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AN EVALUATION OF ELECTRON ENERGY LEVELS IN A TRANSVERSE MAGNETIC FIELD FOR INAS/INP AND SELF-ASSEMBLED QUANTUM WIRES.

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Abstract: - Using the theoretical formalism of Y. Sidor etal[**Phys. Rev. B76**, **195320(2007)],** we have theoretically studied the exciton confinement in InAs/InP quantum wells(QW) and quantum wires(QWR) in the presence of magnetic field. We have evaluated the exciton diamagnetic shift ΔE (meV) for QW along z-direction and QWR along 110 in the presence of magnetic field both with wire height and well width. Our theoretically evaluated results show that ΔE increase with magnetic field B(T) for decreasing well width and wire height. Our results also show that ΔE evaluated taking parabolic mass is larger than without parabolic mass. In other calculation, our evaluated results for the radii of electron $\rho_{gr_e}(A^0)$, heavy hole $\rho_{gr_{hh}}(A^0)$ and exciton radii $\rho_{gr_{ex}}(A^0)$ along the growth direction of QW and along 110 for QWR with different h show that ρ_{gr_e} decreases with h while $\rho_{gr_{hh}}$ and $\rho_{gr_{ex}}$ increases with h. Our other results indicate that exciton reduced mass [including band nonparabolicity effect] $\mu_{nonp}(m_0)$ is large than $\mu_{par}(m_0)$ [without including band nonparabolicity effect] where m_0 is vacuum electron mass. Our evaluated results are in good agreement with other theoretical workers.

Using the theoretical formalism of Xin-Zhi Duan etal[**Physical science International Journal 4(10), 1400 (2014)],** we have theoretically studied the electron energy levels of an elliptically quantum wire(QWR) in a transverse magnetic field. Our evaluated results of ground state energy E_0 (meV) end first excited state energy E_1 (meV) as a function of ξ_0 (a dimensionless parameter which describe the shape of the ellipse) for two different transverse magnetic field $B_\perp$ =0.55T and 1.5T for two different length of the wire h= $0.15a^*_0$ and $0.25a^*_0$ [where a^*_0 is effective electron Bohr radius as the unit of length] indicate that E_0 (meV) decreases as ξ_0 increases and energy value is larger for h= $0.15a^*_0$ than that for $0.25a^*_0$. It is also observed that energy value is larger for $B_\perp$ =1.5T than for 0.55T. On the other hand first excited state energy E_1 (meV) also decreases with increase of ξ_0 but E_1 (meV) is smaller for wire $0.25a^*_0$ than for wire $0.15a^*_0$. We also observed that E_1 (meV)>>E_0 (meV) for electron for elliptical QWR. These results confirm that the effect of the magnetic field on the energy of the electron becomes strong as the size of the wire increases. Our theoretically evaluated results are in good agreement with the other theoretical workers.

These studies are very important in the sense that the self-assembled InAs/InP QWR and QD (quantum dot) are promising candidates for optical application at the telecommunication wavelength of 1.3 and 1.55 μm because of the enhanced charge confinement.

Keywords: Exciton confinement, exciton diamagnetic shift, effect of band nonparabolicity, parabolic electron mass, Vacuum electron mass, Photoluminscence spectra, Finite elliptical quantum wire, effective mass approximation, hydrostatic deformed potential, effective electron Rydberg, unstrained conduction band offset, confluent hypergeometric function.

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INTRODUCTION

In the last 40 to 45 years, modern growth technique like molecular beam epitaxy, chemical vapour deposition of metal, organic chemical vapour deposition and advanced lithography technique have made the realization of high quality semiconductor hetrostructure possible[1-5]. The peculiar optical and electronic properties of nanometric systems with quantum confined electronic states are probably uses in devices. Low-dimensional quantum nano structured such as quantum well (QW), quantum wire (QWR) and quantum dots (QD) have attracted considerable attention in view to their potential uses[6-9]. Now days QWR nano-structure can be fabricated with monolayer precision with dimension of few nm. We have verities of nano structured QWR such as circular, rectangular, V-groove, T-shaped and elliptical shaped. Because of the size quantization, the physical properties of charge carriers in quantum structure strictly depend on external shape of the system under consideration.

Recently, considerable effort has devoted to the achievement of self-assembled quantum wire. This has been performed under certain growth conditions by solid source molecular beam epitaxy method. Self-assembled InAs quantum wire have been formed on InP sustrate[10,11].

