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Condensed Matter Physics

Elixir Condensed Matter Phys. 71 (2014) 24838-24844

Awakening to reality

Elixir ISSN: 2229-712X

Stark effects on the nonlinear optical properties of exciton in a strained $Ga_xIn_{1-x}As/GaAs$ quantum dot

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ARTICLE INFO

Article history:

Received: 27 February 2014;
Received in revised form:
25 May 2014;
Accepted: 9 June 2014;

Keywords

Oscillator strength,
Exciton,
Quantum dot.

ABSTRACT

Electric field induced heavy hole excitons in a strained $Ga_xIn_{1-x}As/GaAs$ quantum dot are studied by considering geometrical confinement. The exciton binding energy and some nonlinear optical properties in the presence of electric field are discussed. Calculations include the anisotropy, non-parabolicity of the conduction band, strain effects and the spatial confinement. A cylindrical dot of $Ga_xIn_{1-x}As$ surrounded by a GaAs barrier material with the constant Ga alloy content, x =0.2 is taken as the model. The exciton binding energy is found within the framework of the variational technique and the nonlinear optical properties are performed using matrix formulism. It is shown that the electronic and optical properties are strongly dependent on the application of electric field.

Introduction

III-V semiconductors especially single InGaAs quantum dots are considered to be the best material for showing the quantum confinement effects in the solid state. Quantum-confined Stark effect and the built-in dipole moment in self-assembled InAs/GaAs quantum dots have been discussed by the dc-biased electroreflectance [1]. Linear and nonlinear optical materials are found to be good candidates for fabricating potential devices optical integrated circuits. Optical amplifiers and modulators in signal processing and telecommunication applications require smaller sizes and the external electrical field can improve its performance because the electric field can be linked with the telecommunications with ease. The modulators can be produced using low dimensional semiconductors, specifically, quantum wells and quantum dots can be realized to produce efficient modulators [2]. Further, the quantum confinement effects still demonstrate the enhanced opto-electrical effects [3]. Highly polarized independent characteristics are required for fabricating efficient optical amplifiers and modulators which are meant for high speed communications. Optical amplifiers and modulators based on Stark effect show high speed performance in order to get optimizing design of optical devices [4].

Electric field induced excitonic interband optical transitions have been investigated in As self-assembled quantum dots in a transmission experiment at 4.2 K and the excitonic energy levels of a single quantum dot have been tuned into resonance with a narrow-band laser line using the energy shift due to the applied electric field [5]. Optical properties of InAs quantum dot wave guides have been studied in the presence of electric field , observed the enhancement of linear electro-optic efficiency at 1.515 μm on InAs/GaAs quantum dot structures and the red shift in absorption measurements have been detected with the application of electric field [6]. The electro-optic coefficients of InGaAs quantum dots have been shown much larger than those obtained for quantum wells and further, the spatial separation of the electron and hole wave functions in the dots have been brought out with the asymmetric Stark shift with the applications of electric field [7,8]. The effect of the built-in dipole moment on lasing properties of InAs quantum dot laser diodes has been reported with the experimental evidence [9]. Electro-optical and lasing properties of hybrid InGaAs quantum dot/quantum well material system for photonic devices in the presence of electric field has been performed recently [10].

Nonlinear optical properties in III-V semiconductors are given due attention because of the potentially viable opto-electronic device fabrications. Simple harmonic generation has been reported experimentally earlier [11]. Khaledi-Nasab et al., performed a theoretical study on nonlinear optical rectification and second harmonic generation in InAs/GaAs quantum dots using compact density matrix framework and effective mass approximation [12]. Intraband absorption spectra in InAs semiconductor have been computed theoretically [13,14].

In the present work, electric field induced heavy hole excitons in a strained $Ga_xIn_{1-x}As/GaAs$ quantum dot are studied by considering geometrical confinement. The exciton binding energy and some nonlinear optical properties in the presence of electric field are discussed. Calculations include the anisotropy, non-parabolicity of the conduction band, strain effects and the spatial confinement. A cylindrical dot of $Ga_xIn_{1-x}As$ surrounded by a GaAs barrier material with the constant Ga alloy content, x =0.2 is taken as the model. The exciton binding energy is found within the framework of the variational technique and the nonlinear optical properties are performed using matrix formulism. It is shown that the electronic and optical properties are strongly dependent on the application of electric field. In Section 2, the theoretical model used in our calculations of obtained eigen functions and eigen energies of exciton states, some non linear optical properties are narrated . The results and discussion are presented in Section 3. A brief summary and results are presented in the last Section.

