

MAGNETIC FIELD, Pressure and temperature dependent optical properties IN A $GaAs_{0.9}P_{0.1}$ QUANTUM DOT

Ada Vinolin¹ and A.John Peter^{2*}

¹Dept.of Physics, Madurai Kamaraj University College, Alagarkoil Road, Madurai-625 002.

²P.G and Research Dept.of Physics, Government Arts College, Melur-625 109. Madurai.

E-mail : a.john.peter@gmail.com

ABSTRACT

Simultaneous effects of magnetic field, pressure and temperature on the exciton binding energies are found in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot. Numerical calculations are carried out taking into consideration of spatial confinement effect. The cylindrical system is taken in the present problem with the strain effects. The electronic properties and the optical properties are found with the combined effects of magnetic field strength, hydrostatic pressure and temperature values. The exciton binding energies and the nonlinear optical properties are carried out taking into consideration of geometrical confinement and the external perturbations. Compact density approach is employed to obtain the nonlinear optical properties. The optical rectification coefficient is obtained with the photon energy in the presence of pressure, temperature and external magnetic field strength. Pressure and temperature dependence on nonlinear optical susceptibilities of generation of second and third order harmonics as a function of incident photon energy are brought out in the influence of magnetic field strength. The result shows that the electronic and nonlinear optical properties are significantly modified by the applications of external perturbations in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot.

Keywords

Quantum dot; Exciton; Optical properties

PACS

73.21.Fg; 42.65.An; 71.38.-k

Council for Innovative Research

Peer Review Research Publishing System

Journal: JOURNAL OF ADVANCES IN PHYSICS

Vol. 6, No.2

www.cirjap.com, japeditor@gmail.com

1. INTRODUCTION

Group III-V semiconductors, especially GaAsP semiconductors, are given attention for fabricating opto-electronic devices such as optical switches, detectors, modulators, efficient power lasers and high mobility field effect transistors. High power lasers can be directly applied for industrial, military and medical applications. The large optical nonlinearity can be achieved with the GaAsP piezo-electrically active materials due to the built in internal electric fields [1]. The semiconductor heterostructure made up of GaAs/GaAsP materials are quite interesting because the GaAs semiconductor experiences compressive strain whereas GaAsP material suffers tensile strain [2]. Further, these lattice matched layers achieve higher polarization. The electronic and optical properties can be significantly modified by the strain effects and in fact, these properties are improved with the inclusion of strain effects [3]. GaAsP quantum well structures have been grown by means of MOVPE and the strain-induced piezoelectric field has been studied and it is found that it can be adjusted by the energy band offset [4]. The optical properties of tensile-strained GaAsP/GaInP square quantum wells grown by MOCVD have been investigated with various characteristics of the PL spectra [5].

Optical properties of reduced dimensional semiconductors show exotic behaviour more than their counter part bulk materials and their nonlinear optical coefficients are found to be higher [6]. The electrical and optical properties of low dimensional semiconductors are motivated for fabricating optical devices. The dependence of external perturbations with the additional geometrical confinement shows some interesting physical phenomena. Especially, the application of magnetic field is considered to be an interesting probe for the investigations of physical properties. They have been studied theoretically and experimentally [7 -10]. Optical gain of triple quantum wells, GaAsN/GaAs/GaAsP, has been studied using both 10-band and 8-band $\mathbf{k} \cdot \mathbf{p}$ Hamiltonian [11].

In the present work, the dependence of pressure, temperature and the magnetic field on the electronic and optical properties are dealt in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ strained quantum dot. The computation is performed with the spatial confinement effect. The cylindrical quantum dot is followed taking into account the strain effects. The electronic properties and the optical properties are found with the combined effects of magnetic field strength, hydrostatic pressure and temperature values. Compact density approach is applied to obtain the nonlinear optical properties. The optical rectification coefficient with the photon energy is calculated in the presence of pressure, temperature and external magnetic field strength. Pressure and temperature dependence on nonlinear optical susceptibilities of second and third order harmonic generations as a function of incident photon energy are brought out in the influence of magnetic field strength. In Section 2, the method used in our calculation is briefly explained and the results and discussion are presented in Section 3. A brief summary and results are summarized in the last section.