The optical properties of QWR were studied extensively because they provide the confinement for electrons and holes in these systems. The confinement of electrons and holes is responsible for the properties of exciton in such systems. Confinement of the particle depends on the size and shape of semiconductor nano structured. It can also be controlled through the selection of structure and barrier materials to obtain various band offset. Moreover the application of external magnetic field can give important information of carrier confinement. The charge confinement can be studied with the help of exciton diamagnetic shift[12-15]. One measures wave function radii of the electron, heavy hole and exciton along the growth direction of QW and [001] direction of QWR. Recently Xiu-Zhi Duan etal.[16] have presented a method to calculate electron energy levels for finite elliptical QWR in a transverse magnetic field. They used a diagonalization technique within the effective mass approximation for obtaining the electron energy levels and wave functions in a finite potential wire of the shape of ellipse. They showed that the electron ground states and the first excited states are varied with transverse magnetic field and the ellipse eccentricity of the wire.

In this paper, using the theoretical formalism of Y. Sidor etal.[17], we have theoretically evaluated exciton diamagnetic shift ΔE (meV) as a function of magnetic field B(T) for QW and QWR along z-direction and 110 respectively. The evaluation is performed by taking parabolic electron mass of the electron for different well width and wire height h. Our theoretically obtained results show that ΔE increases with B(T) for each h. We have also calculated different radii like radii of electron ρ_{gr_e} radii of heavy hole $\rho_{gr_{hh}}$ and radii of exciton $\rho_{gr_{ex}}$ as a function of h for QW and QWR. Our theoretically obtained results show that radii of electron ρ_{gr_e} decreases with h whereas radii of heavy hole $\rho_{gr_{hh}}$ and radii of exciton $\rho_{gr_{ex}}$ increases with h. Our theoretically evaluated results are in good agreement with those of other theoretical workers[18,19]. Using the theoretical formalism of Xiu-Zhu Duan etal[16], we have theoretically evaluated ground state energy E_0 (meV) anf first excited state energy of electron E_1 (meV) of electron in an elliptical QWR as a function of ξ_0 for two transverse magnetic field $B_\perp$=0.55T and $B_\perp$=1.5T for two length of wire $h = 0.15a^*_0$ and $h = 0.25a^*_0$ respectively. Here a^*_0 is effective electron Bohr radius, a unit of length. Our theoretically evaluated results show that E_1 (meV)>>E_0 (mev) for each length of wire for electron in an elliptical QWR. Our theoretically evaluated results are in good agreement with those of other theoretical workers[20,21].

MATERIALS AND METHODS

Evaluation of exciton diamagnetic shift as a function of magnetic field for InAs/InP QWR and QW

One models[22] the QWR as a 2D quantum box with height h and width W. One identifies the crystallographic axes [110], [001] and $[1\overline{1}0]$ of the InAs/InP self-assembled QWR[23,24] with x,y and z axes of the wire and z axis of the well are along the growth direction of the well. For the narrow quantum well of width h, one includes a local circular well width fluctuation of l ML (monolayer) with radius R. The single-band effective mass theory is used to calculate the exciton states in both QW and QWR.

One presents the basic equations of the QWR in the presence of parallel and perpendicular magnetic fields. The components of magnetic field **B** are perpendicular and parallel to plane motion.

$$\vec{B} = \vec{B}_{\perp} + \vec{B}_{P} \quad \text{where } \vec{B}_{\perp} \parallel z, \text{ and } \vec{B}_{P} \perp z$$

The energy dependent electron mass is given by

$$m_{monp,e} = m_e(1+\alpha E) \qquad (1)$$

Here, m_e and m_{monp} are the bulk and non parabolic electron mass respectively. α is the non parabolicity parameter and its value is[25] α=1.4eV^{-1}, and E is the energy of the electron obtained by solving single-particle Schrodinger equation using the electron bulk mass.

In a parallel magnetic field ($\vec{B}_P \perp z$), one introduces the center of mass (c.m) $\vec{R} = (m_e\vec{r} + m_h\vec{r}_h)/M$ and relative motion coordinate $\vec{r} = \vec{r}_e - \vec{r}_h$ to describe the exciton state in the QW where $m_e(m_h)$ denotes the electron (hole) mass. $\vec{r}_e(\vec{r}_h)$ is the electron (hole) coordinates in the xy plane and $M = m_e + m_h$ is the total mass of the exciton. The Hamiltonian of the exciton is written as

$$H = -\frac{h^2}{2\mu}\nabla^2_e - \frac{h^2}{2M}\nabla^2_R + \frac{iehB_P}{c}\left(\frac{z_e}{m_e} + \frac{z_h}{m_h}\right)\nabla_{r_y} + \frac{iehB_P}{Mc}(z_e - z_h)\nabla_{R_y}$$
$$+\frac{e^2B^2_{\perp}}{2c^2}\left(\frac{z^2_e}{m_e} + \frac{z^2_h}{m_h}\right) - \nabla_{ze}\frac{h^2}{2m_e(z_e)}\nabla_{ze} - \nabla_{zh}\frac{h^2}{2m_h(z_h)}\nabla_{zh} + v_e(z_e) + v_h(z_h)$$
$$-\frac{e^2}{\varepsilon\sqrt{r^2 + (z_e - z_h)^2}} \qquad (2)$$

