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The Electronic Properties of the Coupled Quantum Dot – Quantum Well (QD – QW) system

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Abstract

We derive extended theoretical model for the coherent tunneling from quantum dot to quantum well which based on the transition – probability formulation. This model is attractive since it analysis the tunneling probability from a zero – dimension (0D) subsystem to two – dimension (2D) subsystem. In our treatment, the barrier layer between the sub – system is neglected, while the effective mass discontinuity is taken into consideration. The quantum dot and quantum well energy spectrum are calculated as a function of the quantum dot radius and the quantum well width respectively. Then, the matrix element of the coupling interaction between the quantum dot and the quantum well is formulated to be depend on the electronic properties of the system. This matrix element formula is employed to formulate the tunneling rate between the quantum dot and the quantum well. The GaAs spherical quantum dot and GaAs quantum well are considered in our calculations. All the scientific steps, that are presented in our work, are important and necessary to study the electronic and transport properties of the device.

Key wards: Nano electronic , QD – QW Coupling

1 – Introduction

Much attention is paid to the physics of low dimensional semiconductor structures. This has been stimulated by the rapid progress in nanometer-scale fabrication technology. Among those, quantum dots (QD's) are of particular interest[1]. The most striking properties of semiconductor quantum dots is the massive change in optical properties as a function of quantum-dot size. For example, the transition energy (or new band gap) can be tuned by the core diameter.

The semiconductor quantum wells QWs, where narrow – band gap semiconductor material is sandwiched between different wide band gap materials by means of hetrojunctions causes the electron confinement in two – dimensions [2].

Recently, a remarkable nano crystal heterostructure called quantum-dot quantum well (QDQW) structure was synthesized, which is composed of two different semiconductor materials [3] . The transition energy (or new band gap) can be tuned by the core diameter as well as the thickness of the well, and the thickness of the outmost shell [4].

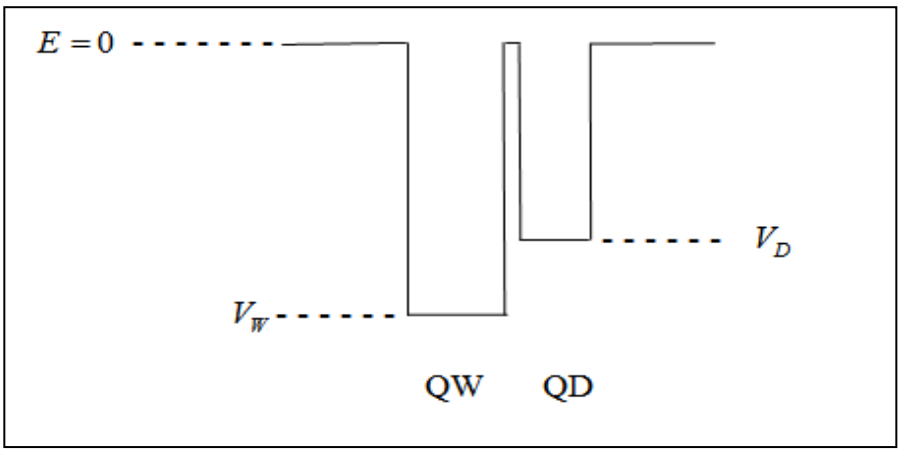
The wet chemical synthesis, the characterization, and some linear and nonlinear optical properties of QDQW have been reported in detail [5,6,7]. It has been shown that the linear absorption of QDQW differs significantly from that of the composite materials [8].

Recent attempts to control the localization to certain regions of the nano crystal have led to the synthesis of quantum – dot quantum well (QDQW) structures [5,6,7]. In these QDQW structures, a ''quantum – well'' layer is synthesized as a shell embedded in the quantum dot. The exciton should experience a lower potential at the quantum-well layer and localize to this layer. The QDQW structure consists of a large band – gap CdS semiconducting core surrounded by a monolayer of smaller band-gap HgS capped by a layer of CdS.

In this paper, we are concerned with the GaAs quantum well – quantum dot nanostructure system and develop a theoretical modeling for the electron tunneling from the quantum well into the quantum dot based on the electron properties of the quantum well – quantum dot hetrostructure, i.e. the electron tunneling from a two – dimensional (2D) structure into zero – dimensional (0D) structure. In the next sections, we present an extended theoretical treatment to formulate and calculate the electronic properties for the subsystems and consequently the tunneling rates between them.

2 – Theoretical modeling of coupled quantum dot – quantum well structure

In our treatment, we neglect the barrier layer between them, while the effective mass discontinuity is taken into consideration.



Fig(1):Schematic illustration of the quantum dot – quantum well system .V_D and V_W are the potential energy depths of the quantum dot and the quantum well respectively.