Model and calculations

A Mott-Wannier exciton is considered in a $Ga_xIn_{1-x}As$ quantum dot surrounded by a cylindrical potential barrier with GaAs material. The potential inside a dot is assumed to be zero

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and V_0 outside. The Hamiltonian of the exciton in the presence of electric field is given by

$$\hat{H}_{exc} = \sum_{j=e,h}\left(\frac{\vec{p}_{\rho_j}^{\,2}}{2m_j^*} + V^j\right) + \frac{p_Z^2}{2M} + \frac{p_z^2}{2\mu} - \frac{e^2}{\varepsilon\sqrt{(\rho_e-\rho_h)^2+z^2}} \pm eF(z_e - z_h) \quad (1)$$

where j = e, h refer electron and hole respectively, m_j^* is the effective mass of electron (hole), ε is the dielectric constant of the material inside the quantum dot and e is the absolute value of electron charge. p_Z^2 denotes the momentum due to exciton centre of mass, p_z^2 is the momentum due to the position and the relative motion along the z-direction and p_ρ^2 is the momentum of the particle in the x-y plane. E is the applied electric field strength field. The total mass of exciton is defined as $M = m_e^* + m_h^*$ and the reduced mass is given by $\mu = m_e^* m_h^* / m_e^* + m_h^*$. + sign indicates for electrons and – sign refers hole.

The extra potential induced by the strain is included with the values of barrier height which is the addition of energy band offsets and the strain induced potential. The electron (hole) confinement potential (V_{conf}^j) due to the band offset in the $Ga_xIn_{1-x}As/GaAs$ quantum dot structure is given by

$$V(\rho,z) = \begin{cases} V_I(\rho) & -\frac{L}{2} \le z \le \frac{L}{2} \\ V_{II} & |z| > \frac{L}{2} \end{cases} \quad (2)$$

$$V(\rho) = \begin{cases} 0 & \rho \le R \\ V_0 & \rho > R \end{cases} \quad (3)$$

where L is the height of the cylindrical quantum dot, R is the dot radius and V_0 is expressed as

$$V_0 = Q_c \Delta E_g \quad (4)$$

where Q_c is the conduction band offset parameter. The barrier height of conduction band is taken to be 288 meV and for valence band is 192 meV, for x = 0.2. The conduction band offset parameter is taken as 60:40 between conduction band and valence band [15].

The band gap difference between the quantum dot and the barrier at Γ-point given by

$$\Delta E_g^{\Gamma}(x) = 0.359 + 0.491x + 0.58x^2 \quad (5)$$

For any low dimensional semiconductor system, the conduction and the valence edge energies are mainly affected by the strain contribution which has been introduced in the Hamiltonian by means of band offset values. Hydrostatic strains will influence the lattice volume resulting the energy level change of materials whereas uniaxial strain is the cause for the lattice constant mismatch of two materials.

The strain-induced shift of the conduction band is given by [16]

$$V_{e-strian} = a_c(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) \quad (6)$$

where a_c is the deformation potential for the conduction band, the strain tensor components defined as $\varepsilon_{xx} = \varepsilon_{yy} = \frac{a_0 - a}{a}$ where a_0 and a are the lattice parameters of bulk InAs and GaAs respectively and $\varepsilon_{zz} = -2\frac{C_{12}}{C_{11}}\varepsilon_{xx}$ where C_{ij} are the elastic stiffness constants and their values are given in Table 1.

The strain-induced shift of the valence band is expressed as [17]

$$V_{v-strain} = a_v(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) - \frac{b}{2}(\varepsilon_{xx} + \varepsilon_{yy} - 2\varepsilon_{zz}) \quad (7)$$

where a_v and b are the equibiaxial deformation potential for the valence band and the uniaxial deformation deformation potential constants for the valence band respectively .