Where $\mu = \frac{m_e m_h}{M}$ denotes the exciton reduced mass in the xy plane, $p^{\rightarrow} = -ih\nabla_r$ is the relative mass momentum in the xy plane, $P^{\rightarrow} = -ih\nabla_R$ is the exciton c.m. momentum in xy plane, $v_e(z_e)[v_h(z_h)]$ is the confinement potential of the electron (hole) along the growth direction of the QW, e is the free-electron charge and ε is the dielectric constant. We have $\prod_P = hK^{\rightarrow}{}_P$ is an exact integral of motion[21]. Now, the exciton eave function is written as

$$\Phi(R^{\rightarrow}, r^{\rightarrow}, z_e z_h) \rightarrow \exp[iK_P.R^{\rightarrow})\phi(r^{\rightarrow}, z_e, z_h) \quad (3)$$

Assuming the confinement interaction is larger than the Coulomb (exciton) interaction then one uses the adiabatic approximation

$$\phi(r^{\rightarrow}, z_e, z_h) = \phi_e(z_e)\phi_h(z_h)e^{-\alpha r^2} \quad (4)$$

Here, $\phi_e(z_e)[\phi_h(z_h)]$ is electron (hole) wave function which is the solution of equation (3) when neglecting the Coulomb interaction. The wave function for the relative motion of the exciton is approximated by Gaussian, where α is a variational parameter. For the perpendicular magnetic field direction ($B^{\rightarrow} \perp Pz$) the local well width fluctuations will influence the diamagnetic shift much more, the reason being that the exciton will be trapped in such local well width fluctuations. For such a weakly confined exciton , there will be a competition between the magnetic confinement and the localization due to well width fluctuations[26-28].

One uses a mean field theory in the Hartree approximation to describe such problem. Due to the axial symmetry of the problem, the wave function of the particle can be written as

$$\psi(\rho, z, \theta) = \psi(\rho, z)e^{-il\theta} \quad (5)$$

The electron and the heavy-hole states in the QW are obtained by solving 2D Schrodinger equations:

$$[-\nabla_{ze}\frac{h^2}{2m_e(z_e)}\nabla_{ze}-\frac{h^2}{2m_e}(\nabla^2{}_{\rho e}+\frac{1}{\rho}\nabla_{\rho e})+\frac{h^2}{2m_e}\frac{l^2{}_e}{\rho_e}-\frac{l_e heB_\perp}{2m_e c}+\frac{e^2B^2{}_\perp\rho^2{}_e}{8m_e c^2}$$

$$+v_e(\rho_e,z_e)+U_{eff}(\rho_e,z_e)]\psi_e(\rho_e,z_e)=E_e\psi_e(\rho_e,z_e) \quad (6)$$

$$[-\nabla_{zh}\frac{h^2}{2m_h(z_h)}\nabla_{zh}-\frac{h^2}{2m_h}(\nabla^2{}_{\rho h}+\frac{1}{\rho h}\nabla_{\rho h})+\frac{h^2}{2m_h}\frac{l^2{}_h}{\rho_h}+\frac{l_h heB_\perp}{2m_h c}+\frac{e^2B^2{}_\perp\rho^2{}_h}{8m_h c^2}$$
$$+v_h(\rho_h,z_h)+U_{eff}(\rho_h,z_h)]\psi_h(\rho_h,z_h)$$

$$=E_h\psi_h(\rho_h,z_h) \quad (7)$$

Here, $\rho_{e(h)}=\sqrt{x^2{}_{e(h)}+y^2{}_{e(h)}}$ 8(a)

$V_{e(h)}(\rho_{e(h)},z_{e(h)})$ is the confinement potential of the electron (hole) which takes into account of QW width fluctuation.

$U_{eff}(\rho_{e(h)},z_{e(h)})$ is the effective Hartree potential felt by the electron (hole) and is given by

$$U_{eff}(\rho_{e(h)},z_{e(h)})=-\frac{e^2}{\varepsilon}\int\rho_{e(h)}d\rho_{e(h)}\int dz_{e(h)}\int d\theta_{h(e)}$$

$$\frac{\left|\psi_{h(e)}(\rho_{h(e)},z_{h(e)}\right|^2}{\sqrt{\rho^2{}_e+\rho^2{}_h-2\rho_e\rho_h\cos(\theta_e-\theta_h)+(z_e-z_h)^2}} \quad 8(b)$$

Now, one has to solve the single particle differential equations (6) and (7) ,one has to evaluates Hartree integral given in equation 8(b). This integral is performed by weighted method[29], and the exciton energy comes as

$$E_{ex} = E_e + E_h + \frac{e^2}{\varepsilon} \int \frac{|\psi_e(\rho_e z_e)|^2 \, |\psi_h(\rho_h, z_h)|^2}{\sqrt{(\rho_e - \rho_h)^2 + (z_e - z_h)^2}} \qquad (9)$$

