Non-resonant Laser Field Effect on Electronic and Optical Properties in GaAs/AlGaAs Quantum Rings

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INTRODUCTION: Low dimensionality structures exhibit outstanding charge carrier properties. In particular, the optical properties may be tuned by means of size, geometry, shallow impurities and externally applied electric, magnetic, and laser fields [1].

COMPUTATIONAL METHODS: The Schrödinger equation under non-resonant intense laser field effect is defined as

$$i\hbar\,\frac{\partial}{\partial t}\psi(x,y,t) = \left[\widehat{\mathbf{P}}\cdot\left(\frac{1}{2\,m^{*}(x,y)}\widehat{\mathbf{P}}\right) + V(x,y)\right]\psi(x,y,t),$$

by using Kramers-Henneberger transformation [2], the time independent Schrödinger equation is given by

$$E\,\phi(x,y) = \left[\nabla\cdot\left(-\frac{\hbar^2}{2\,m^{*}(x,y)}\nabla\right) + V_d(x,y)\right]\phi(x,y),$$

where $V_d = \frac{\omega}{2\pi}\int_0^{\frac{2\pi}{\omega}} V(X(t),Y(t))\,dt$ is the laser-dressed potential and

$$X(t) = x + c_x\,\alpha_0\cos(\omega t), \qquad c_x = \sqrt{\frac{2}{1+\varepsilon^2}},$$

$$Y(t) = y + c_y\,\alpha_0\cos(\omega t + \pi/2), \quad c_y = \varepsilon\sqrt{\frac{2}{1+\varepsilon^2}} = \varepsilon\,c_x.$$

In this work, it is used the coefficient form PDE interface of the COMSOL Multiphysics® simulation software to calculate the energies, wavefunctions, and dipole matrix elements of a confined electron in a circular GaAs quantum ring (QR) and embedded in a matrix of AlGaAs as it is depicted in Fig. 1.