2. THEORY AND MODEL

In a cylindrical dot, $GaAs_{0.9}P_{0.1}$ semiconductor is taken as the inner material which is surrounded by the $GaAs_{0.6}P_{0.4}$ outer material. The Hamiltonian of the charged carriers in the presence of magnetic field, pressure and temperature, within the effective mass-approximation, is given by

$$H_{exc}(P, T) = H_0(P, T) - \frac{e^2}{\varepsilon(P, T) \sqrt{\rho_{eh}^2 + (z_e - z_h)^2}} \quad (1)$$

where

$$H_0(P, T) = \sum_{j=e,h} \left\{ -\frac{\hbar^2}{2m_j(P, T)} \left[\frac{\partial^2}{\partial \rho_j^2} + \frac{1}{\rho_j} \frac{\partial}{\partial \rho_j} + \frac{1}{\rho_j^2} \frac{\partial^2}{\partial \phi_j^2} + \frac{\partial^2}{\partial z_j^2} \right] \mp \frac{i\hbar e B}{2m_j(P, T)c} \frac{\partial}{\partial \phi_j} + \frac{e^2 B^2 \rho_j^2}{8m_j(P)c^2} + V_j(\rho_j, z_j, P, T) + \sigma_z \mu_B g_j(P) B \right\} \quad (2)$$

where $j = e, h$, $\varepsilon(P, T)$ is the pressure and temperature dependent dielectric constant of $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot, e is the absolute value of electron charge. $m_e^*(P, T)$ and $m_h^*(P, T)$ are the pressure and temperature dependent effective masses of electron and heavy hole respectively. The pressure and temperature dependent confinement potentials are denoted by $V_j(\rho_j, z_j, P, T)$ due to the band offset between the inner and outer materials. $a_1 = -0.1 \times 10^{-3}$ kbar, $a_1 = 5.56 \times 10^{-6}$ kbar², μ_B is the Bohr magneton and σ is the spin taken as $\pm 1/2$ [13]. The z-component of the spin has been taken as $\pm 1/2$ for simplicity for holes.

The pressure and temperature dependent effective masses at Γ point are given by [12]



$$m_e^*(P,T) = \frac{m_0}{1 + E_p \left(\frac{2}{E_g^\Gamma(P,T)} + \frac{1}{E_g^\Gamma(P,T) + \Delta_0} \right)} \quad (3)$$

and

$$\frac{m_{hh}^*(P,T)}{m_0} = \frac{m_{hh}^*}{m_0} + a_1 P + a_2 P^2 \quad (4)$$

where Δ_0 is the spin orbit splitting, m_0 is the single bare electron mass, E_p is the Kane energy related to the momentum matrix element between the conduction and valence bands. The effects of strain due to internal electric fields bring out that the total confinement potential which is the addition of energy offsets of the conduction band (or valence band).

The pressure and temperature related dielectric constant is given by [14]

$$\varepsilon(P,T) = 12.786 - 0.021T - 2.881 \times 10^{-3} P \quad (5)$$

where P is the pressure measured in GPa and T is the temperature in K. $E_g^\Gamma(P,T)$ is the pressure and temperature dependent energy gap in eV given by [15,16],

$$\Delta E_g^\Gamma(P,T) = \Delta E_g^\Gamma(\text{unstrained})(0,T) + \alpha_0 P + \beta_0 P^2 + \delta E_{c(v)} \quad (6)$$

where α_0 and β_0 are pressure coefficients and their values are presented in Table.1. The temperature dependent band gap is given by [17]

$$\Delta E_g^\Gamma(\text{unstrained})(0,T) = 1.543 - \frac{\delta_1 T^2}{T + \delta_2} \text{ eV} \quad (7)$$

where δ_1 and δ_2 are the thermal expansion coefficients. The shifts due to the strain effects are given by

$$\delta E_c = 2a_c \varepsilon (C_{11} - C_{12}) / C_{11}, \quad (8)$$

and

$$\delta E_v = 2a_v \varepsilon (C_{11} - C_{12}) / C_{11} + b \varepsilon (C_{11} + 2C_{12}) / C_{11}, \quad (9)$$

where a_c is the deformation potential constant of conduction band, a_v is the deformation potential constant of valence band, b is the uniaxial strain, the strain in the layer is expressed as $\varepsilon = \frac{a_0 - a}{a}$ where a_0 and a are the lattice parameters of the inner dot and the outer barrier materials respectively. The effect of strain results in the change in energy band gap of the conduction and valence band.