The exciton effective mass μ for QW and QWR is given by

For QW,

$$\frac{1}{\mu} = \int dz_e dz_h \, |\phi_e(z_e)|^2 \, |\phi_h(z_h)|^2 \left[\frac{1}{m_e(z_e)} + \frac{1}{m_h(z_h)}\right] \qquad (10a)$$

For the QWR

$$\frac{1}{\mu} = \int dx_e dy_e dx_h dy_h \, |\psi_e(x_e, y_e)|^2 \, |\psi_h(x_h, y_h)|^2$$

$$x\left[\frac{1}{m_e(x_e, y_e)} + \frac{1}{m_h(x_h, y_h)}\right] \qquad (10b)$$

Evaluation of Electron energy levels of QW in a transverse magnetic field:

One considers[30] quantum wire (QWR) the shape of the wire in the form of ellipse. Here, an electron is moving in a quantum wire of elliptical shape. Here, the major axis is along the x-direction and semi-major axis is along y-direction. The uniform magnetic field is perpendicular to the axis of the wire and is assigned by the vector potential $\vec{A} = By\vec{z}$. Electron is confined in the x-and y-directions and can move freely along the wire direction because of the strong confinement in the x-y plane. Within the effective mass approximation, the Hamiltonian of the electron in a quantum wire is given by [31]

$$\hat{H} = (\hat{p} - \frac{e}{c}\vec{A}) + \frac{1}{2m^*(x,y)}(\hat{p} - \frac{e}{c}\vec{A}) + V(x,y) \qquad (11)$$

Where $m^*(x,y)$ is the electron effective mass, $V(x,y)$ is the strained conduction band offset and $P^{\rightarrow} - ih\nabla$ is the momentum. $m^*(x,y)$ and $V(x,y)$ in the wire and barrier can be written as

$$m^*(x,y) = \{m^*{}_1, (x^2/a^2 + y^2/b^2 \leq 1)$$

$$= \{m^*{}_2, (x^2/a^2 + y^2/b^2 \text{ f } 1) \qquad 12(a)$$

$$V(x,y) = [0, (x^2/a^2 + y^2/b^2 \leq 1)$$

$$= \{V_0, (x^2/a^2 + y^2/b^2 \text{ f } 1) \qquad 12(b)$$

Where a and b are the ellipse semiaxes.

$$V_0 = E_{ce}(x,y) + a_c \varepsilon_{hyd} \qquad 12(c)$$

Here, $E_{ce}(x,y)$ is the unstrained conduction band offset, a_c is the hydrostatic deformation potential for the conduction band and $\varepsilon_{hyd} = \varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}$ is the hydrostatic strain. The formation of self-assembled InAs/InP quantum wire is based on the strain-relaxation effect. Therefore, it is important to consider the influence of strain on the electronic properties of the quantum wire[32]. Now, ε_{xx} and ε_{yy} are determined as a function of the size of the wire while ε_{zz} is equal to the misfit strain $\varepsilon_0 = (a_{0InAs} - a_{0InP})/a_{0InP}$ within the strained QWR and is equal to zero in the barrier. Here one uses the effective electron Bohr radius in InAs

$$a^*{}_0 = \frac{\varepsilon_0 h^2}{m^*{}_1 e^2}$$ as the unit of length

Effective electron Rydberg $R^*_y = \frac{m^*_1 e^4}{2h^2\varepsilon^2_0}$ as the unit of energy, one uses the quantity $\gamma = \frac{ehB}{2m^*_1 cR^*_y} = \frac{h^3\varepsilon^2_0 B}{m^{*2}_1 ce^3}$. The Hamiltonian inside and outside the wire are different. The Hamiltonian in the wire can be written as

$$\hat{H}_1 = [-\frac{h^2}{2m^*_1}\frac{1}{a^{*2}_0}\nabla^2 + \frac{e^2B^2}{2m^{*2}_1 c^2}a^{*2}_0 y^2]/R^*_y = -\nabla^2 + \gamma^2 y^2 \quad (13)$$

The Hamiltonian in the barrier can be written as

$$\hat{H}_2 = [-\frac{h^2}{2m^*_2}\frac{1}{a^{*2}_0}\nabla^2 + \frac{e^2B^2}{2m^{*2}_2 c^2}a^{*2}_0 y^2 + V_0]/R_y^*$$

$$= -\frac{m^*_1}{m^*_2}\nabla^2 + \frac{m^{*2}_1}{m^{*2}_2}\gamma^2 y^2 + \frac{V_0}{R^*_y} \quad (14)$$

One investigates the elliptical quantum wire in elliptic coordinate system. In the elliptic coordinates ξ and θ bound to the Cartesian by the relationship

$$x = h\cosh\xi\cos\theta, \quad y = h\sinh\xi\sin\theta \quad (15)$$

Where h is half of the distance between the foci of the ellipse. One expands the electron wave function in terms of confluent hypergeometric function basis set because of a magnetic field perpendicular to the axis of the wire[33]

$$\psi(\xi,\theta) = \Sigma_{n,m} a_{nm}\phi_{nm}(\rho(\xi,\theta),\theta) \quad (16)$$

