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Effects of Laser Field on Excitonics States of Spherical Quantum Dots with Different Confinements

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ABSTRACT

In this paper, we have studied the effect of intense laser field on excitonic states of excitons confined in spherical quantum dots by means of variational technique within the effective mass approximation. The results show that the exciton binding energy depends on the laser field parameter and quantum dot radii. And the laser field lowers total energy (E), kinetic energy (T) , coulombic potential (Vc) and the binding energy of exciton for all confinements and for any material used.

Key words : Exciton, Quantum Dot, Laser Field, Dressed Potential, Binding Energy, Variational Method.

1. INTRODUCTION

In last decades, the progress in nanostructures had made possible the fabrication of quantum dots(QDs) .QDs are interesting, due to fact that the motions of the charges carriers are restricted in all three dimensions, which lead to new physics . It can be made into different forms such as the cubic ,spherical or cylindrical [1-5].The incorporation of small amounts of nitrogen into (In,Ga)As can cause a significant decrease in the band gap energy and an increase in the effective mass [6-8]. GaInNAs exhibit interesting new properties and differ considerably from the 3-5 aloys , such as InGaAs, AlGaAs, and GAInAsP.
Significant changes occur in the electronic band structures compared to GaAS with incorporation of only a small fraction of nitrogen into GaAs.
Dillute nitride semiconductors are considerd as an alternative to current systems for using applications such as laser, photodiode, solar cell, optical amplifier, etc. due to their superior performance and low cost production. The study of semiconductors heterostructures under laser field, has attracted the attention of many researchers in the recent years .It has become possible to measure the effect of intense laser radiation on ionization and perturbation of dopants in semiconductors systems[9-10],with the development and applications of coherent, high power, long wavelength, frequency-tunable and linearly polarized radiation sources such as THZ or far infrared free electron lasers.

In this work, we have studied the effects of an intense high-frequency laser field on excitonic states of excitons in spherical quantum dots, using the variational technique in the framework of effective mass approximation..

2. THEORY

We consider an exciton confined in spherical quantum dots with radii R. In the effective mass approximation, the Hamiltonian for the exciton without laser field ,by use of excitonic units is given by :

$$\mathrm{H_0} = -\frac{\Delta_e}{1+\sigma} - \frac{\sigma\Delta_h}{1+\sigma} - \frac{2}{r_{eh}} + V_e + V_h \qquad (1)$$

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We have used as unit of length the 3D exciton effective Bohr radius $a^* = \frac{\varepsilon\hbar^2}{\mu.e^2}$ and σ=m_e/m_h is the effective mass ratio . And as unit of energy the Rydberg $R^* = \frac{\mu e^4}{2\epsilon^2\hbar^2}$, which represents the absolute value of 3D exciton ground state energy.

ε is the relative dielectric constant of the semiconductor material and V_e (V_h) is the confinement profile for the electron (hole) with .

$$V_i = \begin{cases} 0, & r_i < R \\ \infty, & r_i \geq R \end{cases} \quad (2)$$

In the presence of the intense laser field the Coulombic interaction term takes the following form described in Ref [11] :

$$Vc = -\frac{k}{2\,\varepsilon_r}\left\{\frac{1}{\lceil \mathbf{r_e} - \mathbf{r_h} + \boldsymbol{\alpha} \;\rceil} + \frac{1}{\lceil \mathbf{r_e} - \mathbf{r_h} - \boldsymbol{\alpha} \;\rceil}\right\} \quad (3)$$

where $\alpha = \frac{eF_0}{\mu.\omega^2}$ is the laser –dressing parameter and F_0 is the field strength.