The heavy hole mass is taken into consideration for this problem The heavy-hole mass corresponding to the curvature of the heavy hole band around Γ is taken as

$$\frac{m_0}{m_{hh}^*} = \gamma_1 - 2\gamma_2 \quad (8)$$

where m_0 is the free electron mass, γ_1 and γ_2 is the Luttinger parameters. The effect of band non-parabolicity is used in our calculations with energy dependent electron mass given as

$$m_{NP}^* = m_e^*(1 + \alpha E) \quad (9)$$

and

$$\frac{m_0}{m_e^*} = \frac{2m_0P^2}{3\hbar^2}\left(\frac{2}{E_g + E} + \frac{1}{E_g + \Delta + E}\right) \quad (10)$$

where m_0 is the free electron mass, α is the material dependent non-parabolicity parameter, 0.0025 meV^{-1}, [18], E_g is the band gap and Δ is the spin orbit splitting energy. The lowest energy of the electron (hole), E obtained by solving the single particle Schrödinger equation using the electron (hole) bulk mass.

In order to calculate the binding energy of 1S state of an exciton as a function of dot radius, a variational approach is followed. Considering the correlation of the electron-hole relative motion, the trial wave function can be chosen as,

$$\Psi(\bar{r}_e, \bar{r}_h) = f_e(z_e) f_h(z_h) e^{-\alpha\rho^2} e^{-\beta z^2}(1 - \gamma F z) \quad (11)$$

where f_e and f_h are ground state solution of the Schrödinger equation for the electrons and holes in the absence of the Coulomb interaction, given by

$$f_e(z_e) = \begin{cases} \cos(k_e z_e) z(\xi) & z_e \le |L/2| \\ A_e \exp(-\delta_e |z_e|) z(\eta) & z_e > |L/2| \end{cases} \quad (12)$$

$$f_h(z_h) = \begin{cases} \cos(k_h z_h) z(\xi) & z_h \le |L/2| \\ A_h \exp(-\delta_h |z_h|) z(\eta) & z_h > |L/2| \end{cases} \quad (13)$$

where

$$z(\xi) = Bi(\xi)Ai(-\xi) - Ai(\xi)Bi(-\xi), \quad (14)$$

$$\xi = a_c z - \frac{E - E_{nlk}}{\omega_c}, \quad (15)$$

and

$$\eta = a_c z - \frac{E - (V_0 - E_{nlk})}{\omega_c}, \quad (16)$$

with $\omega_c = \left(\frac{2m_e eF}{\hbar^2}\right)^{2/3}$. The Eq.(11) describes the correlation of the electron-hole relative motion. α and β are variational parameters responsible for the in-plane correlation and the correlation of the relative motion in the z-direction respectively [19]. γ is the variational parameter pertaining to the applied electric field. By matching the wave functions and the effective mass and their derivatives at boundaries of the quantum dot and along with the normalization, we fix all the constants in the above equations except the variational parameters. These constants are obtained by the interface conditions between the dot and the barrier. So the wave function Eq.(11) completely describes the correlation of the electron-hole relative motion.

Eventually, the exciton binding energy and the optical transition energy are given as

$$E_{exc}(x) = E_e + E_h - \langle H_{exc} \rangle_{\min}. \tag{17}$$

where $E_{e,h}$ is the sum of the lowest binding energy of electron and the hole obtained by self-consistent calculation. $E_g^{\Gamma}(x)$ the band gap of the inner dot material. The envelope wave functions and the exciton binding energy are considered to be significant factors for computing the oscillator strength which is important for comprehending absorption spectra experimentally

The stark shifts on the exciton is obtained as

$$\Delta E_{exc} = E_{exc}(F) - E_{exc}(F=0) \tag{18}$$

The expression for the oscillator strength is given by

$$f = \frac{E_p}{E_{exc}} \left| \int_V \psi_{exc}(r) dr \right|^2 \tag{19}$$

where the E_{exc} is the exciton binding energy, E_p is the Kane energy of InAs and ψ_{exc} is the exciton wave function. The oscillator strength is increased with the dot radius. The radiative life time can be calculated as [20]

$$\tau = \frac{2\pi\varepsilon_0 m_0 c^3 h^2}{\sqrt{\varepsilon} e^2 E_{exc}^2 f} \tag{20}$$

where f is the oscillator strength as given in Eq.(19) and all the other parameters are universal physical constants.