The effects due to strain introduce an additional potential field in the z-direction. And hence, the confinement potential is the sum of energy band offsets of the conduction band (or valence band) with the inclusion of strain-induced potential for any strained quantum dot nanostructure. The confinement potentials due to the band offset in the $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot are given by

$$V_j(\rho_j, z_j, P, T) = \begin{cases} 0 & \rho_j \leq R(P), |z_j| \leq L(P)/2 \\ V_j(P, T) & \rho_j > R(P), |z_j| > L(P)/2 \end{cases} \quad (10)$$

where the potential barrier height is given by

$$V_j(P, T) = Q_j \Delta E_g^\Gamma(P, T) \quad (11)$$



where Q_j is the conduction band offset parameter which is taken as 80:20 [18]. $\Delta E_g^\Gamma(P, T)$ is the pressure and temperature dependent energy band gap between quantum dot and the barrier.

The effect of pressure modifies the dimensions of the cylindrical quantum dot. It alters the lattice constants, effective masses and the dielectric constants. The pressure dependent dot radius and the height of the quantum dot are given by [19]

$$R(P) = R_0[1 - 2(S_{11} + 2S_{12})P] \tag{12}$$

and

$$L(P) = L_0[1 - 2(S_{11} + 2S_{12})P] \tag{13}$$

where R_0 is the original radius of the quantum dot and where L_0 is the original height of the quantum dot. S_{11} and S_{12} are the elastic compliance constants which are expressed as

$$S_{11} = \frac{C_{11}C_{33} - C_{13}^2}{(C_{11} - C_{12})(C_{33}(C_{11} + C_{12}) - 2C_{13}^2)} \tag{14}$$

and

$$S_{12} = \frac{C_{12}C_{33} - C_{13}^2}{(C_{11} - C_{12})(C_{33}(C_{11} + C_{12}) - 2C_{13}^2)} \tag{15}$$

The heavy-hole and light-hole masses in terms of Luttinger parameters, γ_1 and γ_2 , (Table 1) are given by [20]

$$\frac{m_0}{m_{hh}^*} = \gamma_1 - 2\gamma_2, \tag{16}$$

$$\frac{m_0}{m_{lh}^*} = \gamma_1 + 2\gamma_2, \tag{17}$$

where m_0 is the free electron effective mass.

The trial wave function is assumed to be the product of the hydrogenic part and the radial solution of the exciton confined. In the presence of magnetic field strength, it is given by

$$\psi_{nlk}(\rho_j, \phi_j, z_j) = N_1 J_l(r_{nl}\rho_j) \exp(\pm il\phi_j) \exp(ikz_j) \exp(-\gamma\rho_j^2/4) \tag{18}$$

where N_1 is the normalization constant. J_l is the cylindrical Bessel function for a given value of l . The measure of

magnetic field, γ , is given by $\gamma = \frac{\hbar\omega_c}{2Ry^*}$ where Ry^* is the effective Rydberg which is obtained as 6.937 meV and ω_c

is the cyclotron frequency.

The exciton binding energy is obtained using the variational approach with the two parameter variational Gaussian wave function. It is used to obtain the energy eigen values. We have considered the correlation of the electron-hole relative motion in the problem with the following wave function.

$$\Psi_{exc}(\rho_j, \phi_j, z_j) = N_2 \psi_{nlk}(\rho_j, \phi_j, z_j) \exp(-\alpha\rho_{eh}^2 - \beta z_{eh}^2) \tag{19}$$

where α and β are variational parameters. The $\psi_{nlk}(\rho_j, \phi_j, z_j)$ is the electron (hole) wave function confined in the quantum dot as explained earlier. N_2 is the normalization constant. In the above variational ansatz two variational parameters α and β are employed. Here, α refers the variational parameter which is related to in-plane correlation of the exciton and the other variational parameter β denotes the relative motion in the z-direction in the cylindrical quantum dot [21]. Hence, as a result, the above said two variational parameters are responsible for the anisotropy of nature of the system taken in the present situation. It is also believed that the used Gaussian type wave function is more suitable wave function in the strong confinement region in the presence of magnetic field strength [22].



