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Intense laser field effects on a Woods–Saxon potential quantum well

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ABSTRACT

This paper presents the results of the theoretical study of the effects of non-resonant intense laser field and electric and magnetic fields on the optical properties in an quantum well (QW) make with Woods–Saxon potential profile. The electric field and intense laser field are applied along the growth direction of the Woods–Saxon quantum well and the magnetic field is oriented perpendicularly. To calculate the energy and the wave functions of the electron in the Woods–Saxon quantum well, the effective mass approximation and the method of envelope wave function are used. The confinement in the Woods–Saxon quantum well is changed drastically by the application of intense laser field or either the effect of electric and magnetic fields. The optical properties are calculated using the compact density matrix.

1. Introduction

The structure of space quantized energy levels is the key feature of any optoelectronic nanostructure-based device. Mostly it is a result of geometry and dimensions of the concrete structure and

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therefore it is quite difficult to change arrangement of the energy levels when the structure has already been grown. Therefore any methods allowing for that without modifying the physical nature of the structure attract great attention. One of such method is the influence of a so-called nonresonant intense laser field (ILF) on the quantum confined structures [1–3], and this is the first key feature, we use in our article. Second is that we use the Woods–Saxon potential for describing the QW spatial confinement. It is well known [4–7] that using the Woods–Saxon potential provides big flexibility and apparently in treating the obtained results as it has only two adjustable parameters. Hence in this work we are going to study interaction of ILF with QW described by the Woods–Saxon potential. It has to be noted that authors of the work [8] made similar investigations with rectangular QW energy profile and they predicted the transformation of a single QW into the double QW structure for a big ILF parameter α_0. Other authors [9,10] have used the Woods–Saxon potential to model confinement in a semiconductor quantum dots and calculated nonlinear optical responses. It has to be concluded that it is of interest to compare the results obtained for two different models of the QW. Besides we consider the influence of the ILF on absorption coefficient and refractive index change of the structure under study at strong magnetic (applied in the plane of the QW) and electric (applied in the growth direction) fields.

2. Theoretical framework

The Hamiltonian for the one electron in the Woods–Saxon confining potential of quantum well under effects of the ILF, DC electric field applied along the growth direction of the structure and the magnetic field oriented perpendicular to the one:

$$H = \frac{1}{2m^*}\left[\vec{p} + \frac{e}{c}\vec{A}(\vec{r})\right]^2 + V_{WS}(z, \alpha_0) + eFz \tag{1}$$

Here m^* is the effective electron mass, e – unit charge, c – velocity of light in vacuum, z coordinate along the growth direction of the structure, $\vec{A}(\vec{r}) = (0, -Bz, 0)$ (B is the magnetic field strength), $\vec{p}$ – momentum operator, F - electric field strength.

$V_{WS}(z, \alpha_0)$ is the Woods–Saxon potential of the quantum well with applied ILF with nonresonant frequency ϖ and laser dressing parameter $\alpha_0 = eF_0/(m^*\varpi^2)$, F_0 is the ILF amplitude. $V_{WS}(z, \alpha_0)$ was calculated by the method proposed in Lima et al. [8]. Without ILF it takes the form of:

$$V_{WS}(z) = \frac{V_0}{1 + \exp[(Z_0 - z)/\gamma]} + \frac{V_0}{1 + \exp[(Z_0 + z)/\gamma]}, \tag{2}$$

where $Z_0 = L/2$ with L is a quantum well width ($z = 0$ corresponds to the center of the well), γ is a parameter describing the slope of the barrier of the potential profile. The quantum confined energy levels and corresponding wave functions for the Hamiltonian above has been found numerically using diagonalization method [12].

The absorption coefficient $\beta(\omega)$ and refractive index change $\frac{\Delta n(\omega)}{n_r}$ of the transitions between the first and second quantum confined subbands for z-polarized radiation has been calculated in accordance with [13,14]:

$$\beta(\omega) = \omega\sqrt{\frac{\mu}{\varepsilon_R}}\frac{|M_{21}|^2\sigma_V\hbar\Gamma_{12}}{(\Delta E - \hbar\omega)^2 + (\hbar\Gamma_{12})^2} \tag{3}$$

and the relative refractive index change are:

$$\frac{\Delta n(\omega)}{n_r} = \frac{\sigma_V|M_{21}|^2}{2n_r^2\varepsilon_0}\frac{\Delta E - \hbar\omega}{(\Delta E - \hbar\omega)^2 + (\hbar\Gamma_{12})^2} \tag{4}$$

In these expressions, μ is the magnetic permeability, ε_0 – the vacuum permittivity, n_r – the refractive index and ε_R is the real part of the permittivity of the material. $\Delta E = E_2 - E_1$ is the energy difference between the two first electronic states and $M_{21} = |\langle\Psi_2|ez|\Psi_1\rangle|$ is the dipole matrix element. Γ_{12} is the