The oscillator strength and the radiative life time are two important optical parameters for computing the different linear and non-linear optical properties. However, the dipole transition occurring between two energy levels must obey the selection rules, governing $\Delta l = \pm 1$ where l is the angular momentum quantum number. The oscillator strength pertaining to the dipole transition is expressed as

$$P_{fi} = \frac{2m^*}{\hbar^2} \Delta E_{fi} |M_{fi}|^2 \tag{21}$$

where ΔE_{fi} is obtained by knowing the difference of energy between the lower (E_i) and upper states (E_f). The matrix element, $M_{fi} = 2\langle f|er|i\rangle$ is computed from the electric dipole moment of the transition from i state to f state in any low dimensional semiconductor system. Using the compact matrix approach and the Fermi Golden rule, the total optical absorption is expressed as [21]

$$\alpha(\omega, I) = \alpha_1(\omega) + \alpha_3(\omega, I) = \omega\sqrt{\frac{\mu_0}{\varepsilon_r}} \operatorname{Im}[\varepsilon_0 \chi_1(\omega) + \varepsilon_0 \chi_3(\omega) I] \tag{22}$$

where μ_0, I and ε_r are the permeability of the material, the incident light intensity of electromagnetic field and the real part of the permittivity respectively. The absorption coefficients are related to the transition matrix elements and the density of the exciton. The linear and third-order nonlinear optical absorption coefficients of a quantum dot can be obtained by a density matrix approach and the corresponding expressions are given by

$$\alpha_1(\omega) = \frac{4\pi\alpha_f \sigma_s}{n_r e^2} \hbar\omega |M_{fi}|^2 \delta(E_f - E_i - \hbar\omega) \tag{23}$$

and the non-linear optical absorption coefficient is given as

$$\alpha_3(\omega, I) = -\frac{32\pi^2 \alpha_f \sigma_s I}{n_r^2 e^2 \hbar \Gamma_{ff}} \hbar\omega |M_{fi}|^2 \delta(E_f - E_i - \hbar\omega) \left\{ 1 - \frac{|M_{ff} - M_{ii}|^2}{4|M_{fi}|^2} \times \frac{[(\hbar\omega - E_{fi})^2 - (\hbar\Gamma_{fi})^2 + 2E_{fi}(E_{fi} - \hbar\omega)]}{E_{fi}^2 + (\hbar\Gamma_{fi})^2} \right\} \tag{24}$$

where n_r is the refractive index of the material that we have taken, σ_s is electron density of the quantum dot, ω the angular frequency of the incident photon energy, α_f is the fine structure constant and E_i and E_f denote the confinement energy levels for the ground and the first excited state, respectively. The calculations of excited state energies are followed from the Ref.22.

From Eq.(23) and Eq.(24), the energy-conserving delta function by the Lorentzian is given by

$$\delta(E_f - E_i - \hbar\omega) = \frac{\Gamma}{\pi\{(E_f - E_i - \hbar\omega)^2 + \Gamma^2\}} \tag{25}$$

where Γ is the line width of the exciton for which the value, Γ =0.1 meV, is taken into consideration. Further, the homogeneous spectral width due to the finite coherence time between the two energy levels is also taken into account for the calculations.

The second order nonlinear optical rectification coefficient, due to the intersubband transitions by assuming the interaction of a polarized monochromatic electromagnetic field with the ensemble of quantum dots, is given by [23]

$$\chi_0^2 = \frac{4\rho}{\varepsilon_0} M_{fi}^2 \delta_{fi} \frac{E_{21}^2\left(1 + \frac{\tau_1}{\tau_2}\right) + \left[(\hbar\omega)^2 + \left(\frac{\hbar}{\tau_2}\right)^2\right]\left(\frac{\tau_1}{\tau_2} - 1\right)}{\left[(E_{21} - \hbar\omega)^2 + \left(\frac{\hbar}{\tau_2}\right)^2\right]\left[((E_{21} + \hbar\omega)^2 + \left(\frac{\hbar}{\tau_2}\right)^2\right]} \tag{26}$$