The pressure and temperature related lowest ground state binding energy is obtained taking into account the spatial confinement in the $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot in the presence of magnetic field strength. And then, the exciton binding energy is obtained using the trial wave function which includes the above said variational parameters. Thus, the ground state energy of the exciton in the $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot is done by using the following equation

$$E_{exc}(P, T) = \min_{\gamma, \alpha, \beta} \frac{\langle \psi_{exc} | \hat{H}_{exc}(P, T) | \psi_{exc} \rangle}{\langle \psi_{exc} | \psi_{exc} \rangle} \quad (20)$$

The exciton binding energy, in the $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot, is defined as

$$E_b(P, T) = E_e(P, T) + E_h(P, T) + \gamma - E_{exc}(P, T). \quad (21)$$

where $E_{e,h}(P, T)$ is the lowest ground state energies of electron and hole in the presence of pressure, temperature and magnetic field strength.

The pressure and temperature induced interband emission energies associated with the exciton, in the $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot, are calculated by

$$E_{ph}(P, T) = E_e(P, T) + E_h(P, T) + E_g^\Gamma(P, T) + \gamma - E_b(P, T) \quad (22)$$

where $E_g^\Gamma(P, T)$ is band gap energy of $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot.

The oscillator strength enhances the nonlinear optical property of any system and it is defined as [23]

$$f_{exc}(P, T) = \frac{E_p}{E_{exc}(P, T)} \left| \int_V \Psi_{exc}(\rho_j, \phi_j, z_j) d\tau_j \right|^2 \quad (23)$$

where E_p is the Kane energy which is related to the momentum matrix element between the conduction and valence bands. $E_{exc}(P, T)$ is the pressure and temperature dependent exciton binding energy.

The nonlinear optical rectification coefficients are obtained by using the compact density matrix method. The second order nonlinear optical rectification coefficient is expressed as [24,25]

$$\chi_0^2 = \frac{e^3 \sigma_s M_{01}^2 \delta_{01}}{\epsilon_0} \frac{2\Delta E^2}{[(\Delta E - \hbar\omega)^2 + (\hbar\Gamma)^2][(\Delta E + \hbar\omega)^2 + (\hbar\Gamma)^2]} \quad (24)$$

where σ_s is the electron density in the quantum dot, e is the absolute value of electron charge, ϵ_0 is the vacuum permittivity, $\Gamma = 1/\tau$ is the relaxation rate for the states 1 and 2 and $\hbar\omega$ is the photon energy. The matrix element, $M_{01} = \langle \psi_0 | z | \psi_1 \rangle$ is defined as the electric dipole moment of the transition from the ground state (ψ_0) to the first excited state ψ_1 with $\delta_{01} = \langle \psi_1 | z | \psi_1 \rangle - \langle \psi_0 | z | \psi_0 \rangle$. ΔE (transition energy) is the absorption energy from ψ_0 to ψ_1 . We have taken the relaxation time as 1ps and the electron density is taken as $1 \times 10^{24} \text{ m}^{-3}$.

The expression for the second harmonic generations is given by

$$\chi_{2\omega}^2 = \sigma_s M_{if}^2 \frac{M_{22} - M_{11}}{[2\hbar\omega - E_{21} + \hbar\Gamma][\hbar\omega - E_{21} + \hbar\Gamma]} \quad (25)$$



where M_{if} are the matrix elements of the electronic dipole moment defined as $M_{if} = \langle \Psi_i | ez | \Psi_f \rangle (i, f = 1, 2)$ and $E_{if} = E_i - E_f$ is the energy difference between two different states. M_{11} ($M_{11} = \langle \Psi_1 | ez | \Psi_1 \rangle$) and M_{22} ($M_{22} = \langle \Psi_2 | ez | \Psi_2 \rangle$) are the diagonal elements in the matrix elements.

The third-order nonlinear optical susceptibility which is related to optical mixing between two incident light beams with different frequencies (ω_1 and ω_2) is given by [26,27]

$$\chi^3(-2\omega_1 + \omega_2; \omega_1, -\omega_2) = -\frac{2iNe^4 |M_{if}|^4}{\epsilon_0 \hbar^3} \frac{1}{[i(\omega_0 - 2\omega_1 + \omega_2) + \Gamma][i(\omega_2 - \omega_1) + \Gamma]} \left[\frac{1}{[i(\omega_0 - \omega_1) + \Gamma]} + \frac{1}{[i(\omega_2 - \omega_1) + \Gamma]} \right] \quad (26)$$

where N is the number of charge carriers obeying the Fermi-Dirac distribution function, M_{if} denotes the dipole matrix element as defined earlier, the transition frequency is given by $\omega_0 = (E_f - E_i) / \hbar$, and Γ is the relaxation time as defined earlier.