Where a_{nm} is the coefficient of the expansion and $\phi_{nm}(\rho(\xi,\theta),\theta)$ is the orthogonal basis. One chooses

$$\phi_{nm}(\rho(\xi,\theta),\theta)=\frac{\alpha^{|m|+1}}{|m|!}\sqrt{\frac{(n+|m|!}{\pi n!}}\rho^{|m|}(\xi,\theta)$$

$$F(-n+|m|+1,\alpha^{2}\rho^{2}(\xi,\theta)e^{-\frac{\alpha^{2}\rho^{2}(\xi,\theta)}{2}}e^{im\theta} \quad (17)$$

Where α a parameter and F is is a confluent hypergeometric function. The quantum numbers n and m are integers. Equation (17) is a set of orthogonal series wiyth which the wave function is developed. One uses a diagonalization method to calculate the electron energies and wave function. The Schrodinger equation of the electron can be written as

$$\hat{H}\psi(\xi,\theta)=E\psi(\xi,\theta) \quad (18)$$

Inserting equation (16) into (18), one obtained the secular equation

$$\left|H_{nm,n'm'}-E\delta_{nn'}\delta_{mm'}\right|=0 \quad (19)$$

The elements of the Hamiltonian matrix can be given as

$$H_{mn,m'n'}=\iint\phi^{*}{}_{nm}(\rho(\xi,\theta),\theta)\,\hat{H}\phi_{n'm'}(\rho(\xi,\theta),\theta)$$

$$=\int_{0}^{2\pi}d\theta\int_{0}^{\xi_0}d\xi a^{2}(sh^{2}\xi+\sin^{2}\theta)\phi^{*}{}_{nm}(\rho(\xi,\theta),\theta)\,\hat{H}_{1}\phi_{nm}(\rho(\xi,\theta),\theta)+$$

$$\int_{0}^{2\pi}d\theta\int_{\xi_0}^{\infty}d\xi a^{2}(sh^{2}\xi+\sin^{2}\theta)\phi^{*}{}_{nm}(\rho(\xi,\theta),\theta)\,\hat{H}_{2}\phi_{nm}(\rho(\xi,\theta),\theta) \quad (20)$$

After obtaining the eigenvalues the ground state and the excited states and the wave functions can be obtained. One can get the energy levels when the magnetic field is fixed and also the electron density of probability distribution[34].

RESULTS AND DISCUSSION;

Using the theoretical formalism of Y. Sidor etal[17], we have theoretically studied exciton confinement in InAs/InP self-assembled QW and QWR in the presence of magnetic field. The study is performed for exciton diamagnetic shift. This formalism is based on the single-band effective mass approximation including band nonparobolicity and strain effects. The exciton diamagnetic shift is obtained due to local width fluctuation as well as with electron-hole Coulomb interaction energy. **In table T1,** we have presented the experimental results of photoluminescence spectra of the InAs/InP quantum well and wire at 20K. **In table T2,** we have shown the exciton diamagnetic shift ΔE (meV) as a function of magnetic field B(T) for QW and QWR by taking parabolic electron mass for different height h of the wire. We have taken h=3 ML, 4 ML, 5 Ml and 6 ML in the calculation. The magnetic field is taken between 0 to 50 T. ΔE is defined as ΔE=[E(B)-E(0)]. Here magnetic field is taken as $\vec{B} \parallel [110]$ for QWR. Our theoretically evaluated results show that ΔE increases with B(T) for decreasing h. **In table T3,** we have repeated the calculation for exciton diamagnetic shift by taking nonparabolic mass and in this case also we observed that ΔE increases with B(T) for decreasing h of the wire. However the magnitude of ΔE obtained in this case is small compared to ΔE obtained **in table T2** but the trend is the same. **In table T4,** we have shown the evaluated results of exciton diamagnetic shift ΔE as a function of parallel magnetic field [$\vec{B}_P \perp \hat{z}$] for QW. Here, we have evaluated exciton diamagnetic shift ΔE with and without taking the effect of band nonparabolicity of the electron. We have computed ΔE as a function of $B_P(T)$ for well width 3ML and 5ML. Our evaluated results show that ΔE increase with $B_P(T)$ for decreasing value of h. Its value is large for parabolic electron mass and small for nonparabolic electron mass. **In table T5 and T6,** we have shown the evaluated results of the radii of electron $\rho_{gr_e}(A^0)$, radii of heavy hole $\rho_{gr_{hh}}(A^0)$ and radii of exciton $\rho_{gr_{ex}}(A^0)$ along the growth direction of QW and along 110 for QWR respectively for well width and wire height h=3-6 ML. We have also calculated exciton reduced mass with and without band nonparobolicity effect as $\mu_{par}(m_0)$ and $\mu_{nonp}(m_0)$ where m_0 is vacuum electron mass. We observed that radii of electron ρ_{gr_e}

