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Magneto and Magneto-Optical Characteristics of Semiconductor Nano Material with Nonsymmetrical Geometry

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ABSTRACT We have studied and calculated the diamagnetic coefficient for the neutral excitons confined in wobbled semiconductor self assembled quantum rings. We have systematically studied the impact of the rings reflection asymmetry on the excitons ground-state wave function localization, energy and diamagnetic coefficient. Using mapping method, we have reproduced three dimensional geometrical shapes and material compositions of the rings and simulated excitonic properties of the rings with the reflection symmetry and when the symmetry was broken. We have demonstrated that for the rings with reflection symmetry with respect to reflection in (110) plane Y-Z, the ground state excitons wave function is equally distributed between two potential valley of the rings. A small imbalance in geometrical or material characteristics of rings along the (110) direction of x-axis leaded to the localization of the potential valleys of the ring, which caused a significant decrease of the excitons diamagnetic coefficient. We have found that for the noninteracting particles, the electron wave function is more stable to the unbalance in the ring reflection symmetry than the hole wave function. This originates from the difference in the particles effective masses. The effective lateral radii of the electron and hole are shrinking rapidly when absolute values of the parameters are growing. This resulted in the rapid decrease of the neutral excitons diamagnetic coefficient. We have also found that a correlation imbalance in the ring geometry and material content has a recognizable impact on the ground state energy of the neutral excitons. The obtained results were found in good agreement with previously obtained results.

KEYWORDS Diamagnetic coefficient, Neutral Excitons, Wobbled Semiconductor, Quantum Ring, Reflection Symmetry, Potential Valleys.

INTRODUCTION

Lee et al.[1], Moon et al.[2] and Cohen-Taguri et al.[3] studied that in semiconductor nanofabrication technology made it possible to produce the semiconductor self assembled quantum rings within a wide range of geometrical and material parameters. It was found that magnetic and magneto-optical properties of the rings strongly depend on their actual geometrical and material parameters. At the same time the shape of embedded $In_C As_{1-c} Ga / GaAs$ semiconductor self assembled quantum rings grown on a (001) surface of GaAs substrate in general did not possess cylindrical symmetry. The height of the $In_C As_{1-c} Ga / GaAs$ ring at the rim was larger along the [110] direction than in the $[1\bar{1}0]$ direction[4-5]. This formed two distinct hills in the ring's shape and correspondingly two potential valleys for electrons and holes along the *x*-direction. The wobbled geometry affected the magnitude of the single electron magnetization oscillations[6-9] and excitons diamagnetic response[10-12] of the rings. Lorke and Luyken[13] and Lee et al.[14] studied semiconductor self assembled quantum rings were none objects of a non simply connected topology. Teodoro et al.[15] and Ding et al.[16] assumed that semiconductor self assembled quantum rings specific geometry and the absence of crystal defects and impurities provided experimentalists with the unique opportunity to observe topological quantum effects for charged particles confined in the semiconductor self assembled quantum rings including the optical Aharonov-Bohr effect. Jee et al.[17] studied the behavior of semiconductors in crossed high electric and magnetic fields. The efficiency of interelectronic collision in quenching magnetic field have been solved by mutual drag of electrons and phonons. They found that the phonon generation at high external electric and magnetic fields is nonstationary effect. The distribution function of phonons is stationary and has shifted planks distribution function from the effective temperature of phonons. Aparajita et al.[18] studied photonic bands in periodically modulated dielectric media. They have predicted that metallophonic waveguide networks, where waveguides are joined together to form a network structure and realized the tight binding photonic bands through an unsuspended zero point localized photonic states. Aparajit et al.[19] studied the temperature dependent transport coefficient of silicon based quantum wells. They have found that under Bloch-Gruniesen regime of electron scattering obeyed power dependence on temperature. They found that for the change of the observed temperature contained a conductive channel close to quantum well. This type of channel is due to gate electrode in inversion layer. Li and Puters[20] studied that diamagnetic coefficient is connected to the second derivative of the excitons energy with respect to the magnetic field magnitude and for weak field limit. Lin etal[21] proposed that lack of the perfect rotation symmetry is a reason for the hole localization in one of the potential valleys of the ring. They found that due to the electron-hole coulomb interaction the hole's localization should lead to a localized excitons wave function which decrease the neutral excitons effective confinement length and diamagnetic coefficient. The obtained results were compared with previously obtained results.