3. Results and discussion

Pressure and temperature related exciton binding energies and nonlinear optical susceptibilities in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot are investigated in the presence of the magnetic field strength. The present calculations include the effects of external perturbations and the spatial confinement. The results are illustrated in Fig.1-Fig.4. The atomic units are followed in the computations in which the electronic charge and the Planck's constant are assumed to be unity. The heavy hole mass is used to obtain the exciton binding energy and the optical susceptibilities because the heavy excitons are more common in experimental results. The material parameters are listed in Table 1. For $\gamma = 1$, the magnetic field is found to be 7.875 T for the phosphour alloy content, ($x = 0.1$).

In Fig.1, we present the variation of exciton binding energy with the temperature for different magnetic field strengths and the pressure values in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot for a constant dot radius, 50Å. The exciton binding energy is found to enhance with the reduction of dot radius in all the cases of applications of hydrostatic pressure and magnetic field strength for all the temperatures. The exciton binding energy reaches a maximum value for a critical dot radius when the dot radius is reduced and then it starts decreasing when the dot radius is still decreased [28]. The critical dot radius is found to be around 100 Å in which the maximum binding energy is observed. For larger dot radius, the exciton binding energy approaches the bulk behaviour. The effects of magnetic field and the hydrostatic pressure make the exciton binding energy higher because of the additional confinement due to the magnetic field and the changes of lattices parameters due to the pressure. In fact, the hydrostatic pressure changes the material parameters of the system in the GaAsP semiconductor and it results in the enhancement of band gap energy of GaAsP material. The dependence on the pressure and the magnetic field strength on the exciton binding energy in the presence of temperature are shown in the figure. In fact, this behaviour is just opposite to the effect of hydrostatic pressure. It is observed that the effect of temperature has more influence on the exciton binding energy and it decreases linearly with the application of temperature [29].

Fig.2 shows the variation of second order nonlinear coefficient as a function of incident energy, for a confined exciton, for various pressure values and the temperature values with the constant magnetic field strength ($\gamma = 0.254$) in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot. It is found that the resonant peak of second order nonlinear optical coefficient increases when the hydrostatic pressure is enhanced on contrary the resonant peak decreases when the temperature is enhanced. The magnitude of the second order nonlinear coefficient suffers a blue shift when the hydrostatic pressure is enhanced. The magnitude of the resonant peak of nonlinear optical rectification is observed to be $10^{-6} m/V$. It is because the spacing between the energy levels increases with the application of hydrostatic pressure. Thus, the resonant peak frequencies are considered to be important while studying the nonlinear optical properties of exciton in the low dimensional semiconductor nanostructures. Thus, the applications of external perturbations, magnetic field and the hydrostatic pressure, enhances the energy eigen values, the energy difference between the subband energy enhances and eventually the resonant peak suffers the blue shift. But, the effect of temperature shows the opposite nature and it shows the red shift. The occurrence of blue shift is due to the increase in energy levels between the initial and final states [30,31].

In Fig.3, we show the variation of second order harmonic generation coefficient as a function of incident photon energy in the presence of hydrostatic pressure and temperature, with the constant magnetic field strength ($\gamma = 0.254$), in a



$GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot. The effect of temperature on second order harmonic generation is shown here. It is observed that the magnitude of harmonic generation coefficient moves towards the higher energies when the magnetic field strength is increased. The application of magnetic field brings out the blue shift. It is due to the increase of confinement potential and the exciton binding energy when the magnetic field strength is applied [32]. Further, it is noted that the resonant peak decreases when the temperature is increased and it shows the red shift. It is due to the larger dipole transition matrix element and the reduction of the spacing between the energy levels with the increase in temperature. It is observed that the resonant peak moves towards the higher photon energy when the pressure effect is included, it is due to the enhancement of band gap and the exciton binding energy with the application of pressure whereas the peak suffers red shift when the temperature effect is included. This is because the energy difference between the ground and the first excited states decreases with increasing temperature and moreover the electronic dipolar transition matrix element also increases.