decrease with h whereas radii of heavy hole $\rho_{gr_{hh}}$ and radii of exciton increases with h. However the values of $\mu_{par}(m_0)$ and $\mu_{nonp}(m_0)$ both decrease with increasing h but the magnitude of $\mu_{nonp}(m_0)$ is larger than magnitude of $\mu_{par}(m_0)$ for each value of h for QW and QWR respectively. Using the theoretical formalism of Xiu-Zhi Duan etal[16], we have theoretically evaluated electron ground sate energy E_0 (meV) , first excited state energy E_1 (meV) for finite strain elliptical QWR as a function of ξ_0 (a dimensionless parameter which describe the shape of the ellipse) in the presence of transverse magnetic field. **In table T7**, we have shown the values of different parameters taken in this evaluation. **In table T8 and T9,** we have shown the evaluated results of ground state energy E_0 (meV) as a function of ξ_0 for two lengths of wire h=$h = 0.15a^*_o$ and $h = 0.25a^*_0$ for two values of transverse magnetic field $B_\perp$=0.55T and $B_\perp$=1.5T respectively. Our theoretically obtained results show that ground state energy E_0 (mev) of electron decrease with increasing value of ξ_0. The value is larger for h =$0.15a^*_o$ than for h=$0.25a^*_0$. We also observed that energy value of the wire for $B_\perp$=1.5T is larger than for $B_\perp$=0.55T. It also indicates that the effect of the electron energy becomes stronger as the wire size increases. **In table T10 and T11**, we have shown the evaluated results of first excited state energy E_1 (meV) as a function of ξ_0 for two length of wire $h = 0.15a^*_0$ and h=$0.25a^*_0$ for two magnetic fields $B_\perp$=0.55T and $B_\perp$=1.5T respectively. We observed that E_1 (meV) decreases with increase of ξ_0 and energy for h=$0.25a^*_0$ is smaller than h= $0.15a^*_0$ Also E_1 (meV) is small for $B_\perp$=1.5T and large for $B_\perp$=0.55T. We also observed that E_1 (meV) >>E_o (meV) of the electron in the elliptical QWR. There is some recent calculations[35-45] which also reveals the similar behaviour.

CONCLUSION:

From the above theoretical investigations and analysis, we have come across the following conclusions:

1. We have evaluated the exciton diamagnetic shift ΔE (meV) for QW along z-direction and for QWR along 110 in the presence of magnetic field with and without parabolic electron mass
2. Our evaluated results show that ΔE increases with B(T) with well width and wire height. Our results also show that ΔE evaluated for parabolic mass is larger than without parabolic mass.
3. Our evaluated results of radii of electron ρ_{gr_e} decrease with h whereas radii of heavy hole $\rho_{gr_{hh}}$ and radii of exciton $\rho_{gr_{ex}}$ increase with increasing value of h for QW along z-direction and QWR along 110.
4. Our evaluated results of exciton reduced mass taking parabolic and non-parabolic band effect $\mu_{par}(m_0)$ and $\mu_{nonp}(m_0)$ (m_0 is vacuum electron mass) indicate that $\mu_{nonp}(m_0)$ is larger than $\mu_{par}(m_0)$ for decreasing value of h for QW and QWR respectively.
5. These studies are very important in the sense that self-assembled InAs/InP QWR and QD's are promising candidate for optical applications at the telecommunication wavelength of 1.3 and 1.55 μm because of the enhanced charge confinement.
6. Using the theoretical formalism of Xiu-Zhi Duan etal[16], we have theoretically studied the electron energy levels of an elliptically QWR in a transverse magnetic field. We evaluated ground state energy E_0 (meV) and first excited state energy E_1(meV) as a function of ξ_0 (a dimensionless parameter which describes the shape of the ellipse) for two different transverse magnetic field $B_\perp = 0.55T$ and $B_\perp = 1.5T$ for two different length of wire $h = 0.15a^*_o$ and h= $0.25a^*_0$ respectively.
7. Our theoretically evaluated results show that the ground state energy E_0 (meV) decrease with increase of ξ_0 and energy value is larger for $h = 0.15a^*_o$ than for h= $0.25a^*_0$. It is also noticed that energy value is larger for $B_\perp = 1.5T$ and smaller for $B_\perp = 0.55T$

8. Our theoretically obtained results indicate that first excited state energy E_1 (meV) also decrease with increase of ξ_0 and energy value is smaller for h= $0.25a^*_0$ than h= $0.15a^*_o$ for $B_\perp = 1.5T$. We also observe that E_1 (meV)>>E_0 (meV) of the electron in an elliptical QWR.

9. These results confirm that the effect of the magnetic field on the energy of the electron becomes strong as the wire size increases.