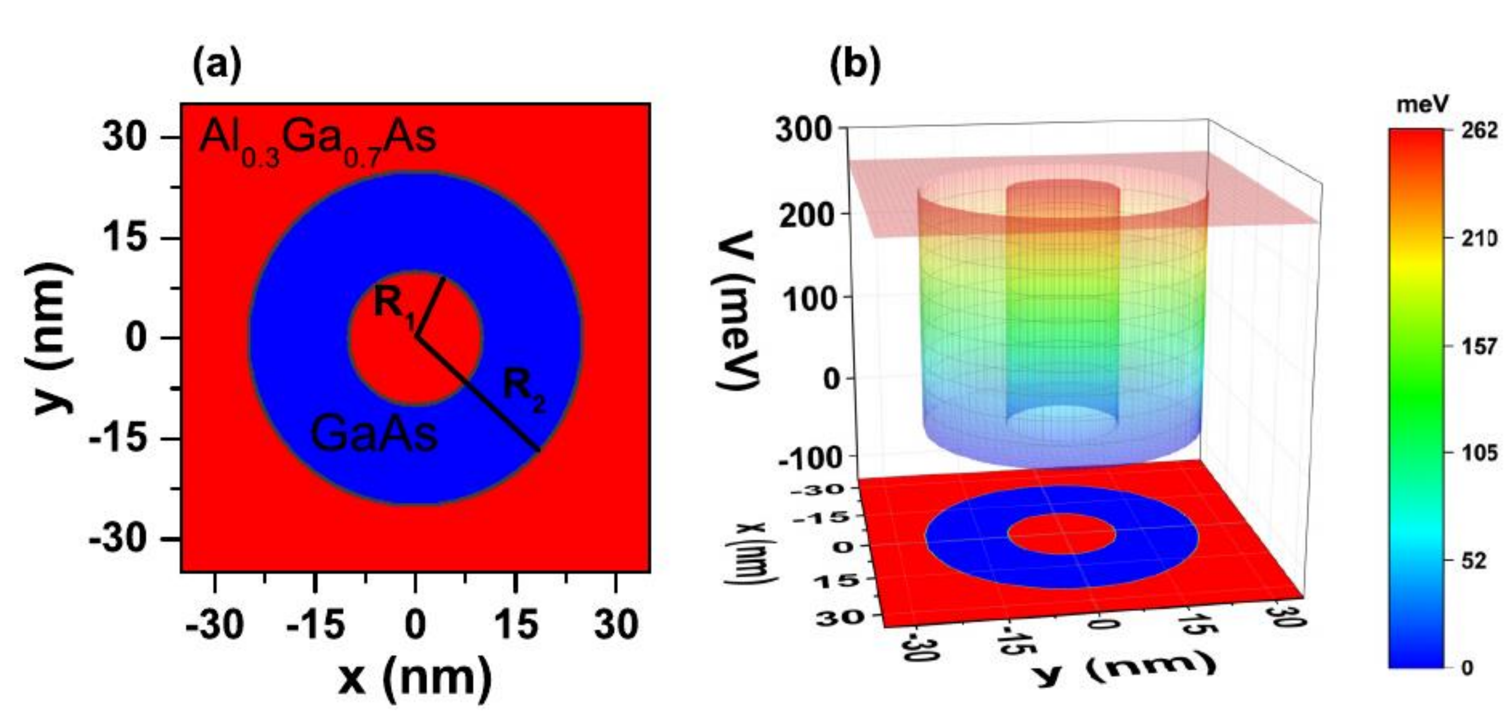

Figure 1. (a) Geometrical representation of the QR, (b) 3D confinement potential view without intense laser field effects

RESULTS: The Figs. 2-4 show the results for different values of the intense laser field parameter α_0. This was achieved by using the parametric sweep tool. An auxiliary variable for V_d was built in the used interface, due to the fact that V_d is calculated as an temporal average value for each node.

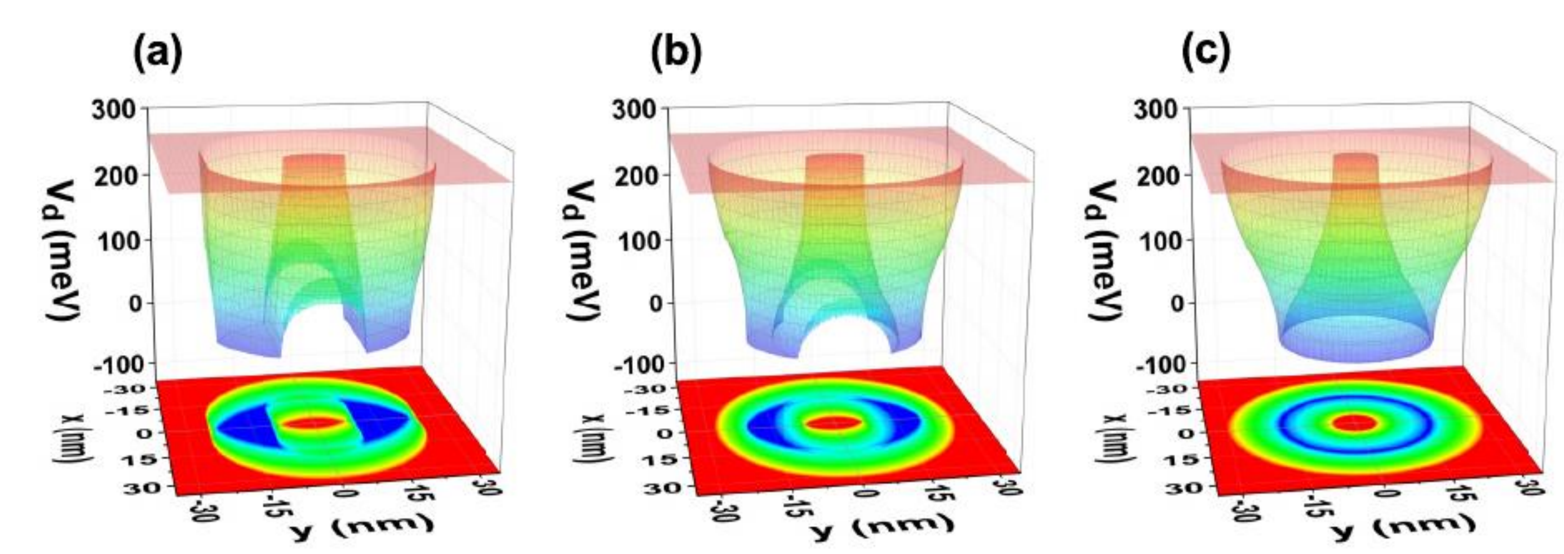

Figure 2. Laser-dressed confinement potential. Three different polarizations for the non-resonant laser field are taken into account: (a) x-linear ($\varepsilon = 0$), (b) elliptical ($\varepsilon = 0.5$), and (c) circular ($\varepsilon = 1.0$)