The variation of third harmonic generation coefficient as a function of incident energy for a confined exciton in the presence of hydrostatic pressure and the temperature, with the constant magnetic field, in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot in Fig.4. We have taken $I = 1MW/m^2$ and $\Gamma = 0.2$ ps. Three different peaks are found at three different photon energies as seen in the figure. It is found that the resonant peaks move towards the higher photon energies when the pressure effect is increased whereas the peak suffers the red shift when the temperature effect is increased. This is because the effect of pressure strengthens the quantum confinement of the exciton leading to decrease of the matrix element. The enhancement of hydrostatic pressure decreases the ground and excited transition energies. Further, the symmetry of the electronic wave function is also affected by application of the external perturbations [33].

In conclusion, simultaneous effects of pressure, temperature and the magnetic field on the exciton binding energies and the optical properties have been obtained in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot in the presence of magnetic field strength. Numerical calculations have been carried out taking into consideration of spatial confinement effect. The cylindrical of a system has been considered taking into account the strain effects. The electronic properties have been found with the combined effects of magnetic field strength, hydrostatic pressure and temperature values. The exciton binding energies and the nonlinear optical properties have been found with the effects of geometrical confinement and the external perturbations. Compact density approach has been employed to obtain the nonlinear optical properties. The optical rectification coefficient has been obtained with the photon energy in the presence of pressure, temperature and external magnetic field strength. Pressure and temperature dependence on nonlinear optical susceptibilities of generation of second and third order harmonics as a function of incident photon energy have been brought out in the influence of magnetic field strength. Considerable modifications on the optical and electronic properties can be obtained by applying the external perturbations.

ACKNOWLEDGMENT

The author (AJP) thanks the CSIR, India for the grant (No.03 (1159)/10/EMR-II) for the financial support of this work.



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Table 1. Material parameters* used in the calculations

Parameter	GaAs _{0.9} P _{0.1}	GaAs _{0.6} P _{0.4}
E_g^Γ (eV)	1.543	1.923
m_e (m_0)	0.085	0.14
Δ (meV)	0.314	0.236
m_{hh}	0.385	0.52
m_{lh}	0.097	0.111
C_{11} (GPa)	12.104	12.776
C_{12} (GPa)	5.467	5.728
a_c (eV)	-7.167	-7.158
a_v (eV)	-1.214	-1.376
γ_1	6.575	5.75
γ_2	1.939	1.456
E_p (eV)	29.06	29.87
α_0 (10^{-2} eV/GPa)	10.22	6.38
β_0 (10^{-4} eV/GPa ²)	-22.05	-14.7
θ_1 (10^{-4} K ⁻²)	5.445	5.563
θ_2 (K)	222.3	277.2
Lattice constant (Å)	5.633	5.572

*Parameters are taken from the Ref.[34,35]