where $\delta_{fi} = M_f - M_i$, ρ is the carrier density, ε_0 is the permittivity in the free space, ω is the frequency of the incident electromagnetic field, and $E_{21} = E_2 - E_1$ is the energy difference between the final and initial states. $\Gamma_{12} = 1/\tau$ is the relaxation rate for states 1 and 2 here τ is the relaxation time. We have taken the relaxation rate as 1ps and the electron density is taken as 1×10^{24} m^{-3}. The observation of oscillator strength is imperative especially in the study of optical properties and they are related to the electronic dipole allowed absorptions. These results are considered to be important for the observation of fine structure of the optical absorption. The expression for the second harmonic generations is given by

$$\chi_{2\omega}^2 = \rho M_{fi}^2 \frac{M_{22} - M_{11}}{[2\hbar\omega - E_{21} + i\hbar\tau_0][\hbar\omega - E_{21} + i\hbar\tau_0]} \tag{27}$$

The third-order nonlinear optical susceptibility $\chi^{(3)}$ which is related to the optical mixing between two incident light beams with different frequencies ω_1 and ω_2 is expressed as [24,25]

$$\chi^3(-2\omega_1+\omega_2,\omega_1,-\omega_2)=\frac{-2i\sigma_s e^4\,|\langle\psi_i\,|\,\vec{r}\,|\,\psi_f\rangle|^4}{\varepsilon_0\hbar^3[i(\omega_0-2\omega_1+\omega_2)+\Gamma][i(\omega_2-\omega_1)+\Gamma]}\times\left[\frac{1}{i(\omega_0-\omega_1)+\Gamma}+\frac{1}{i(\omega_2-\omega_0)+\Gamma}\right] \tag{28}$$

where σ_s is the density of electrons in the quantum well wire, ε_0 is the vacuum permittivity, $\Gamma=1/\tau$ is the relaxation rate for states 1 and 2 and $\hbar\omega$ is the photon energy. We have taken the relaxation rate as 1ps and the electron density is taken as 1×10^{24} m^{-3}.The above equation gives the expression for the third-order susceptibility of third order harmonic generation which has been done by the compact-density–matrix approach.

Results and discussion

Electric field induced binding energy of the heavy hole exciton and some nonlinear optical properties in a $Ga_{0.2}In_{0.8}As$/GaAs strained quantum dot are dealt. The effects of geometrical confinement and the electric field are taken into account. We have taken the constant Ga alloy content so that the barrier height of the quantum dot is fixed. The values of strain contribution are added with the barrier height. The values of material parameters in the present work are given in Table.1. The atomic units have been followed in the determination of electronic charges and wave functions in which the electronic charge and the Planck's constant have been assumed as unity.

In Fig.1, we present the variation of exciton binding energy as a function of dot radius in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot with and without the electric field and the insert figure shows the exciton binding energy with the electric field for three different geometrical confinement. In all the cases, it is observed that the binding energy increases with decreasing dot radius and it reaches the maximum value for a critical dot radius and then rapidly decreases. Enhancement of binding energy with the reduction in dot radius is observed for the all the cases of external electric field whereas the reduction in binding energy with the electric field is observed for all the dot radii. The reason for the earlier effect is the dominant behaviour of geometrical confinement when the dot is reduced, however, for the smaller dot radii, again the exciton binding energy is found to decrease due to the tunneling of wave functions through the barrier. Moreover, the enhancement of Coulomb interaction between the electron and hole eventually causes the decrease in binding energy [26].

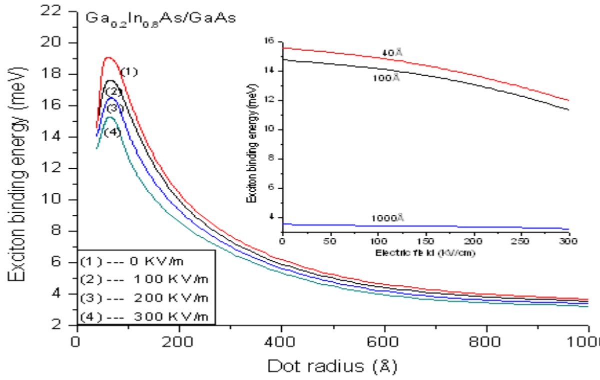

Fig 1. Exciton binding energy as a function of dot radius in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot with and without the electric field and the insert figure shows the exciton binding energy with the electric field for three different dot radii.

