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Optical absorption coefficint of GaN/AlN multi-shells quantum dots: Optical intensity and magnetic field effects

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ABSTRACT

In this work we have studied effect of the optical intensity, magnetic field, number of wells and quantum dot radius on optical properties of an AlN/GaN constant outer radius multi-shells quantum dots. We have shown that, by increasing of the intensity the total absorption coefficient decreases. Higher magnetic fields and smaller outer quantum dot radiuses lead to the more rapidly decrease of the third order absorption coefficients when the number of wells increases. In systems with smaller outer quantum dot radiuses, the third order absorption coefficient more rapidly decreases. The absorption coefficient of the systems with more number of wells grows more slowly than that of systems with fewer numbers of wells. But, the absorption coefficient of the systems at higher magnetic fields grows less slowly than that of systems at lower magnetic fields. Finally, these results can help experimentalists to fabricate their optical devices more easily since they can now have a deeper physical insight when they changes magnetic field values, number of wells and outer quantum dot radiuses. This is because; by using of these parameters they can produce systems with high or low absorptions and high or low nonlinearities.

1. Introduction

Both from the fundamental physics point of view and from the device development one (such as infrared photodetectors and lasers), intersubband transitions in quantum confined semiconductor heterostructures have been an interesting subject. Quantum well nanostructures and detectors have also been extensively studied till now and this was because of the available epitaxial growth techniques such as molecular beam epitaxy (MBE) and chemical vapor deposition [1–4]. Due to the reduced intersubband relaxation times, delta-like sharp density of states and lower detector noises in zero-dimensional quantum dots [5,6], intersubband absorption in these quantum structures has outstanding advantages in optical applications when we compare them with two-dimensional quantum well nsnostructures.

Because of the abovementioned facts, during last few years, investigations of the low dimensional nanostructure have been extensively accelerated. Within these literatures, different aspects of the these nanostructures such as intersubband optical absorption coefficients in finite confining potential quantum boxes [7], Linear changes of absorption and refractive indices in parabolic quantum wells [8], optical absorption and refractive index changes in a cylindrical QD [9], well-width-dependent third-order optical nonlinearities of cylindrical QD-quantum wells [10], conduction band non-parabolicity effect in spherical quantum dots [11] and so on, have been studied. Although, experimental growth of AlN/GaN multiple quantum wells by RF plasma-assisted molecular beam epitaxy [12] as well as experimental [12,13] and theoretical [14] intersubband absorption of this structure with variable total effective length have also been previously done, but the absorption coefficient of GaN/AlN Constant Outer Radius Multi-Wells Quantum dots (COR-MSQDs) has been studied till now.

During our last few works [15–18], we have studied the optical properties of constant total effective length systems based on III–V semiconductors, such as GaAs/AlGaAs [15] and AlN/GaN [16] multiple quantum wells. We have also investigated the optical properties of multi-wells quantum rings with constant total effective radius [17] and also this system with two electrons on its center [18]. In the current work, we have investigated the effect of the intensity, magnetic field, number of wells, and quantum dot radius on the absorption coefficient of GaN/AlN COR-MSQDs.

2. Formalism

Within the envelope-function approximation via effective mass technique for a quantum dot under the influence of a uniform

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0030-4026/

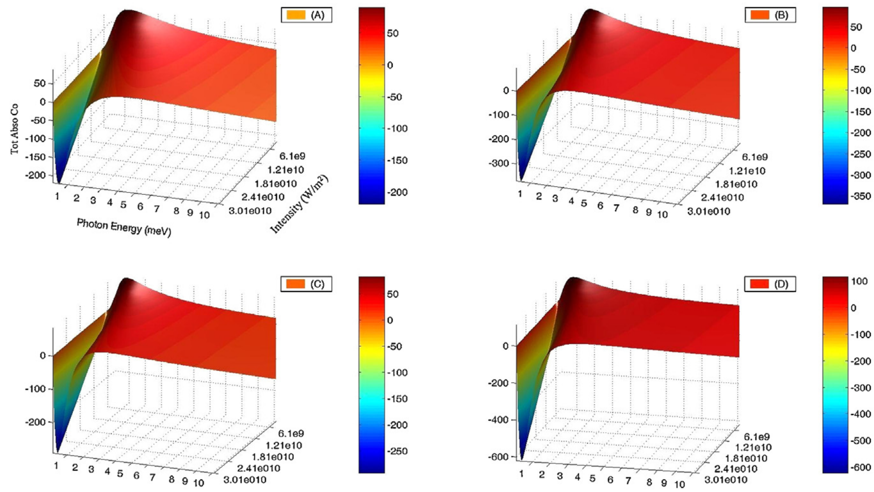

Fig. 1.1. Total absorption coefficient as a function of the incident photon energy (meV) and intensity (W/m^2) for different number of wells and zero magnetic field. Number of wells are assumed to be 1 to 4 in the panels (A) to (D) and the outer quantum dot radius is taken to be R_{out} = 400 Å.