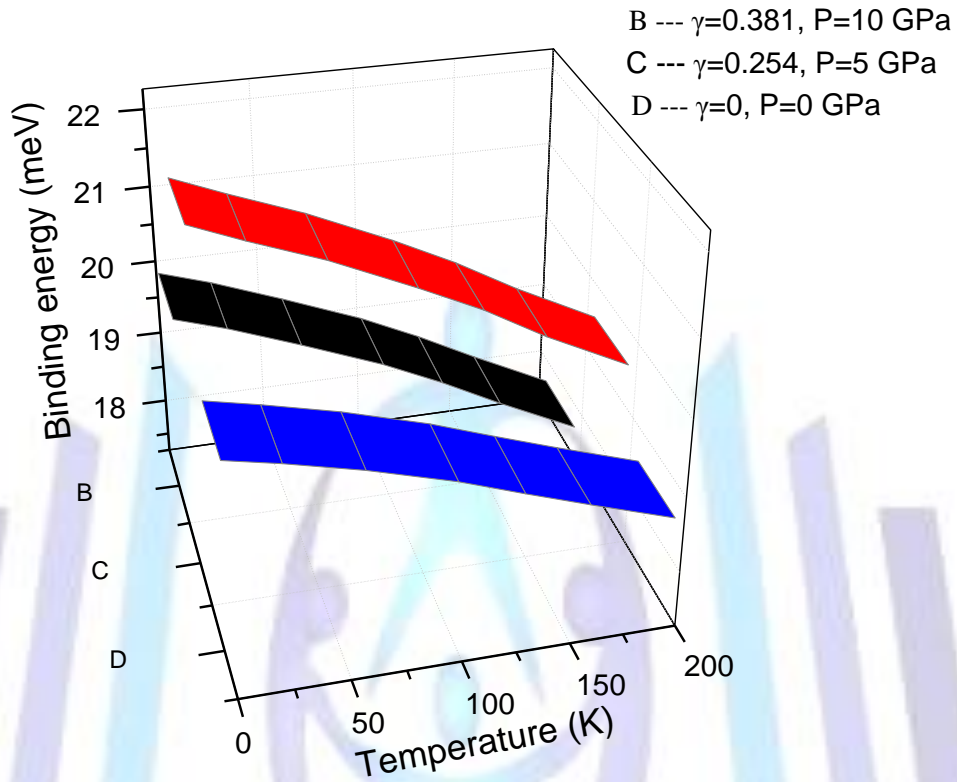


Fig.1 Variation of exciton binding energy with the temperature for different magnetic field strengths and the pressure values in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot for a constant dot radius, 50\AA .

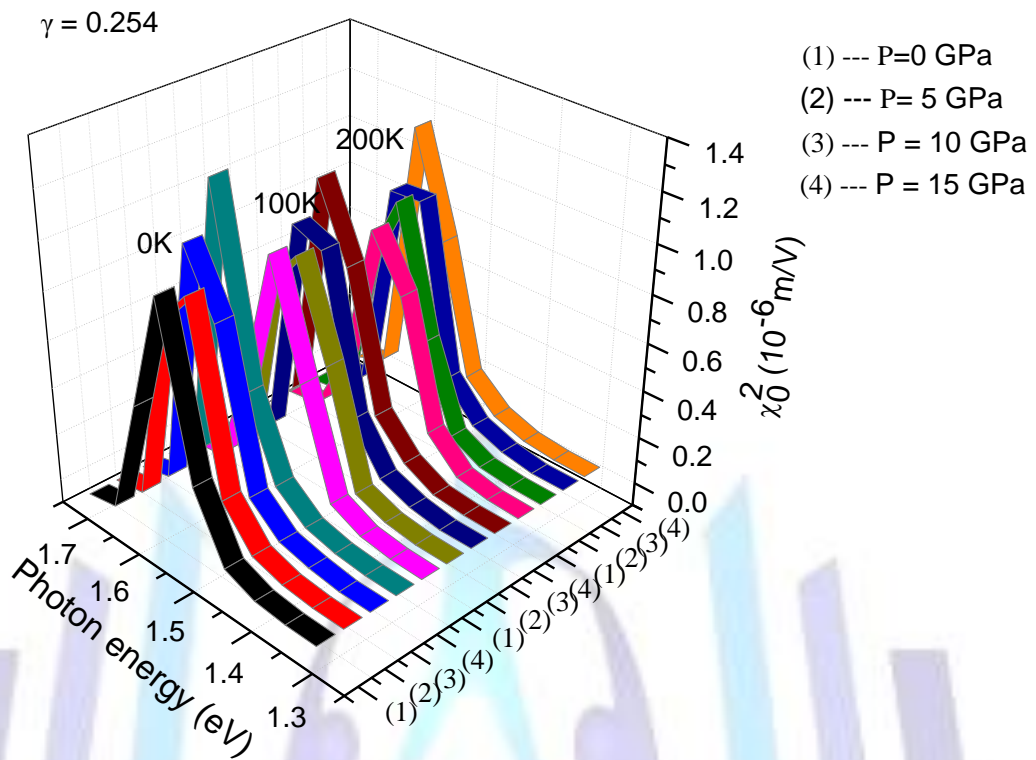


Fig.2 Second order nonlinear coefficient as a function of incident energy for different pressure values and the temperature values in the presence of magnetic field in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot.