METHOD

The ground state energy of an excitons in weak magnetic field can be presented by

$$E_{ext}(B) = E_{ext}^{0} + s\mu_B g_{ext} B + \alpha_d B^2$$

where *B* is magnetic field, E_{ext}^{0} is the excitons energy, μ_B is the Bohr magneton, g_{ext} is the excitons lande factor, *s* is excitons spin polarization along the magnetic field direction and α_d is the excitons diamagnetic coefficient. In the strong confinement regime when the magnetic field is applied along the system growth direction z-axis, the coefficient can be evaluated by using the effective radii, the characteristic confinement lengths of the electron ρ_e and hole ρ_h in the plane perpendicular to the magnetic field

$$\alpha_d = \frac{e^2}{8}\left(\frac{\rho_e^2}{m_e} + \frac{\rho_h^2}{m_h}\right)$$

where e is the electronic charge, m_e is the electron and m_h is the hole effective masses. The actual value of the excitons diamagnetic coefficient can be used for estimation of the excitons confinement length. We have adopted the model of the ring's height profile with some modifications. According to this model the bottom of the ring is perfectly flat and parallel to the x-y plane. The reflection asymmetry in the ring hill's heights is described by the function $F_h(x,y), x_p = \pm(1+\xi_R), y_p = 0$ stands for the position of the appropriate ring's profile maximum and the range of the reflection asymmetry in the wobbling is presented by a parameter b. The model deviation from the reflection symmetry in the ring's shape are controlled by parameter d_h as

$$d_h = \frac{h(x_p, y_p)\big|_{d_h \neq 0} - h(x_p, y_p)\big|_{d_h = 0}}{\left|h(x_p, y_p)\right|_{d_{h=0}}}$$

we have presented the shape of the structure and cross section of the ring by (x, y_p, z) planes for different d_h when the ring height deviations are concentrated as the position of the maximum at the positive $x_p = R(1+\xi_r)$ and $y_p = 0$. We have used $h(x,y)$ to describe the corresponding three dimensional smooth confinement potential for electrons and holes by the shape and composition profiles of the local conduction (e) and valence (h) band offsets.

$$V_{e(h)}(r) = \Delta E^0_{e(h)}\left[1 - Fv(r)T(r)\right]$$

where

$$T(r) = \frac{1}{4}\left[1 + \tan\mathrm{h}\left(\frac{z}{a}\right)\right]\left\{1 - \tanh\left[\frac{z - h(x,y)}{a}\right]\right\}$$

$$Fv(r) = 1 + d_V\left\{\exp\left[-\frac{(x-x_p)^2 + (y-y_p)^2}{b^2}\right] \times \exp\left[\frac{(z-z_p)}{b_z^2}\right]\right\}$$

where $r = (x, y, z)$ is the three dimensional radius vector, $\Delta^0_{e(h)} = \left(E^{out}_{c(v)} - E^{in}_{c(v)}\right)$ is the overall conduction and valence band offset between the inner and outer semiconductor materials, in and out are the actual material parameter inside and outside the ring. The slope and range of the potential change at the boundaries of the ring are controlled by a parameter 'a'. The ring's shape asymmetry, the reflection asymmetry in the ring's potential is presented by the function $F_v(r)$, where $r_p = (x_p, y_p, z_p)$ refers to the position of the appropriate potential valley and the range of the asymmetry in the z-direction is presented by a parameter b_z. Deviation from the reflection symmetry in the ring's potential are controlled by parameter d_v can be presented as

$$d_V = V_{e(h)}(r_p)\big|_{d_{v=0}} - V_{e(h)}(r_p)\big|_{d_{V=0}} + O\left(\frac{a}{z_p}\right)$$

This approximate relationship becomes exact when $a \to 0$. The local band offsets for electrons and holes grow when d_V is positive and increase. The offsets locally decrease when d_V is negative and its absolute value increases.