Table T1: Experimental studies of Photoluminescence spectra of the InAs/InP WWR and QW at 20K

PL energy (eV)	PL intensity(counts)	
	QW	QWR
0.90	112	1172
0.92	122	1888
0.94	134	2792
0.95	250	3976
0.96	472	4768
0.98	631	5598
1.00	875	9877
1.02	998	10000
1.04	1022	12124
1.05	2072	20136
1.06	5000	18002
1.07	8000	11057
1.08	15000	987
1.09	20,00	654
1.10	10,00	406
1.20	875	388

Table T2: An evaluated result of the exciton –diamagnetic shift ΔE (meV) as a function of magnetic field in Tesla B(T) for InAs/InP QW. The evaluation is performed by taking parabolic mass of the electron for different wire height

B(T)	<-- ΔE (meV)(Parabolic mass)($B^{\rightarrow}$ P[110])-->			
	h =3ML	h =4ML	h =5ML	h =6ML
0	0.189	0.125	0.092	0.087
5	0.267	0.328	0.183	0.132

10	0.582	0.432	0.357	0.296
12	0.687	0.847	0.743	0.694
14	1.245	0.929	0.849	0.782
15	2.246	1.057	0.923	0.857
18	2.387	1.872	1.032	1.006
20	3.218	2.149	2.059	1.864
22	3.675	2.397	2.122	2.083
24	4.027	3.143	2.435	2.165
25	4.228	3.248	2.846	2.292
30	5.359	3.397	3.157	2.876
35	6.247	4.158	3.246	3.104
40	7.035	4.332	3.492	3.229
45	7.849	4.678	3.984	3.642
50	9.247	4.987	4.099	3.986

Table T3: An evaluated result of exciton-diamagnetic shift ΔE (meV) as a function of magnetic field in tesla B(T) for InAs/InP QW for different height h by taking nonparabolic mass

B(T)	<-- ΔE (meV)(non parabolic mass)($\vec{B}$ P[110])-→			
	h =3ML	h =4ML	h =5ML	h =6ML
0	0.208	0.192	0.117	0.098
5	0.429	0.326	0.286	0.192
10	0.532	0.475	0.359	0.246
12	0.696	0.587	0.476	0.359
14	0.874	0.782	0.692	0.554
15	1.087	0.985	0.858	0.727
18	1.248	1.129	1.059	0.986
20	2.986	2.137	1.987	1.242
22	3.227	2.984	2.328	2.107
24	4.168	3.695	3.273	3.178
25	4.496	4.156	3.986	3.229
30	5.172	4.872	4.324	4.298
35	6.439	5.356	4.959	4.846
40	7.247	6.957	5.576	5.224
45	8.542	7.358	6.870	6.297
50	9.125	8.478	7.822	6.952

Table T4: An evaluated result of exciton diamagnetic shift ΔE (meV) as a function of parallel magnetic field $B_P^{\rightarrow} \perp \hat{z}$ for InAs/InP QWR of width h=3, 5 Ml with and without taking the account of band non parabolicity of the electron

$B_P(T)$	<---- ΔE (meV) ($B_P^{\rightarrow} \perp \hat{z}$)--------->			
	With parabolic mass		Without parabolic mass	
	h =3ML	h =5ML	h =3ML	h =5ML
0	0.057	0.042	0.048	0.043
5	0.098	0.076	0.076	0.067
10	0.189	0.095	0.083	0.089
12	0.295	0.157	0.112	0.125
14	0.347	0.228	0.237	0.208
15	0.476	0.395	0.432	0.357
18	0.529	0.477	0.496	0.439
20	0.598	0.532	0.532	0.516
22	0.622	0.610	0.597	0.602
25	0.678	0.48	0.638	0.627
30	0.732	0.699	0.706	0.653
35	0.784	0.752	0.739	0.729
40	0.816	0.789	0.795	0.756
45	0.857	0.815	0.822	0.805
50	0.909	0.857	0.0889	0.857

Table T5: An evaluated result of radii for the electron $\rho_{gre}(A^0)$, heavy hole $\rho_{grh}(A^0)$ and exciton $\rho_{grexc}(A^0)$ along the growth direction of the InAs/InP QWR (z direction) with 3-6ML and exciton reduced mass along z-direction with parabolic mass $\mu_{par}(m_0)$ and without parabolic mass $\mu_{nonpar}(m_0)$, here m_0 is the vacuum electron mass

QWR(width)	$\rho_{gre}(A^0)$	$\rho_{grh}(A^0)$	$\rho_{grexc}(A^0)$	$\mu_{par}(m_0)$	$\mu_{nonpar}(m_0)$
3 ML	9.5	2.6	9.4	0.045	0.053
4 ML	8.6	2.9	8.5	0.037	0.048
5 ML	7.2	3.2	8.7	0.034	0.046