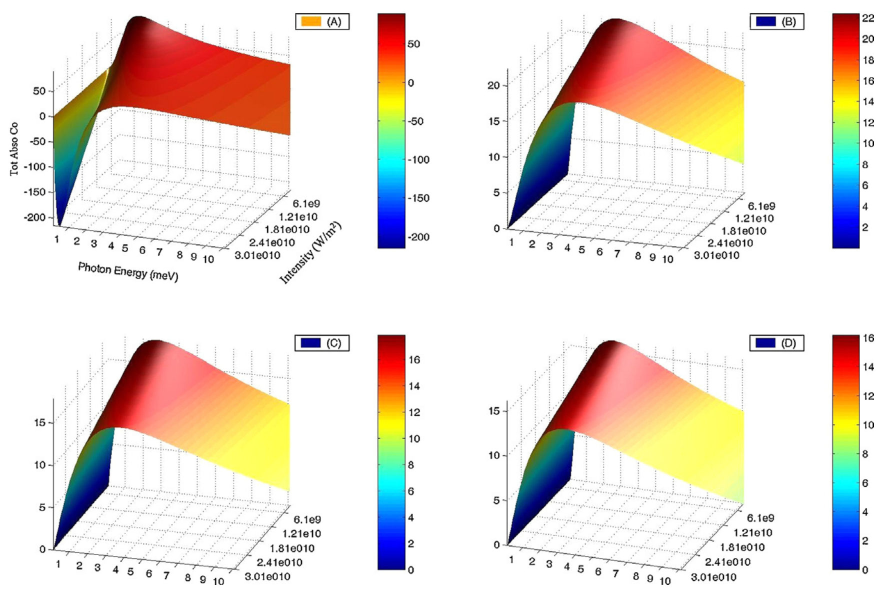

Fig. 1.2. Same as Fig. 1.1 but for magnetic field 5 T.

magnetic field B along the z direction, the radial part of the Schrödinger equation in the cylindrical coordinates can be written as:

$$-\frac{\hbar^2}{2}\frac{\partial}{\partial\rho}\left(\frac{1}{m^*}\frac{\partial R_{n,l}}{\partial\rho}\right)-\frac{\hbar^2}{2m^*}\frac{1}{\rho}\frac{\partial R_{n,l}}{\partial\rho}+\frac{\hbar^2}{2m^*}\frac{m^2}{\rho}R_{n,l}+\frac{1}{2}m\hbar\omega_c R_{n,l} + \frac{1}{8}m^*\omega_c^2\rho^2R_{n,l}+V(\rho)R_{n,l}=ER_{n,l} \quad (1)$$

where m^* is the effective mass, $m = 0, \pm 1, \pm 2, \ldots$ is magnetic quantum number and $\omega_c = \left(eB/m^*\right)$ is the cyclotron frequency. We have also defined the geometrical confining potential $V(\rho)$ as:

$$V(\rho)=\begin{cases} V_{\text{conf}} & i=1,3,\ldots \\ 0 & i=2,4,\ldots \end{cases}; \quad \frac{i-1}{2N+1}R_{\text{in}}<\rho<\frac{i}{2N+1}R_{\text{out}} \quad (2)$$

here N is the Number of wells, L is the orbital quantum number, V_{conf} in the constant relative conduction band offset and i shows the i'th well or barrier. R_{in} and R_{out} are inner and outer quantum dot shell radius respectively. When eigen-energies and eigen-function have been found through numerical discretization techniques [19], the linear absorption coefficient for $(E_f - E_i)$ transition can be calculated by [20],

$$\alpha^{(1)}(\omega)=\omega\sqrt{\frac{\mu}{\varepsilon_r}}\times\frac{\sigma_s e^2\left|M_{fi}\right|^2\hbar\Gamma_{fi}}{\left(\hbar\omega-\Delta E_{fi}\right)^2+\left(\hbar\Gamma_{fi}\right)^2} \quad (3)$$

and the third-order nonlinear optical absorption coefficient for $(E_f - E_i)$ transition read [21],

$$\alpha^{(3)}(\omega)=-\omega\sqrt{\frac{\mu}{\varepsilon_r}}\times\left(\frac{I}{2\varepsilon_0 n_r c}\right)\frac{\sigma_s e^4\left|M_{fi}\right|^2\hbar\Gamma_{fi}}{\left[\left(\hbar\omega-\Delta E_{fi}\right)^2+\left(\hbar\Gamma_{fi}\right)^2\right]^2} \times\left[4\left|M_{fi}\right|^2-\frac{\left|M_{fi}-M_{ii}\right|^2\left[3\Delta E_{fi}^2-4\Delta E_{fi}\hbar\omega+\hbar^2\left(\omega^2-\Gamma_{fi}^2\right)\right]}{\Delta E_{fi}^2+\left(\hbar\Gamma_{fi}\right)^2}\right]. \quad (4)$$

where I is the excitation electromagnetic field optical intensity with the angular frequency W. σ_s represents electron density in this system, E_i and E_f denote the quantized energy levels for the initial and