RESULTS AND DISCUSSION

Figure (1) shows the effective lateral radii of the electron and hole follow the same tendency, the electron's radius decreases smoothly and hole's radius shrinks rapidly. The interparticle interaction drastically changes the sensitivity of the particles wave functions to the imbalance in the reflection symmetry of the ring. Very small ~0.01 non zero d_h and or d_V generate the simultaneous localization of the electron and hole wave functions is one of the potential valleys. The coulomb interaction makes the electron and hole move in the same direction of the position of the hole. The actual mean position $\tilde{x}_{e(h)}$ is controlled by the sign of d_v. The high sensitivity of the holes to the imbalance in the reflection symmetry of the ring is a triggering factor in the one valley localization effect for the excitons. Figure (2) demonstrates the dependency of the electron mean localization position on d_h and d_V becomes very similar to that for the hole when we impose the electron-hole interaction. The coulomb interaction makes the electron and hole effective lateral radii both are very sensitive to the reflection asymmetry of the ring, the radii simultaneously and rapidly decrease when a small imbalance appears. With the obtained actual positions of the electron and hole components of the ground state excitons wave function, we have examined the effect of the reflection asymmetry on the excitons diamagnetic coefficient α_d. Figure (3) (a) shows the dependence of the exciton diamagnetic coefficient on the parameters, d_h and d_v. The electron and hole wave function's localizations and distributions to the imbalance in the reflection symmetry leads to a rapid decrease of the excitons diamagnetic coefficient. The coefficient decreases only gradually when the ring's geometry and material content become more unbalance along the x direction. The obtained results were compared with previously obtained results and were found in good agreement.

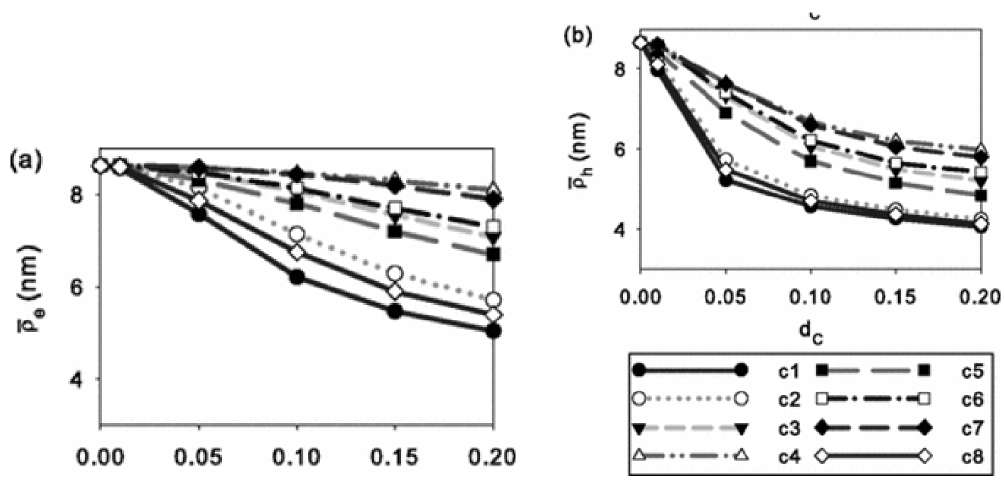

Figure 1: The effective lateral radius of the noninteracting electron (a) and hole (b).