2-1 – The Quantum Dot Energy Spectrum

For electron effective mass M^* moving in a spherical potential field, the wave function of the stationary state with well – defined values L^2 and L_z is given by,

$$\psi_{Elm}(r,\theta,\phi) = F_{El}(r)Y_{lm}(\theta,\phi) \quad (1)$$

Where $F_{EL}(r)$ satisfy the following equation [9],

$$\left[\frac{d^2}{dr^2}+\frac{2}{r}\frac{d}{dr}+\left(\frac{2M^*}{\hbar^2}[E-U(r)]-\frac{l(l+1)}{r^2}\right)\right]F_{El}(r)=0 \quad (2)$$

We consider a simple model for U(r) as,

$$U(r)=\begin{cases}V_D & r \le R_D \\ 0 & r > R_D\end{cases} \quad (3)$$

And by introducing the dimensionless variable $\zeta = k_D r$, we have the following second-order equation,

$$\left[\frac{d^2}{d\zeta^2}+\frac{2}{\zeta}\frac{d}{d\zeta}+\left(1-\frac{l(l+1)}{\zeta^2}\right)\right]F(\zeta)=0 \quad (4)$$

Where $k_D=\sqrt{\frac{2M_D^*}{\hbar^2}(E-V_D)}$ (5)

Eq.(4) has two independent solutions which can be expressed in terms of spherical Bessel's functions $j_l(\zeta)$ and $\eta_l(\zeta)$ [10]. Since the function $\eta_l(\zeta)$ is irregular in the origin, then we have,

$$F_1(\zeta) = A\, j_l(k_D r) \qquad r \le R_D \quad (6)$$

$$F_2(\zeta) = C_D\, h_l^{(1)}(q_D r) \qquad r > R_D \quad (7)$$

choose the general solution outside the well as a combination of the two solutions in terms of Hankle's function of order one

$$h_l^{(1)}(\xi) = j_1(\zeta) + i\eta_1(\zeta) \quad (8)$$

With

$$q_D = \sqrt{2m_D E/\hbar^2} \quad (9)$$

The condition that determine the energy level of the system $E = E_D$ is obtained according to the requirement that the logarithmic derivative of $F_1(\zeta)$ and $F_2(\zeta)$ are equal at $r = R_D$.

$$\left.\frac{dF_1(k_D r)/dr}{F_1(k_D r)}\right|_{r=R_D} - \left.\frac{dF_2(q_D r)/dr}{F_2(q_D r)}\right|_{r=R_D} = 0 \quad (10)$$

The eigen energy is $(2l+1)$-fold degenerate with respect to the angular momentum projection m. The common notations nS, nP, nD, . . . ,are used to

describe eigen dot states with angular momenta $l = 0,1,2,3, \ldots$.respectively.

2 – 2 The Quantum Well Energy Spectrum

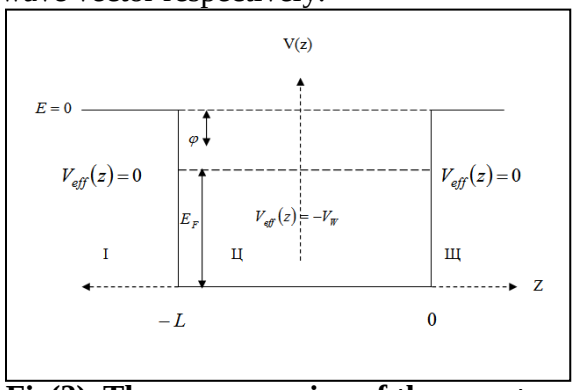
Suppose that we have a quantum well as shown in Fig.(2) with width equals to L and effective potential given by :

$$V_{eff}(z) = \begin{cases} -(\varphi + E_F) & -L < z < 0 \\ 0 & elsewhwere \end{cases} \quad (11)$$

Where φ and E_F are the work function and Fermi energy level respectively. For the quantum well problem, the wave function may be given by [11]:

$$\Psi_w(\bar{r}) = \frac{1}{\sqrt{2V}} \sum_{\bar{g}} A_w(\bar{k}_{\Uparrow} + \bar{g}) \exp\left\{ -\sqrt{(-2M_w^* E/\hbar^2) + (\bar{k}_{\Uparrow} + \bar{g})^2}\, z + i(\bar{k}_{\Uparrow} + \bar{g})\bar{r}_{\Uparrow} \right\} \quad (12)$$

With v is the volume of the quantum well (which is related to normalization factor), A_W, $\bar{g}$ and $k_{\Uparrow}$ are the wave amplitude, the reciprocal lattice vector and the parallel wave vector respectively.



Fig(2). The energy region of the quantum well.

The wave function can also be given by[11],

$$\Psi_{k_{\Uparrow}}(r) = \frac{1}{\sqrt{2v}} e^{i\bar{k}_{\Uparrow}\cdot\bar{r}_{\Uparrow}} \chi_{k_{\Uparrow}}(z) \quad (13)$$

where $\chi_{k_{\Uparrow}}(z)$ is a function of z only. We write the time independent Schrodinger equation in the z direction as follows ,

$$\left\{ -\frac{\hbar^2}{2M^*}\frac{d^2}{dz^2} + V_{eff}(z) \right\} \chi_{k_{\Uparrow}}(z) = \left\{ E - \frac{\hbar^2 \bar{k}_{\Uparrow}^2}{2M^*} \right\} \chi_{k_{\Uparrow}}(z) \quad (14)$$

The solution of equation (14) can take the following form [12] :

In region I

$$\chi_{k_{\Uparrow}}(z) = A_W(k_{\Uparrow}) e^{\alpha z} \qquad z < -L \quad (15)$$

In region II

$$\chi_{k_{\Uparrow}}(z) = B_W(k_{\Uparrow}) e^{ik_Z z} + C_W(k_{\Uparrow}) e^{-ik_Z z} \qquad -L < z < 0 \quad (16)$$

In region III

$$\chi_{k_{\Uparrow}}(z) = D_W(k_{\Uparrow}) e^{-\alpha z} \qquad z > 0 \quad (17)$$

Where, $A_W(k_{\Uparrow})$, $B_W(k_{\Uparrow})$, $C_W(k_{\Uparrow})$ and $D_W(k_{\Uparrow})$ are the amplitudes functions, with

$$k_Z = \sqrt{2M_W^*(E + \varphi + E_F)/\hbar^2 - \bar{k}_{\Uparrow}^2} \quad (18)$$

$$\alpha = \sqrt{-2m_W E/\hbar^2 + \bar{k}_{\Uparrow}^2} \quad (19)$$

with M_W^* is the electron effective mass in the well.