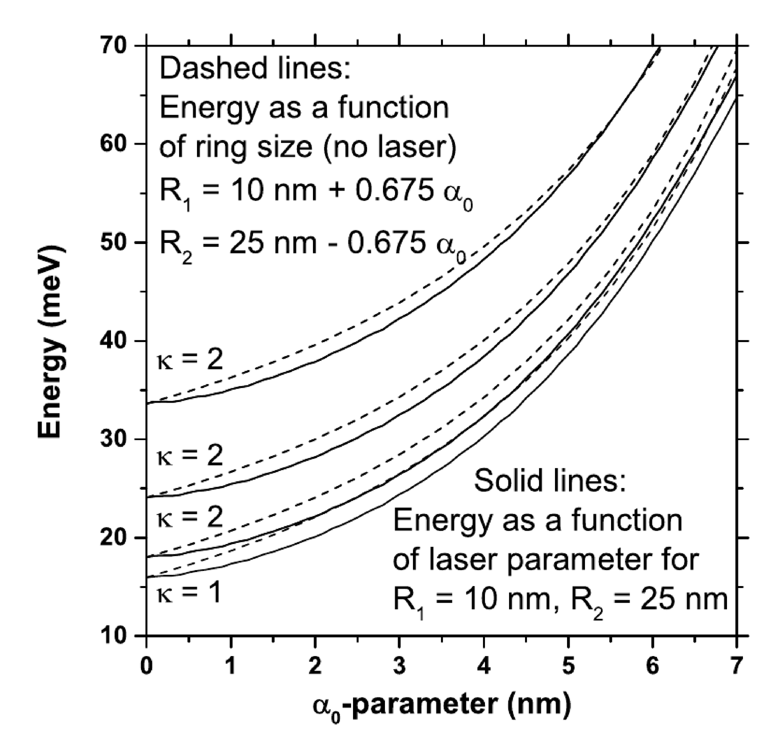

Figure 3. Comparison between two different configurations: (i) Circularly polarized laser effect with fixed dimensions of the QR, (ii) change of the size of the quantum ring

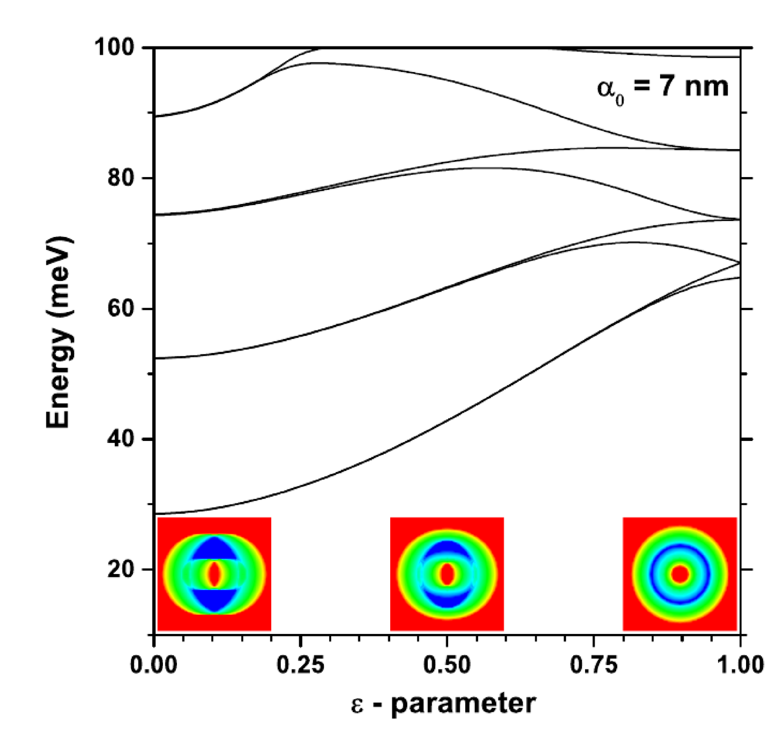

Figure 4. Effects of the ε-parameter on energy levels. The insets correspond to $\varepsilon = 0, 0.5$, and 1.0

CONCLUSIONS: In systems with azimuthal symmetry doubly fold states appear. The linear polarization indicates two coupled quantum dots behavior. The circular polarization preserves the azimuthal symmetry. For intermediate values of the polarization, the degeneracy is broken for high levels.
Similar effects for two different mechanisms are obtained: (i) the non-resonant laser field effect, (ii) size changes of the QR.

REFERENCES:

1. V.M. Fomin, Physics of Quantum Rings, second ed., Springer, Berlin, (2018).
2. C. Rodríguez-Castellanos, M.T. Pérez-Maldonado, Suppression of magnetic subbands in semiconductor superlattices driven by a laser field, Superlattice Microstruct. 27, 15 (2000)