The Hamiltonian of the exciton under laser field is given by:

$$H = -\frac{\Delta_e}{1+\sigma} - \frac{\sigma\Delta_h}{1+\sigma} - \left\{\frac{1}{\sqrt{r_{eh}^2 + 2\alpha(z_e - z_h)^2 + \alpha^2}} + \frac{1}{\sqrt{r_{eh}^2 - 2\alpha(z_e - z_h)^2 + \alpha^2}}\right\} + V_e + V_h \quad (4)$$

The energy E and the envelope wave function ψ are solutions of effective schrôdinger equation :

$$H\,\psi(r_e, r_{h,} r_{eh}, z_e, z_h) = E\,\psi(r_e, r_{h,} r_{eh}, z_e, z_h) \quad \textbf{(5)}$$

This equation cannot be solved analytically, so we have to determine its ground sate solutions using the Ritz variational principle .

we have chosen the following trial wave function :

$$\psi = N\varphi(r_e).\varphi(r_h).[1 + \beta.\alpha.(z_e - z_h)].\exp(-\lambda.r_{eh}) \quad (6)$$

$$\boldsymbol{\varphi}(\boldsymbol{r_e}) = \frac{\sin\left(\frac{\pi * \boldsymbol{r_e}}{R}\right)}{\boldsymbol{r_e}} \quad ; \boldsymbol{\varphi}(\boldsymbol{r_h}) = \frac{\sin\left(\frac{\pi * \boldsymbol{r_h}}{R}\right)}{\boldsymbol{r_h}}$$

N is are the coefficient of normalisation

Where $\varphi(r_e)$.and $\varphi(r_h)$ are, respectively, the wave function of electron and the hole [12], β and λ are two variational parameters.

The ground state exciton binding energy is obtained as follows:

$$E_b = E_e + E_h - \min_{\beta,\lambda}\frac{\langle\psi|H|\psi\rangle}{\langle\psi|\psi\rangle} \quad (7)$$

Where $E_e$and E_h are the lowest electron and hole subband energy.

For the ground, state it is sufficient to consider a wave function depending on the distance r_e ,r_h,r_{eh},z_e,z_h (Hylerass coordinates with cotes z_e,z_h) .

Within these coordinates,the laplacian read [12] :

$$\Delta_i\psi = \frac{\partial^2\psi}{\partial r_i} + \frac{2}{r_i}\frac{\partial\psi}{\partial r_i} + \frac{(r_i^2 + r_{ij}^2 + r_j^2)}{r_i r_{ij}}.\frac{\partial^2}{\partial r_i}\frac{\psi}{\partial r_{ij}} + \frac{2}{r_{ij}}\frac{\partial\psi}{\partial r_{ij}} + \frac{\partial^2\psi}{\partial z_i^2} + \frac{2z_i}{r_i}\frac{\partial^2}{\partial z_i}\frac{\psi}{\partial r_i} + 2\frac{(z_i - z_j)}{r_{ij}}\frac{\partial^2}{\partial z_i}\frac{\psi}{\partial r_{ij}} \quad (8)$$

i,j=e,h

3. RESULT AND DISCUSSION

As application of the theory developed here above, calculations of the binding energy for confined excitons were performed for the case of GaAs material characterized by its σ parameter and its excitonic units R^* and a^*. Integrations over r_e, r_h and r_{eh} were calculated by using Gauss-Legendre method within Maple platform. For minimizing energy, several standard numerical

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methods were tested and led to the same results. The binding energy of the QD-exciton under field was then computed for different values of the field intensity parameter α . and for various radius values R ranged between $0.5a^*$ (the strong confinement regime) and $3a^*$ (quasi 3D-exciton). The result is reported in figure 1. Several interesting points can be noted: (i) the laser field lowers the binding energy for all confinements, (ii) the rate of this lowering decreases with increasing size of the dot, (iii) for high intensity values of the filed, the system becomes insensitive to the confinement (iv) for negligible confinement (*R=3*) and $\alpha = 0$ the binding energy approaches the limit value *1,5 R** found by F.M.S. Lima *et al* in the case of bulk exciton [16] which is one half higher than the limit *1R**. These results show that the exciton remains stabilized against the field ionization and predict an infrared shift in its photoluminescence edge spectra. For $\alpha > 1$, the field effect reduces drastically the confinement effect making the exciton as bulk one.