The reason for the latter effect is as follows; as the electric field is increased the electron is pulled towards one side of the quantum dot resulting the overall decrease of the binding energies. We notice from the insert figure that the binding energy is more for smaller dot radii than the larger dot radii due to the confinement. The effect of attractive Coulomb potential on the total energy is brought out in the figure. The enhancement of exciton binding energy with the reduction of dot radius is due to the spatial confinement.

Fig.2 shows the variation of exciton binding energy shifts as a function of electric field for three different dot radii in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot. Stark effect on electron-hole pair interaction with the geometrical confinement is brought out here. The reduction of Stark shift with the application of electric field is observed for all the dot radii. The Stark effect with the strong confinement has more influence than the dots in the weak confinement. It is because the effects of exciton binding energy have more influence for narrow dots in the stronger confinement region than the wider dots. It is clearly seen that the effect of electric field has more influence on the smaller dot radius than the bigger ones. The results indicate that any quantum device depends on the external electric field and the spatial confinement of geometrical size [27].

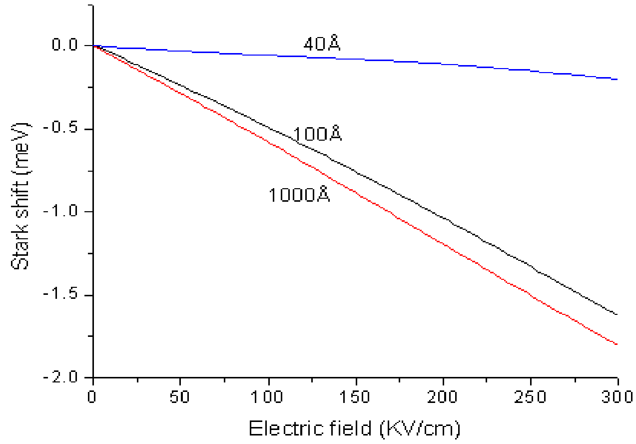

Fig 2. Variation of exciton binding energy shifts as a function of electric field for three different dot radii in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot

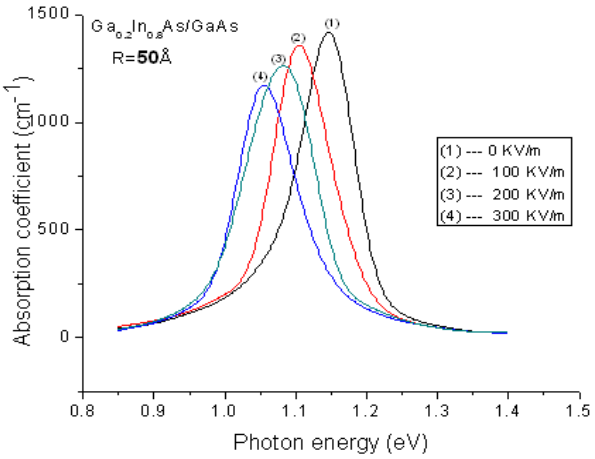

Fig 3. Variation of total absorption coefficient of an exciton in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot, for a constant radius 50 Å, as a function of photon energy in the presence of electric field

In Fig.3, we display the variation of total absorption coefficient of an exciton in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot with the constant dot radius, 50 Å as a function of photon energy in the presence of electric field is shown in Fig.3. We have taken I =10 MW/m^2. It is noticed that the resonant peak value of the nonlinear absorption coefficient shifts towards the lower photon energies as the electric field strength increases.