$\gamma = 0.254$

- (1) P=0 GPa
- (2) P= 5 GPa
- (3) P = 10 GPa
- (4) P = 15 GPa

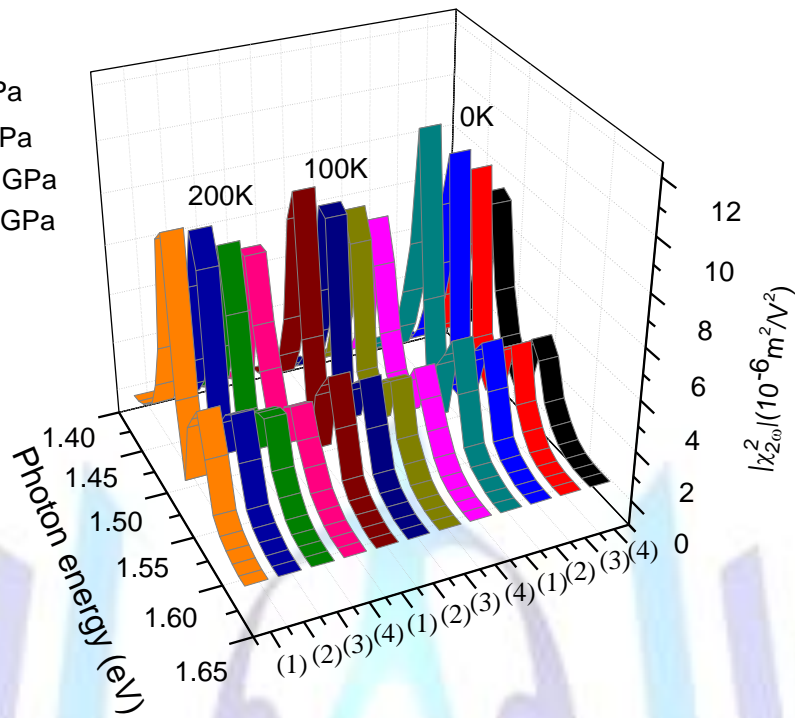


Fig.3 Second order harmonic generation coefficient with the incident energy for a confined exciton in the presence of hydrostatic pressure and temperature values, with the constant magnetic field strength, in a $GaAs_{0.9}P_{0.1} / GaAs_{0.6}P_{0.4}$ quantum dot.

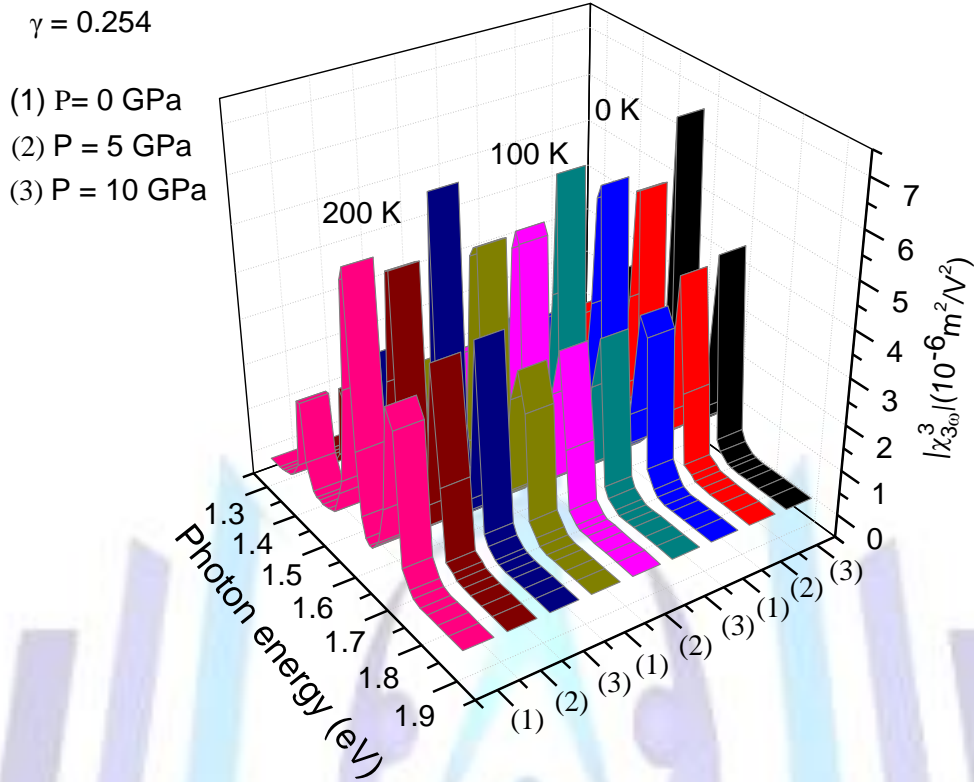


Fig.4 Third harmonic generation coefficient with the incident photon energy for a confined exciton in the presence of hydrostatic pressure and the temperature values, with the constant magnetic field, in a $\text{GaAs}_{0.9}\text{P}_{0.1} / \text{GaAs}_{0.6}\text{P}_{0.4}$ quantum dot.