By applying the continuity conditions at the boundaries, we get

at $z = -L$

$$A_W(k_{\Uparrow}) e^{-\alpha L} = B_W(k_{\Uparrow}) e^{-ik_Z L} + C_W(k_{\Uparrow}) e^{ik_Z L} \quad (20)$$

at $z = 0$

$$D_W(k_{\Uparrow}) = B_W(k_{\Uparrow}) + C_W(k_{\Uparrow}) \quad (21)$$

at $z = -L$

$$\alpha A_W(k_{\Uparrow}) e^{-\alpha L} = ik_Z B_W(k_{\Uparrow}) e^{-ik_Z L} - ik_Z C_W(k_{\Uparrow}) e^{ik_Z L} \quad (22)$$

at $z = 0$

$$-\alpha D_W(k_{\Uparrow}) = ik_Z B_W(k_{\Uparrow}) - ik_Z C_W(k_{\Uparrow}) \quad (23)$$

Then by multiplying equation (20) by α and subtracts it from equation (22) we get:

$$0 = (\alpha - ik_Z) B_W(k_{\Uparrow}) e^{-ik_Z L} + (\alpha + ik_Z) C_W(k_{\Uparrow}) e^{ik_Z L} \quad (24)$$

also by multiplying equation (21) by α and subtracts it from equation (23) we get:

$$0 = (\alpha + ik_Z) B_W(k_{\Uparrow}) + (\alpha - ik_Z) C_W(k_{\Uparrow}) \quad (25)$$

We rearrange eqs.(24)and (25) in the following from ,

$$(\alpha - ik_Z)B_W(k_{\Uparrow})e^{-ik_Z L} = -(\alpha + ik_Z)C_W(k_{\Uparrow})e^{ik_Z L} \quad (26)$$

$$(\alpha + ik_Z)B_W(k_{\Uparrow}) = -(\alpha - ik_Z)C_W(k_{\Uparrow}) \quad (27)$$

From multiplying eq.(26) by eq.(27) we get:

$$B_W(k_{\Uparrow}) = \pm C_W(k_{\Uparrow})e^{ik_Z L} \quad (28)$$

Then, for even state we take the positive sign,

$$\chi_{k_{\Uparrow}}(z) = 2B_W(k_{\Uparrow})^{-ik_Z L/2}\cos(k_Z(z + L/2)) \quad (29)$$

and the negative sign is taken for the odd one ,

$$\chi_{k_{\Uparrow}}(z) = 2iB_W(k_{\Uparrow})^{-ik_Z L/2}\sin(k_Z(z + L/2)) \quad (30)$$

Dividing (26) on (27), and then dividing its real and imaginary parts, one get

$$\tan(k_Z L) = -2\alpha k_z / \left(\alpha^2 - k_z^2\right) \quad (31)$$

Equation (31) give the electronic energy spectrum of the quantum well.

For the odd state, we write,

$$\chi_{k_{\Uparrow}}(z) = -A_W(k_{\Uparrow})e^{\alpha L}e^{\alpha z} \qquad z < -L$$

$$\chi_{k_{\Uparrow}}(z) = 2iB_W(k_{\Uparrow})e^{-ik_z\frac{L}{2}}\sin(k_z z + \frac{L}{2}) \qquad -L < z < 0$$

$$\chi_{k_{\Uparrow}}(z) = -A_W(k_{\Uparrow})e^{-\alpha L}e^{-\alpha z} \qquad z > 0 \quad (32)$$

Then, by applying the normalization condition, $\int_{-\infty}^{\infty} \left|\chi_{k_{\Uparrow}}\right|^2 dz = 1$, we get ,

$$\left|A_W(k_{\Uparrow})\right|^2 = e^{2\alpha L}\left[\frac{1}{\alpha} + \frac{L - \frac{1}{k_z}\sin(k_z L)}{2\sin^2(k_z L/2)}\right]^{-1} \quad (33)$$

2-3- The Matrix Element of the QW – QD Coupling Interaction

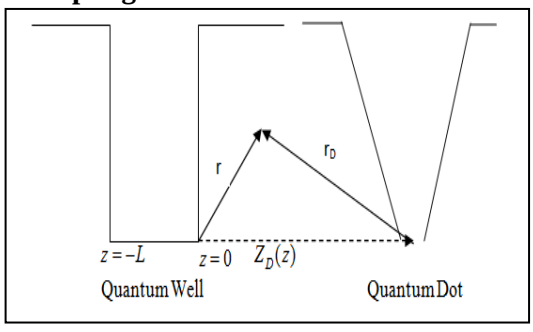


Fig.(3).Schematic illustration for the quantum dot- quantum well system coordinates.