Fig 1:Variation of the binding energy of the exciton Eb as a function of quantum dot radii R for different laser field parameter α

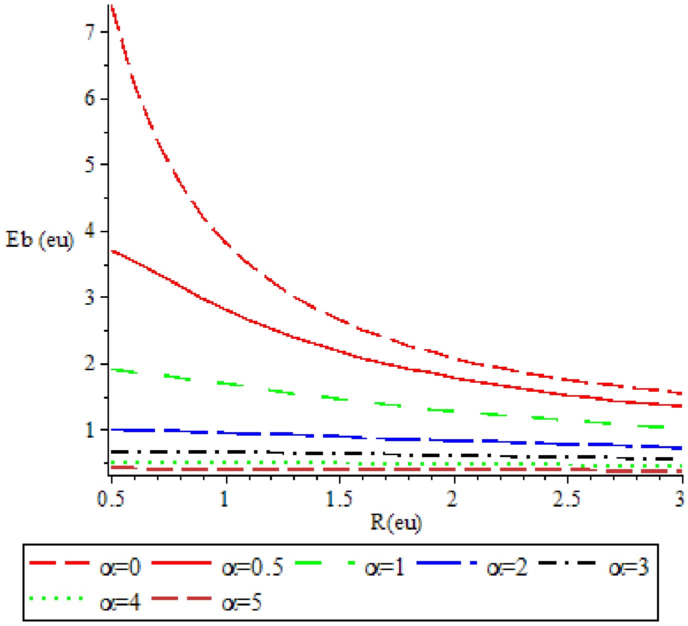

Fig.2: variation of the binding energy as a function the effective mass ratio σ with R=0.5 and α = 0

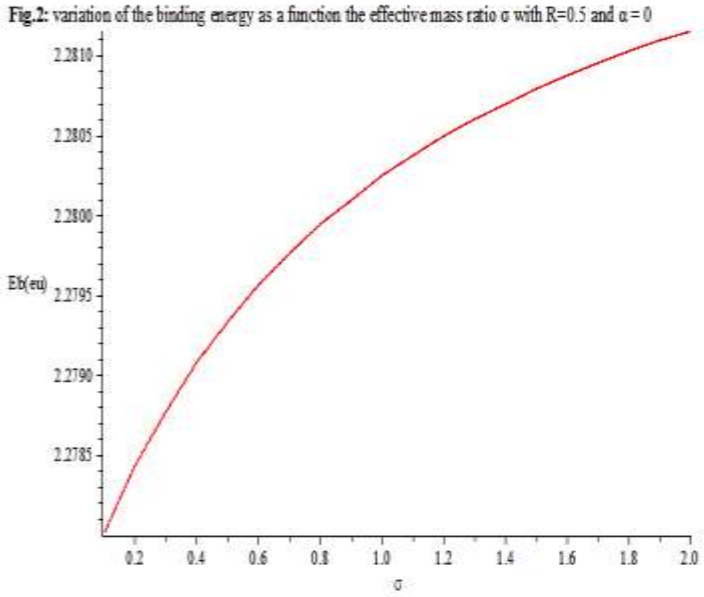

Figure 2 shows the variation of the exciton binding energy as a function the effective mass ratio σ without laser field effect. In this figure ones see that when the quantum dot radii increases, the exciton binding energy increase slightly for any material used, and takes the value $E_b \approx 2.27R^*$ for $m_e < m_h$ ($\sigma < 1$) and the value $E_b \approx 2.28R^*$ for $m_e > m_h$ ($\sigma > 1$).

Figure 3 shows the variation of the exciton binding energy as a function the effective mass ratio σ under and without laser field effect and for different quantum dots radii. In this figure we can see that the laser field lowers the binding energy for all confinements and for any material used ,and the stark shift $\Delta E = E_b(\alpha) - E_b(0)$ is greater for strong confinement (R = 0.5) and becomes weaker for negligible confinement (R = 2). This fact can be explained by, when the laser field amplitude α increases,the geometric confinement of the particles , due to changes in laser field increases as they get to be more energetic and can penetrate into potential barriers easily .This behavior weakens the coulombic interaction between the electron and hole and the exciton binding energy decreases.

