$. The electro-optic properties of these structures promise many potential applications in high speed spatial light modulators and switches. So, it can be adjusted RIC and the resonant peak size of the linear OA and OR coefficient by changing Al density at the well center in addition to the barrier dimensions.

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1. Introduction

There is considerable interest in the electronic and optical properties of asymmetric quantum wells (AQW) because they are ideal systems for studying electromagnetic radiation from semiconductor hetero-structures [1–9]. This interest is mainly due to the practical applications of high-speed electronics of quantum devices and the production and detection of terahertz bandwidth signals. It is well known that the non-linear optical properties of the semiconductor quantum well (QW) depend predominantly on the asymmetry of the limiting potential. By changing the semiconductor QW profile, both the state energy levels and the wave functions change and develop various physical properties depending on them. Due to the wide variety of technological applications, semiconductor QW structures have been extensively investigated in different situations including magnetic, electrical and intense laser fields, hydrostatic pressure, temperature and external perturbations such as different doping operations. Rather than a rectangular profile, the QWs, which consist of inhomogeneous pieces, show increasing interest due to their various applications. In most investigations, there have been experimental and theoretical studies on the effects of electric, laser and magnetic fields and hydrostatic pressure in square quantum well (SQW) [10–15]. Apart from the well-known SQW, parabolic quantum well (PQW) [14,16–18], inverse parabolic quantum well (IPQW) [17,19], graded quantum well (GQW) [20–23], V-shaped quantum well (V-QW) [14,24] have been studied.

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http://dx.doi.org/10.1016/j.ijleo.2017.04.003
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Symmetric double quantum well (DQW) structures are interesting because they relate to the electronics and optical device industry, as by the interlayer distance between wells and the barrier changes, an improvement in the transport properties is realized [25–27]. The main advantage that multiple semiconductor structure offers over the single quantum wells is the enhanced exciton electro-optic response. In the construction of an asymmetric double quantum well (ADQW) consisting of two different width wells connected to a thin bar, the lower subbands in each well have different energy levels in the flat band conditions; For this reason, the carrier material that tunneled from the narrow quantum well to the large quantum well becomes easy and important. ADQW structures are ideal structures to investigate carrier transport mechanisms when compared to symmetric double and single quantum wells [28–32].

The optical processes involved in the intersubband transitions in low dimensional semiconductor systems were noted due to the strong quantum confinement effect and allowed to reach the great values and resonance states of the dipole transition matrix elements to differentiate the energy between these levels. When the system is significantly altered in its limiting potential, optical properties and associated state energy levels are significantly affected. The optical properties of the structural parameters related to the limiting potential and corresponding relative state energy levels, as well as the transitions in the conduction band of the quantum wells, are very important problems. So, the effect of the barrier width (b) and the Al concentration at the well center (σ) on the resonant heights of the linear optical absorption (OA) and the linear optical rectification (OR) coefficients, the linear OA coefficient and the linear refractive index change (RIC) both in asymmetric double parabolic quantum well (ADPQW) and asymmetric double inverse parabolic quantum well (ADIPQW) is investigated in this work. As far as I know, RIC and the resonant peaks of OA and OR for ADPQW and ADIPQW with different b and σ-values have not been calculated. Such systems provide the desired optical properties for device outlines, which can be used to control and modulate the density output of semiconductor devices.

2. Theory

Within effective-mass approximation, the subband energy levels and wave functions for electrons in GaAs–$Ga_{1-x}Al_xAs$ ADPQW and ADIPQW can be obtained by solving the Schrödinger equation with a suitable Hamiltonian. The one-dimensional Schrödinger equation is given by

$$\left(\frac{-\hbar^2}{2m^*}\frac{d^2}{dz^2}+V(z)\right)\Psi(z)=E\Psi(z) \tag{1}$$

where "m^* is the effective mass of electron, $V(z)$ is the confinement potential for the electron in z- direction". $V(z)$ can take for ADPQW and ADIPQW, respectively.

$$V^{ADPQW}(z)=\begin{cases}\frac{V_0}{\sigma_l}\left(\frac{z_1}{L_l/2}\right)^2\Theta\left(L_l/2-|z_1|\right)+V_0\Theta\left(|z_1|-L_l/2\right)+\\ \frac{V_0}{\sigma_r}\left(\frac{z_2}{L_r/2}\right)^2\Theta\left(L_r/2-|z_2|\right)+V_0\Theta\left(|z_2|-L_r/2\right)-V_0\end{cases} \tag{2 a}$$

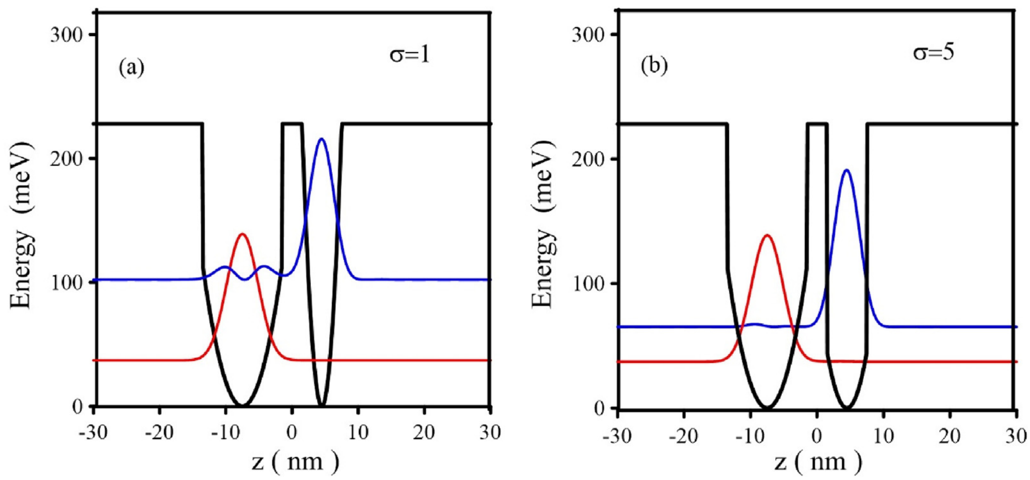

Fig. 1. The potential profile (black curves) and the two lowest energies with their squared envelope wave functions of ADPQW structure for a) b = 3 nm, σ = 1; b) b = 3 nm, σ = 5 (The red and blue curves are for the ground and second energy levels, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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