To study the electrical properties of the system considered in our study , we will derive a formula for the matrix element of the quantum well – the quantum dot coupling interaction which includes all the system parameters. Where the coordinate reference is located at $z = 0$

$$\bar{r} - \bar{r}_D - \bar{Z}_D(z) = 0 \quad (34)$$

With $\bar{r} \equiv (\bar{r}_{\Uparrow}, z)$ and $\bar{r}_D \equiv (\bar{r}_{D\Uparrow}, \bar{Z}_D(z))$.

Where $\bar{Z}_D(z)$ is the normal distance to the interface between the quantum dot and the quantum well.

Then, for isolated quantum dot and for $r_D > R_D$ the wave function of quantum dot is given by:

$$\Psi_D(\bar{r}_D) = C_D h_l^{(1)}(q_D r_D)\mathrm{Y}_{lm}(\theta,\varphi) \quad (35)$$

Equation (35) can be written as ,

$$\Psi_D(\bar{r}_D) = C_D\frac{i^{-l}}{2\pi q_D}\iint d^2k_{\Uparrow}\sum\frac{-e^{-iK^-(\bar{k}_{\Uparrow}+\bar{g}).\bar{R}_D}\mathrm{Y}_{lm}(\hat{K}(\bar{k}_{\Uparrow}+\bar{g}))e^{iK^-(\bar{k}_{\Uparrow}+\bar{g}).\bar{r}}}{K_Z^+(\bar{k}_{\Uparrow}+\bar{g})} \quad (36)$$

With ,

$$K^{\pm}(\bar{k}_{\Uparrow}+\bar{g}) = \{(\bar{k}_{\Uparrow}+\bar{g}) \pm i\sqrt{\frac{2m_D|E_D|}{\hbar^2} + (\bar{k}_{\Uparrow}+\bar{g})^2}\} \quad (37)$$

$$k_z^+(\bar{k}_{\Uparrow}+\bar{g}) = i\sqrt{\frac{2m_D|E_D|}{\hbar^2} + (\bar{k}_{\Uparrow}+\bar{g})^2} \quad (38)$$

To convert the integration into summation ,we use the relation [13],

$$\frac{1}{4\pi^2}\iint d^2k_{\Uparrow}(\ldots) = \frac{1}{L^2}\sum_{k_{\Uparrow}}(\ldots) \quad (39)$$

Then eq.(36) becomes ,

$$\Psi_D(z) = \frac{2\pi C_D}{L^2}\frac{i^{-l}}{q_D}\sum_{\bar{k}_{\Uparrow}}\sum_{\bar{g}}\frac{e^{-iK^-(\bar{k}_{\Uparrow}+\bar{g}).\bar{R}_D}}{K_Z^+(\bar{k}_{\Uparrow}+\bar{g})}\mathrm{Y}_{lm}(\hat{K}(\bar{k}_{\Uparrow}+\bar{g}))e^{i(\bar{k}'+\bar{g}')r_{\Uparrow}}e^{z_{\Uparrow}\sqrt{\frac{2m_D|E_D|}{\hbar^2}+(\bar{k}'+\bar{g}')^2}} \quad (40)$$

The wave function of the quantum well (eq.(12))can be written as :

$$\Psi_W(z) = \frac{1}{\sqrt{2v}}\sum D_W(\bar{k}_{\Uparrow}+\bar{g})e^{-z\sqrt{\frac{2m_W E_W}{\hbar^2}+(\bar{k}_{\Uparrow}+g)^2}}e^{i(\bar{k}_{\Uparrow}+g)^2.\bar{r}_{\Uparrow}} \quad (41)$$

Where, v is the quantum well volume and $1/\sqrt{2v}$ is the normalization factor.

The matrix element of the coupling between quantum well and quantum dot is given by[14]:

$$V_{WD} = \hbar^2 \iint (\Psi_D \frac{1}{2M_W^*} \frac{\partial \Psi^*}{\partial z} - \Psi^* \frac{1}{2M_D^*} \frac{\partial \Psi_D}{\partial z})_{z=0} d^2 \bar{r}_{\Uparrow} \quad (42)$$

Then, by using following relation [11] ,

$$\frac{1}{L^2} \iint e^{-i(\bar{k}_{\Uparrow} - \bar{k}'_{\Uparrow}).\bar{r}_{\Uparrow}} d^2 r_{\Uparrow} = \delta(\bar{k}_{\Uparrow} - \bar{k}'_{\Uparrow}) \quad (43)$$

the atomic units then putting g=0 one can get the formula,

$$V_{WD} = -\frac{\pi}{\sqrt{2v}} \frac{i^{-l} C_D}{\sqrt{2m_D|E_D|}} \left(\frac{1}{M_W^*} + \frac{1}{M_D^*} \frac{\sqrt{2m_W|E| + \bar{k}_{\Uparrow}^2}}{\sqrt{2m_D|E_D| + \bar{k}_{\Uparrow}^2}}\right) Y_{lm}(\hat{K}^-(\bar{k}_{\Uparrow})) D^* e^{-i(\bar{k}_{\Uparrow}).R_{d\Uparrow}} e^{-Z_D(z)\sqrt{2m_D|E_D| + \bar{k}_{\Uparrow}^2}} \quad (44)$$