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Fig.3: Variaion of the binding energy as a function the effective mass ratio σ with (α = 5) and without (α = 0) laser field , and for different quantum dots radii R .

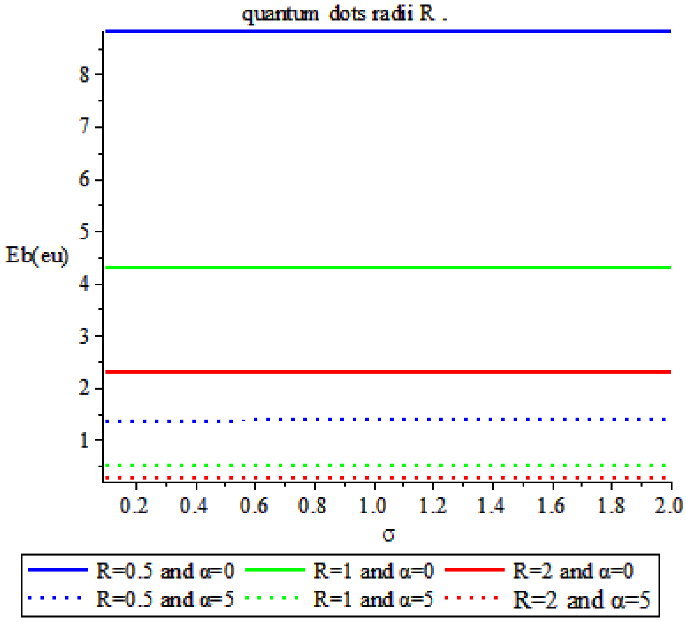
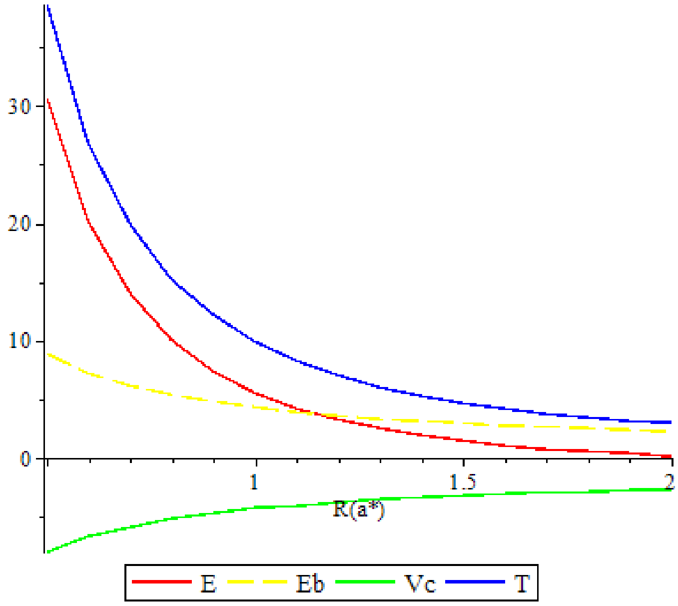


Fig.4 : variation of total energy (E),kinetic energy(T),coulombic energy (Vc) and the binding energy(Eb) as a function of quantum dot radii without laser field(α = 0 a^*)



Figures 4 and 5 shows the variation of total energy (E) ,kinetic energy (T) ,coulombic potential (Vc) and the binding enery of exciton as a function of quantum dots radii without and with laser field . In figure 4, we see that the energies: kinetic, total and the binding enery, decrease almost exponontially, while the Coulombic interaction energy increases and tends towards 0 when R is greater (negligible confinement). The same results are obtained in Ref [14]. On the other hand, in Figure5, and under the effect of the laser field (α = 1), we notice the decrease in energies mentioned above is faster and the coulombic interaction energy quickly tends to 0 when R is greater.