Table 1. Material parameters* used in the calculations (all the other parameters are linearly interpolated)

Parameter	InAs	GaAs	Unit
E_g	0.418	1.517	eV
m_e	0.023	0.067	(m_0)
ε	15.15	13.13	
E_p	21.5	51.78	
Δ	0.39	0.554	
γ_1	20	6.98	
γ_2	8.5	2.06	
C_{11}	83.29	11.88	GPa
C_{12}	45.26	5.38	GPa
C_{44}	23.0	5.94	GPa
a_c	-5.08	-7.17	eV
a_v	1	-1.16	eV
b	-1.8	2	eV
a	0.6058	0.565	nm

It is due to the reduction of exciton binding with the application of electric field. Further, the dominant behaviour of geometrical confinement in the low dimensional semiconductor systems is brought out. In our calculations, the absorption coefficient values include both the real and imaginary parts. The nonlinear optical properties are strongly affected by the exciton binding energies and the transition energies, the oscillator strength and the absorption profile. It is observed from the expression of absorption coefficients, the linear absorption coefficient is larger due to the positive linear susceptibility term whereas α_3 governed by the third order nonlinear susceptibility term is negative. Hence the total absorption coefficient is reduced significantly as given by the Eq.(24) while combining these two effects. However, the contribution from the nonlinear optical absorption coefficient should be considered provided the optical intensity is very strong. Also one notices that the observed optical nonlinearity becomes stronger and stronger as the dot size becomes larger and larger. Further, it is observed that the absorption coefficient peak moves to the lower photon energy as the electric field is increased with the increase in the value of absorption coefficients. It implies that the resonant values of electric field shift towards the red region in quantum dots. It is because that the spacing between the energy levels decreases with additional confinement due to the electric field [28].

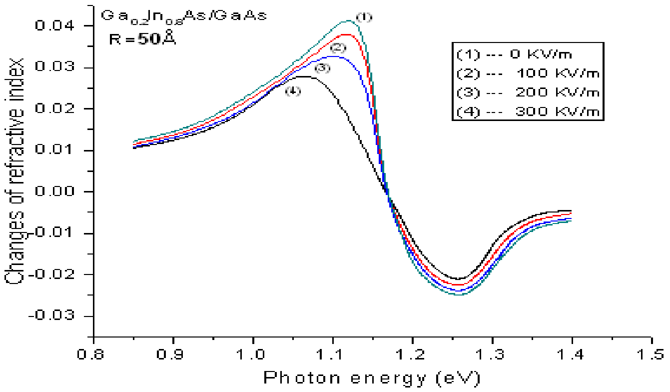

Fig 4. Variation of changes of refractive index in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot, for a constant radius 50 Å, as a function of photon energy in the presence of electric field

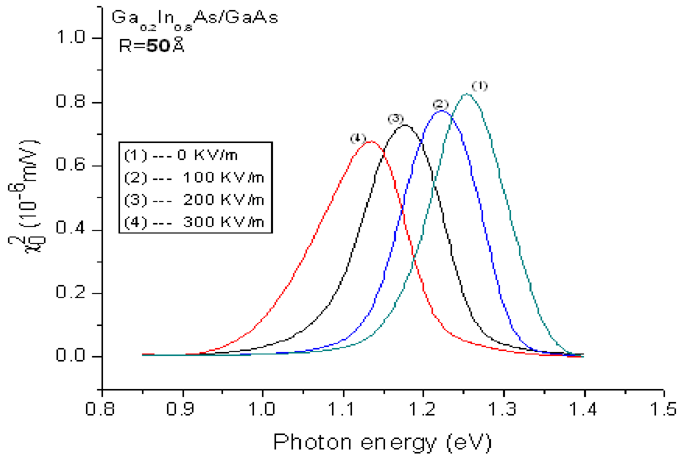

Fig 5. Variation of second order nonlinear rectification coefficient as a function of incident energy for a confined exciton in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot, for a constant radius 50 Å, in the presence of electric field

We present the variation of total refractive index changes of the exciton confined in a $Ga_{0.2}In_{0.8}As$/GaAs quantum dot as a function of photon energy in the presence of electric field in Fig.4. The dot radius is taken as 50Å. It is observed that the external application of electric field has an important effect. The changes of refractive index related to the intersubband transition energy are investigated here. It brings out the two components of refractive index, namely, $\frac{\Delta n_{(1)}(\omega)}{n_r}$ and $\frac{\Delta n_{(3)}(\omega)}{n_r}$. The combination of these terms is calculated as a function of incident energy with the constant confining potential in the presence of application of electric field. It is noticed that the changes of refractive index decreases with the application of external electric field. It is also observed from the equations related to changes of refractive index that the linear relative change in refractive index does not depend on photon intensity whereas the third order relative change in refractive index changes with photon intensity. Further, it changes quadratically with the matrix element of the electric dipole moment of the transition. Thus, the nonlinear term must be considered when calculating the refractive index change of quantum dot systems in the presence of external perturbations [29].