2-4- The line - width function

The broadening in quantum dot energy level, due to coupling interaction between the quantum well and the quantum dot is given by[15] :

$$\Delta_D(E) = \pi \sum_W |V_{WD}|^2 \delta(E - E_W) \quad (45)$$

By getting use of the following equation[13]:

$$\sum_W (...) = \frac{v}{8\pi^3} \int dE_W \iint dk_{\Uparrow} \left|\frac{\partial E_W}{\partial k_z}\right|^{-1} (...) \quad (46)$$

$$\Delta_D(E) = \pi \frac{2v}{(2\pi)^3} \iint d^2 k_{\Uparrow} \left|\frac{\partial k_z}{\partial E} |V_{WD}|^2\right|_{E_W = E} \quad (47)$$

And by using eq.(45) we get

$$\Delta_{Dlm}(E_D, E_W) = \frac{|C_D|^2 I_{lm}}{16 m_D \sqrt{2M_W^*(E_W + V_W)}} \left\{\frac{1}{M_W^*} + \frac{\sqrt{2m_W|E_W|}}{M_D^* \sqrt{2m_D|E_D|}}\right\}^2 \left\{\frac{1}{\sqrt{2m_W|E_W| + k_{\Uparrow}^2}} + \frac{L - \frac{\sin(L\sqrt{2M_W^*(E_W + V) - k_{\Uparrow}^2})}{\sqrt{2M_W^*(E_W + V) - k_{\Uparrow}^2}}}{2\sin^2((L/2)\sqrt{2M_W^*(E_W + V) - k_{\Uparrow}^2})}\right\}^{-1} \quad (48)$$

Where, $I_{lm} = \int_0^{k_{\Uparrow}} 2k_{\Uparrow} dk_{\Uparrow} e^{-2Z_D(z)\sqrt{2m_D|E_D| + k_{\Uparrow}^2}} |Y_{lm}(\bar{k}_{\Uparrow})|^2$

2-5- The Quantum Dot Local Density of States

We write the quantum dot density of states as the sum of the following lorentizain – like, $\rho_D(E) = \rho_{D10}(E) + 2\rho_{D1\pm1}(E)$ (49)

Where , $\rho_{D10}(E) = \frac{1}{\pi} \frac{\Delta_{D10}}{(E - E_D)^2 + \Delta_{D10}^2}$

and $\rho_{D1\pm1}(E) = \frac{1}{\pi} \frac{\Delta_{D1\pm1}}{(E - E_D)^2 + \Delta_{D1\pm1}^2}$

2-5- The Quantum Dot Local Density of States

The quantum well density of states is given by [16] ,

$$\rho_W(E) = \frac{L}{2\pi} \Big/ \frac{\partial E}{\partial k_z} \quad (50)$$

Then by using equation (18),(19) and (31) we get

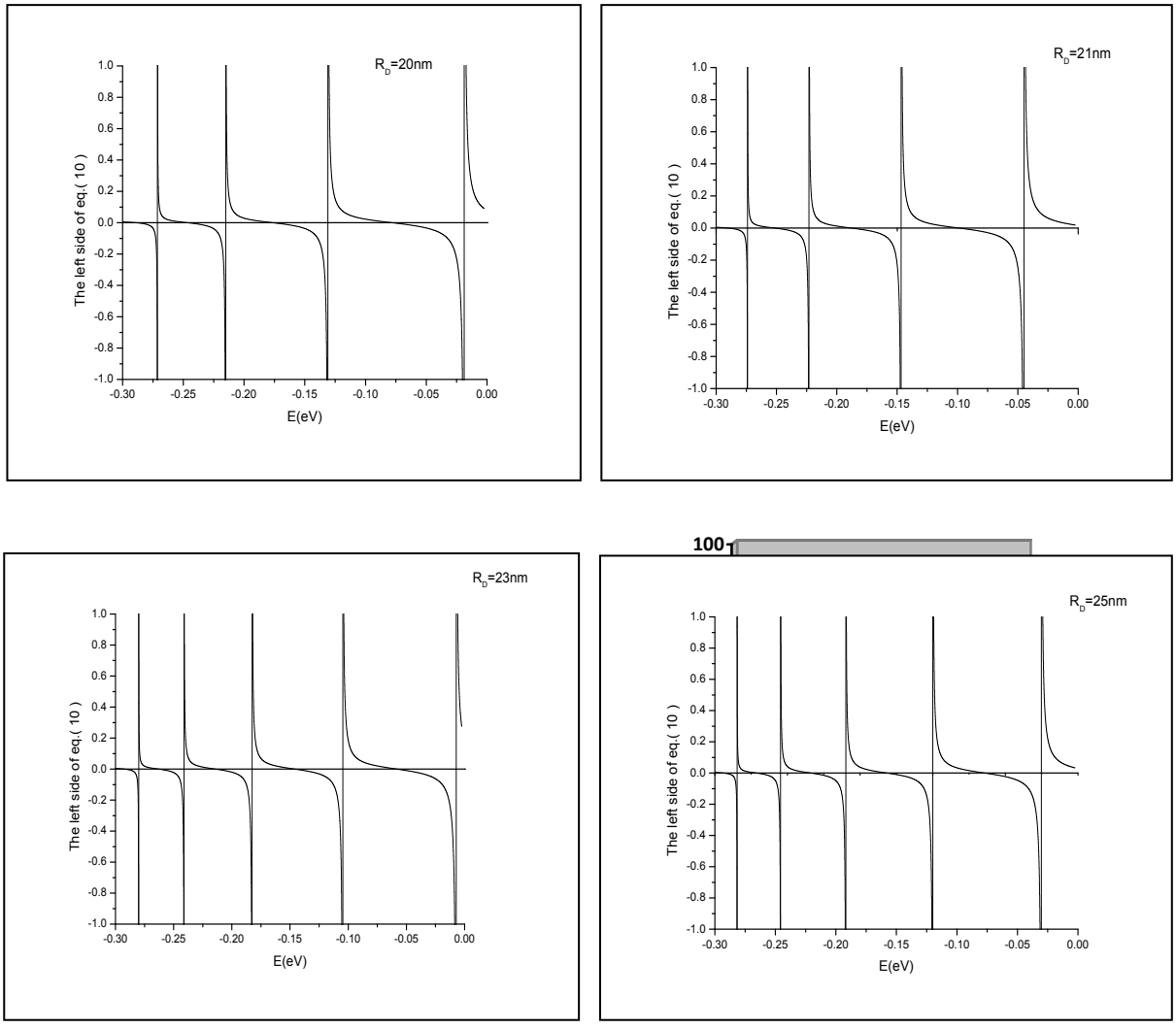
$$, \rho_W(E) = \frac{L}{2\pi} \frac{L^2 \sec^2(Lk_z) + \frac{2\alpha}{(\alpha^2 - k_z^2)} + \frac{4\alpha k_z^2}{(\alpha^2 - k_z^2)^2}}{\frac{2k_z}{\alpha(\alpha^2 - k_z^2)} - \frac{4\alpha k_z}{(\alpha^2 - k_z^2)^2}} \quad (51)$$