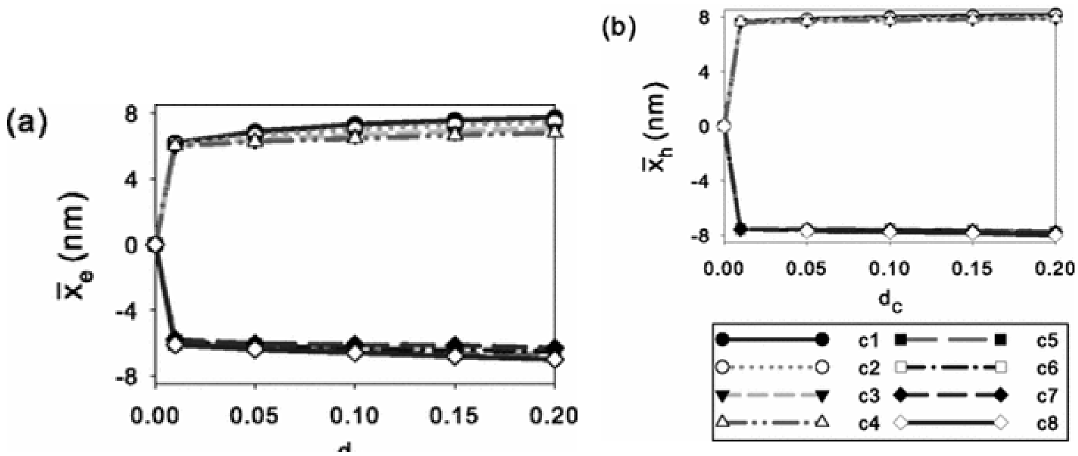

Figure 2: The expectation value of the position of the electron (a) and hole (b) on the *x* axis for the excitons in the ground state (type-A rings).

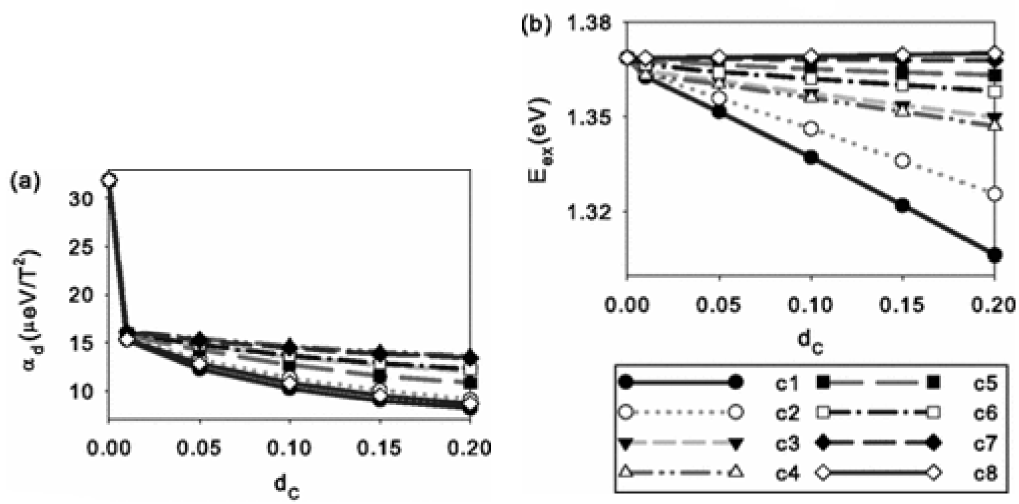

Figure 3: Exciton diamagnetic coefficient (a) and ground-state energy (b) for the type –A ring.

CONCLUSION

We have studied magneto and magneto-optical characteristics of semiconductor nano material with nonsymmetrical geometry. We have shown that reflection affected the neutral excitons diamagnetic coefficient in self assembled semiconductor wobbled rings. Simulation resulted that the excitons wave unction of the reflection symmetrical wobbled ring was distributed equally over two potential valleys corresponding to the hills in the ring shape. We have studied that the impact of the broken symmetry on the diamagnetic coefficient of the ground state of the neutral excitons confined in semiconductor. We have found that a small imbalance in geometrical or material characteristics of the rings along the [110] direction, i.e. -axis leaded to the localization of the excitons wave function in one of the potential valleys of the ring, which caused a significant decrease of the excitons diamagnetic coefficient. We have found that even a very small reflection imbalance in the geometry or material content of the wobbled rings destroys the ring like shape of the excitons wave function. Which caused a rapid decrease of the excitons diamagnetic coefficient? The obtained results were compared with previously obtained results of theoretical and experimental research works and were found in good agreement.

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