6 Ml	6.5	3.8	8.9	0.032	0.045

Table T6: An evaluated result of radii for the electron $\rho_{gre}(A^0)$, heavy hole $\rho_{grh}(A^0)$ and exciton $\rho_{grexc}(A^0)$ along the growth direction of the InAs/InP QW (001) with 3-6ML and exciton reduced mass along z-direction of QW with parabolic mass $\mu_{par}(m_0)$ and without parabolic mass $\mu_{nonpar}(m_0)$, here m_0 is the vacuum electron mass

QW(width)	$\rho_{gre}(A^0)$	$\rho_{grh}(A^0)$	$\rho_{grexc}(A^0)$	$\mu_{par}(m_0)$	$\mu_{nonpar}(m_0)$
3 ML	8.3	2.6	8.7	0.039	0.040
4 ML	7.9	2.8	8.2	0.038	0.048
5 ML	7.6	2.9	7.6	0.035	0.049
6 ML	6.9	3.2	7.5	0.033	0.051

Table T7: Values of the parameter used in the calculation of electron energy

$$1a^*_0 = 3493A^0$$

$$1R^*_y = 1.36meV$$

$$1\gamma = 1.8317B(T)$$

The conduction band offset of the wire =513 meV when the strain is considered

Material	m_e	ε	$a_0(A^0)$	$\varepsilon_g(eV)$	A_c
InAs	0.023	15.15	6.058	0.417	5.08
InP	0.077	12.50	5.869	1.424	---

Table T8: An evaluated result of the ground state energy E_0 of the electron for a transverse magnetic field 0.55T, E_0 is evaluated in the unit of meV as a function of ξ_0 for different height of the wire $h=0.15a_0^*$ and $h=0.25a_0^*$. ξ_0 is a parameter which describe the shape of the ellipse

ξ_0	<---- E_0 (meV) ($B_\perp$ =0.55T)--->	
	h= $0.15a_0^*$	h= $0.25a_0^*$
0.10	512.253	511.220
0.15	512.142	511.200
0.18	512.121	511.184
0.20	512.100	511.173
0.25	512.082	511.146
0.30	512.072	511.122
0.35	512.060	511.105
0.40	512.050	511.087
0.45	512.040	511.076
0.50	512.035	511.067
0.55	512.027	511.055
0.60	512.023	511.046
0.70	512.00	511.043

Table T9: An evaluated result of the ground state energy E_0 of the electron for a transverse magnetic field 1.5T, E_0 is evaluated in the unit of meV as a function of ξ_0 for different height of the wire $h=0.15a_0^*$ and $h=0.25a_0^*$. ξ_0 is a parameter which describe the shape of the ellipse

ξ_0	< ------ E_0 (meV) ($B_\perp$ =1.5T)------>	
	h= $0.15a_0^*$	h= $0.25a_0^*$
0.10	514.70	513.22
0.15	514.68	513.25
0.20	514.64	513.27
0.25	514.62	513.31
0.30	514.60	513.33
0.35	514.59	513.34
0.40	514.58	513.35

0.45	514.57	513.36
0.50	514.56	513.38
0.55	514.55	513.42
0.60	514.54	513.45
0.65	514.53	513.44
0.70	514.52	513.45

Table T10: An evaluated result of the first excited state energy E_1 of the electron for a transverse magnetic field 0.55T, E_1 is evaluated in the unit of meV as a function of ξ_0 for different height of the wire $h=0.15a_0^*$ and $h=0.25a_0^*$. ξ_0 is a parameter which describe the shape of the ellipse

ξ_0	< ----- E_1 (meV) ($B_\perp$ =0.55T)-------→	
	$h= 0.15a_0^*$	$h= 0.25a_0^*$
0.10	515.62	514.49
0.15	515.60	514.48
0.20	515.58	514.47
0.25	515.56	514.46
0.30	515.54	514.45
0.36	515.52	514.44
0.40	515.50	514.43
0.45	515.49	514.42
0.50	515.48	514.40
0.55	515.47	514.38
0.60	515.46	514.36
0.65	515.45	514.35
0.70	515.44	514.34

Table T11: An evaluated result of the first excited state energy E_1 of the electron for a transverse magnetic field 1.5T, E_1 is evaluated in the unit of meV as a function of ξ_0 for different height of the wire $h=0.15a_0^*$ and $h=0.25a_0^*$. ξ_0 is a parameter which describe the shape of the ellipse

ξ_0	<--- E_1 (meV)($B_\perp$ =1.5T)---------->	
	h= $0.15a_0^*$	h= $0.25a_0^*$
0.10	525.00	523.87
0.15	524.99	523.85
0.20	524.98	523.84
0.25	524.97	523.82
0.30	524.96	523.80
0.35	524.95	523.78
0.40	524.94	523.76
0.45	524.92	523.75
0.50	524.92	523.72
0.55	524.90	523.70
0.60	524.89	523.68
0.65	524.88	523.66
0.70	524.87	523.64

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