Finely, figure 6 shows the variation of total energy (E) ,kinetic energy (T) , coulombic potential (Vc) and the binding energy (Eb) as a function of laser field parameter. Unexpected behavior is highlighted: Vc curve are closed to those obtained for E_b by inverting sign what means that the kinetic part of the binding energy is negligible. Indeed, plots of T versus α □□as shown in figure 6, reveals the constance of T for any given radius R following the simple relation $TR^2 \approx \pi^2$ or $T \approx k^2$which leads effectively to $E_b \approx -V_c$. Subsequently, the expression of E_b (in excitonic units) is σ□-independent and then, it may be used for all materials, satisfying the approximations of our model.

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Fig.5: variation of total energy (E),kinetic energy(T),coulombic energy (Vc) and the binding energy(Eb) as a function of quantum dot radii under laser field(α = 1 a*)

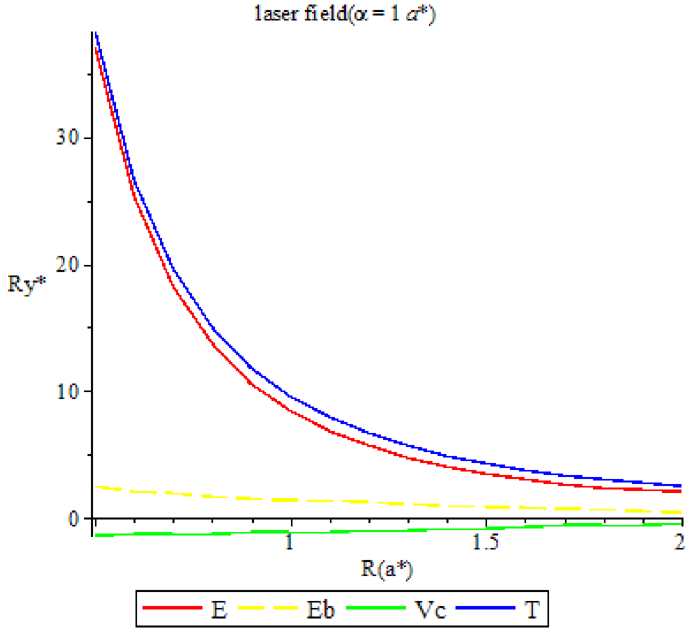
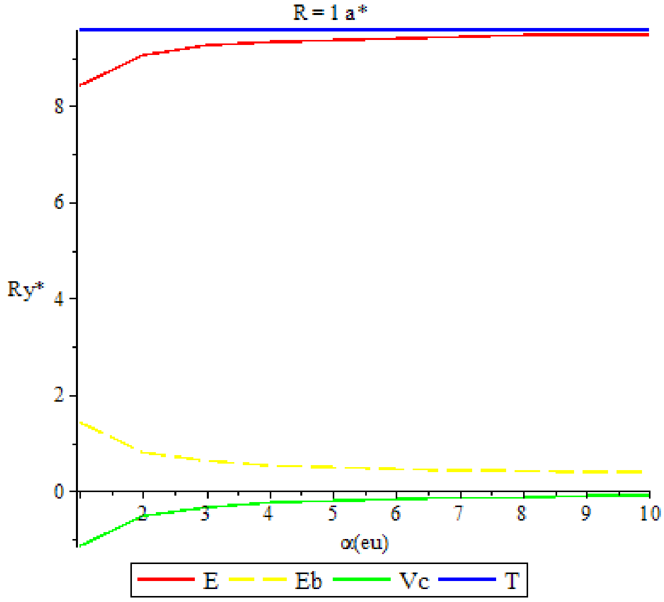


Fig.6: Variation of total energy (E),kinetic energy(T),coulombic energy (Vc) and the binding energy(Eb) as a function of laser field and R = 1 a*



4. CONCLUSION

We have investigated the effects of intense laser field, on excitonic states of spherical quantum dot by use of variational method in the framework of the effective mass approximation. The results shows that the laser –field parameter and effective mass ratio are an important effect on electronic and optical properties of the spherical quantum dots, and the binding energy is mainly due to the dressed potential making the kinetic part insensitive to the field. We hope that our results can stimulate further investigations of the related physics, as well as the device application of group III-nitrides.

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