3 – Calculation and Results

3 – 1 The Quantum Dot Energy Spectrum Calculation

GaAs spherical quantum dot is considered in our calculation with effective mass $M_D^* = 0.067$ a.u[17] and $V_D = 300$ meV. We calculate the quantum dot eigen energy , by using eq.(10), for the orbital 4p where we found the 4th intersection of the left side of equation (10) with the line for $l = 1$ and $n = 4$ for different values of quantum dot radius R_D (see Fig . (4)).

The diagrammatic solution of eq.(10) is presented in Fig.(4) , where the 4th intersection of the left side of eq.(10) with the line $E = 0$ determines the required p state energy level. However, the usual relation between the energy level position and the quantum dot radius is also checked as shown in Fig.(5).



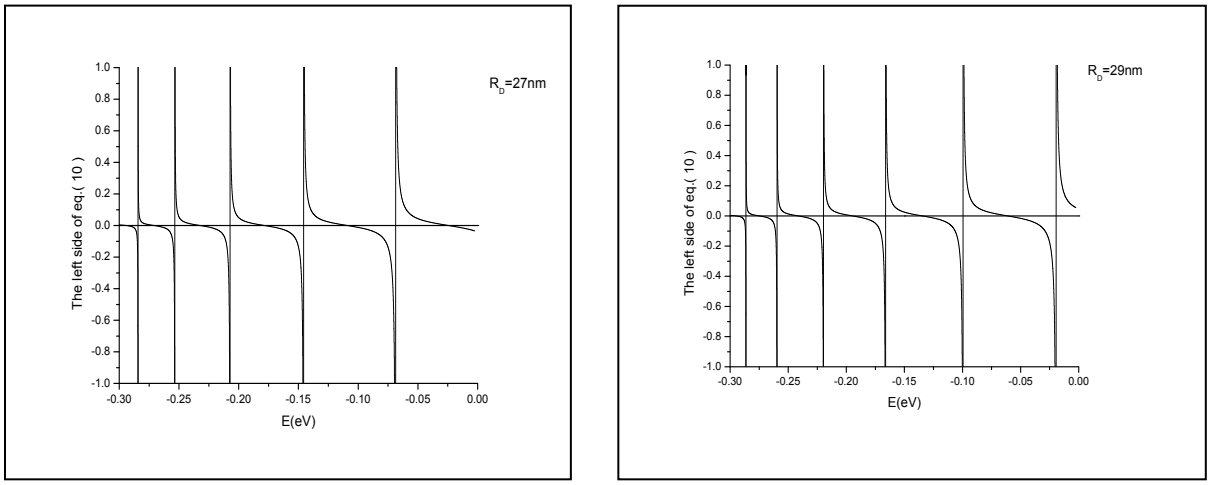


Fig.(4): The left side of eq.(10) value as a function of energy for different values of R_D.