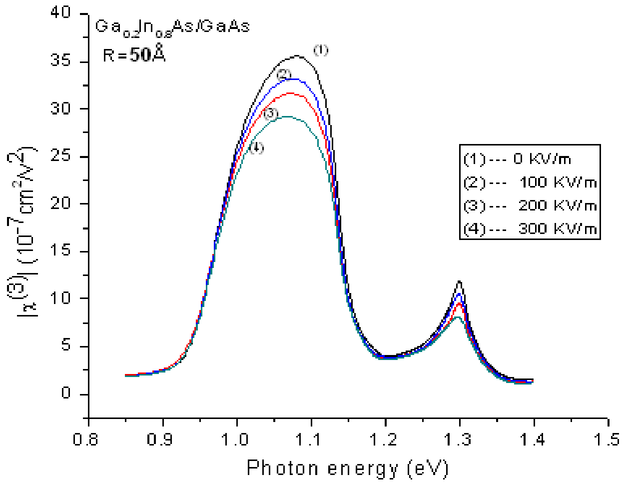

Fig 6. Variation of third-order susceptibility of third harmonic generation as a function of photon energy with and without the polaron effects in a $Ga_{0.2}In_{0.8}As/GaAs$ quantum dot, for a constant radius 50 Å, in the presence of electric field

In Fig.5, we show the variation of second order nonlinear rectification coefficient as a function of incident energy for a confined exciton in a $Ga_{0.2}In_{0.8}As/GaAs$ quantum dot, for a constant radius 50 Å, in the presence of electric field. It is observed that the resonant peak value not only shifts towards the red region but also becomes lesser when the application of electric field is included. Generally, the resonant frequencies are considered to be important for the study of non-linear optical properties in the low dimensional nanostructures. Further, it is noticed that the resonant absorption peak value is found to be linearly decreasing with the increase of electric field and the energy levels are separated largely the reduction of overlap integral due to the increase in dipole matrix. It is because there occurs a competition between the energy interval and the dipole matrix element which determine these features. Thus, the electric field has more influence on the second order nonlinear optical rectification coefficient [30].

Fig.6 shows the variation of third-order susceptibility of third harmonic generation as a function of photon energy in the presence of electric field in a $Ga_{0.2}In_{0.8}As/GaAs$ quantum dot, for a constant radius 50 Å. It is noticed that the susceptibility has two peaks and the contribution of electric field makes the resonant peak lower region of energies. Further, it is noted that the magnitude of the resonant peak moves towards the higher energies with the increase of the application electric field. The coefficient of third-order susceptibility of third harmonic generation has been enhanced with the application of electric field. The relaxation time has more influence on the third-order susceptibility. It is due to the enhancement of matrix element. And hence, it is concluded that the contribution of electric field has more influence on the resonant peak of third order susceptibility of third harmonic generation [31].

In conclusion, heavy hole excitons in a strained $Ga_{0.2}In_{0.8}As/GaAs$ quantum dot, in the presence of external electric field, have been investigated. The interface strain effect has been included with the barrier height of the quantum dot. The effects of spatial confinement have been taken into consideration. The exciton binding energy and some nonlinear optical properties in the presence of electric field have been discussed. Some important parameters such as the anisotropy, non-parabolicity of the conduction band, strain effects and the quantum confinement have been considered. A cylindrical dot of $Ga_{0.2}In_{0.8}As$ semiconductor has been taken as inner material and the GaAs has been taken as outer material. The results show that the exciton binding energies and the nonlinear optical properties are strongly dependent on the application of external electric field.

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