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Second-order nonlinear optical properties in a strained InGaN/AlGaN quantum well under the intense laser field

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A B S T R A C T

In this work, the optical rectification and the second harmonic generation coefficients in a strained InGaN/AlGaN quantum well are studied. Impacts of the spontaneous and piezoelectric polarization fields on the potential profile are taken into account. The energy levels and wave functions are calculated using the fourth-order Runge–Kutta method and optical properties are obtained using the compact density matrix approach. Effects of intense laser field, In composition, Al composition, the well width and barrier width on the second-order nonlinear optical properties are investigated. Results reveal that the confinement potential is considerably affected by the laser field and internal electric field. Results also indicate that the resonant peaks experience a red-shift with increasing the laser field strength and barrier width. Moreover, the resonant peaks suffer a blue-shift with the increase in In and Al compositions.

1. Introduction

In recent years, the wide band gap GaN-based semiconductor quantum wells (QWs) such as InGaN/GaN, AlGaN/GaN and InGaN/AlGaN heterostructures have attracted much attention because of their unique physical characteristics and potential applications. These ternary compound semiconductor

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heterostructures are good candidates for some important electronic devices such as high-electron mobility transistors (HEMTs) [1] and optoelectronic devices such as light emitting diodes (LEDs) [2]. The III-nitride semiconductors with wurtzite crystal structure have spontaneous polarization and exhibit much large piezoelectric polarization than the zinc-blende structures [3,4]. These polarization fields can produce a strong internal built-in electric field (in order of MV/cm) which plays a very important role in electronic and optical properties of wurtzite GaN-based QWs. Within this context, a great deal of efforts has been devoted to investigate the electronic and optical properties of the strained nitride semiconductor quantum heterostructures [5–18].

Among the nonlinear optical properties, more attention had been paid to the second-harmonic generation (SHG) [17–26] and optical rectification (OR) [23–33] coefficients. It is well known that these even-order nonlinear optical properties are only non-zero in asymmetric quantum systems. In conventional GaAs-based QWs, breaking the symmetry of the confinement potential profile can be obtained by applying an external electric field or by an asymmetric composition or both. But, as mentioned before, the wurtzite GaN-based QWs have the strong internal built-in electric field which breaks the symmetry of these systems.

On the other hand, the advent of high-power tunable laser sources such as free-electron lasers, has opened a new area in the study of the interaction between the laser field and electrons in semiconductors and related nanostructures. Recently, several authors investigated the effects of intense laser field (ILF) on the electronic and optical properties of GaAs-based nanostructures such as: square [34–37], graded [37,38], semi-parabolic [39], parabolic [40], double-square [41], double-graded [42], V-shaped [43,44] and Pöschl–Teller [26] QWs, cylindrical quantum wire [45,46] and spherical quantum dot [47].

To our knowledge, the effect of non-resonant ILF on the OR and SHG coefficients of the strained wurtzite QWs have not been studied yet. In this work, we will investigate the effects of the intense laser field and structural parameters such as the Indium composition, Aluminium composition, the well width and barrier width on the OR and SHG coefficients of the strained InGaN/AlGaN QWs.

The paper is organized as follows: We describe the theoretical framework in Section 2. Then, the results are discussed in Section 3, and finally, the conclusions are given in Section 4.

2. Theory

2.1. Electronic structure

We consider a strained single QW consisting of an $In_yGa_{1-y}N$ well with thickness L_w, and two $Al_xGa_{1-x}N$ barriers with thickness L_b. The layers are grown on GaN substrate along *c*-axis direction denoted as z direction. The internal built-in electric field in the well (F_w) and barrier (F_b) layers are given by [48,49],

$$F_w = \frac{2(P_b - P_w)L_b}{\varepsilon_0(\varepsilon_b L_w + 2\varepsilon_w L_b)} \tag{1}$$

$$F_b = \frac{(P_w - P_b)L_w}{\varepsilon_0(\varepsilon_b L_w + 2\varepsilon_w L_b)} \tag{2}$$

where ε_0 is the vacuum permittivity, ε_v and P_v are the dielectric constant and total polarization of layer $v(=w,b)$. The total polarization in each layer is given by

$$P_v = P_v^{sp} + P_v^{pz} \tag{3}$$

where P_v^{sp} and P_v^{pz} are spontaneous and piezoelectric polarizations, respectively. The piezoelectric polarization is written as [17,48]

$$P_v^{pz} = 2\frac{a - a_v}{a_v}\left(e_{31} - e_{33}\frac{c_{13}}{c_{33}}\right) \tag{4}$$

where a is the lattice constant of the substrate, a_v is the lattice constant of the well or barrier, $c_{13},\ c_{33}$ and $e_{31},\ e_{33}$ are elastic and piezoelectric constants, respectively [3,4].