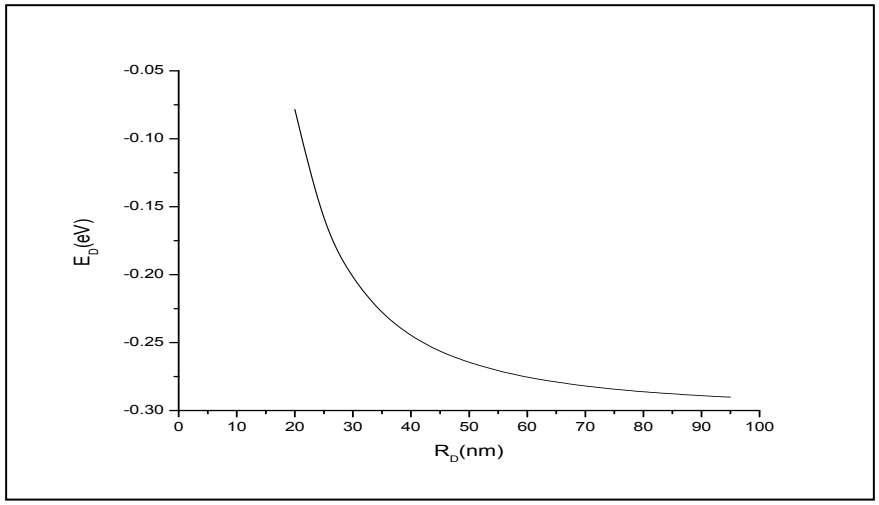
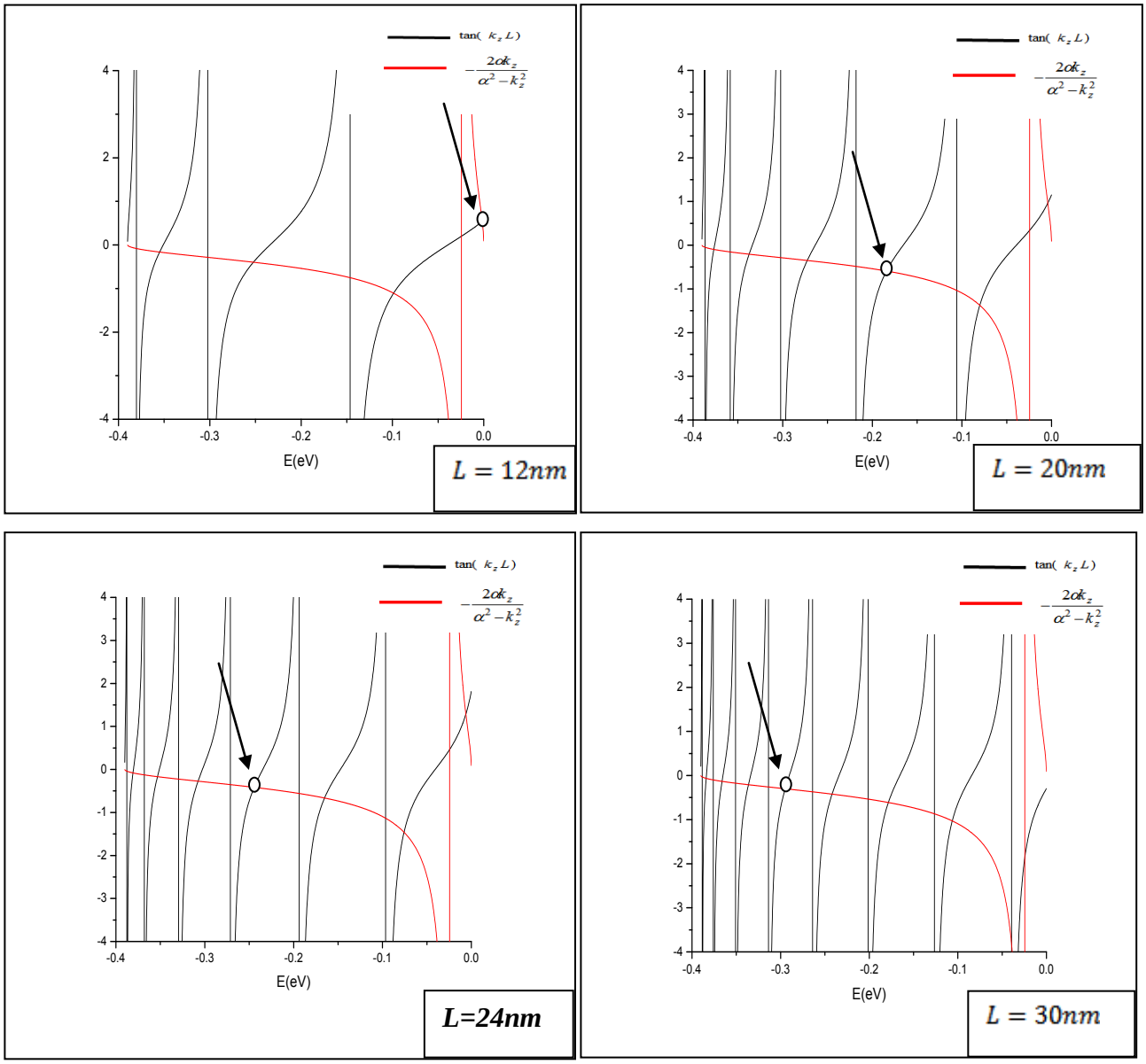


Fig.(5) : The quantum dot energy level position as a function of R_D.

3 – 2 The Quantum Well Energy Spectrum Calculation

To calculate the quantum well energy spectrum we get use of eq.(31) where $\tan(k_z L)$ and $-2\alpha k_z / \left(\alpha^2 - k_z^2\right)$ are calculated as a function of energy, considering the odd state, for different values of well width L , with $V_W = 390meV$ and $M_W^* = 0.067a.u$. The intersection between the two curves that represents the eigen energy value $E = E_W$ as in Fig.(6)

As the quantum well width increases , the quantum well energy level is shifted more towards the high negative values of energy.



Fig(6): The GaAs quantum well energy spectrum for different values of well width .

3 – 3 The Quantum Dot Local Density of States

We firstly calculate the broadening function by using eq.(48) for the different quantum numbers *lm* , and for different values of R_D *and L*. These results are used to calculate the quantum dot density of states by using eq.(49) . Our calculations are presented in Fig.(7) for *L=12nm* and in Fig.(8) for *L=24nm*.

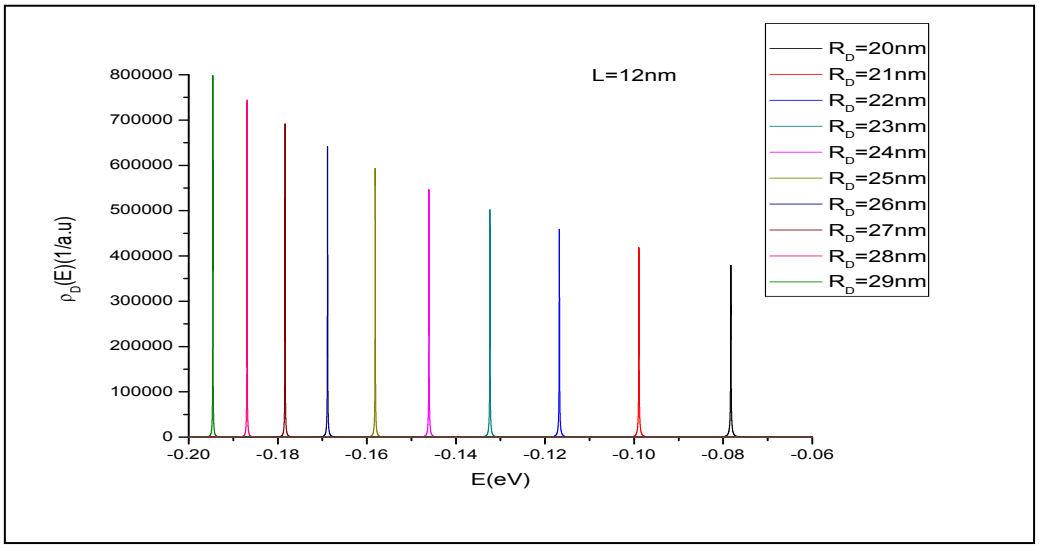


Fig.(7):The quantum dot local density of states as function of energy with $L = 12nm$.

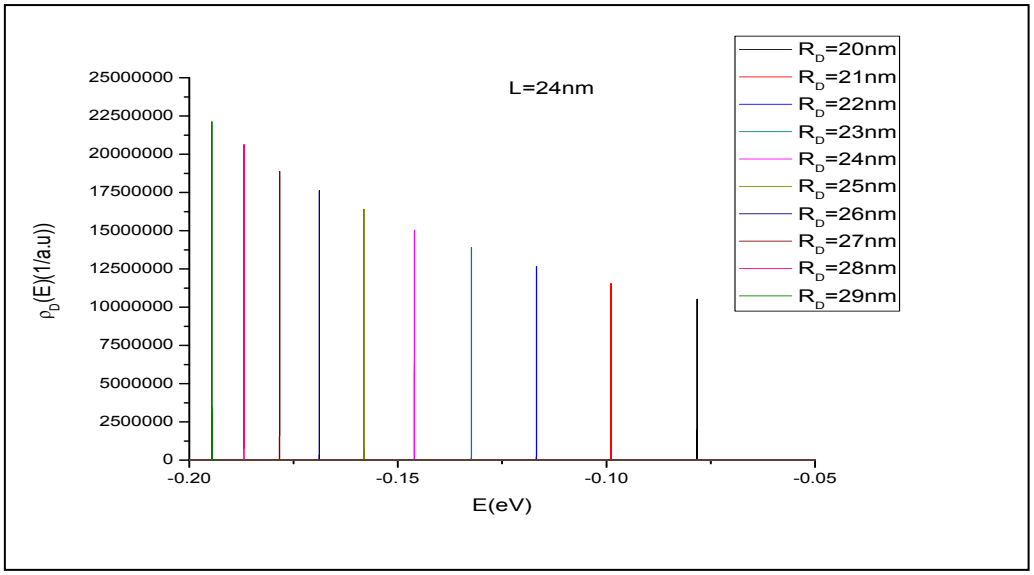
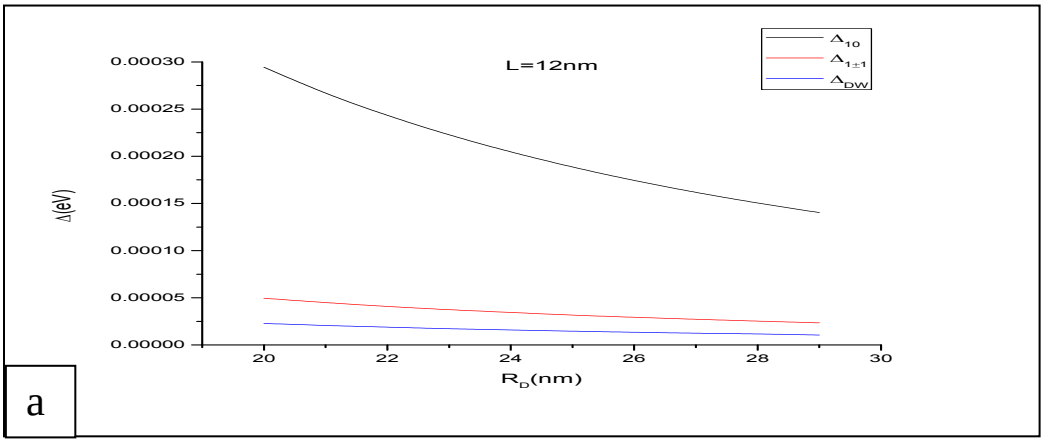


Fig.(8):The quantum dot local density of states as function of energy with $L = 24nm$.



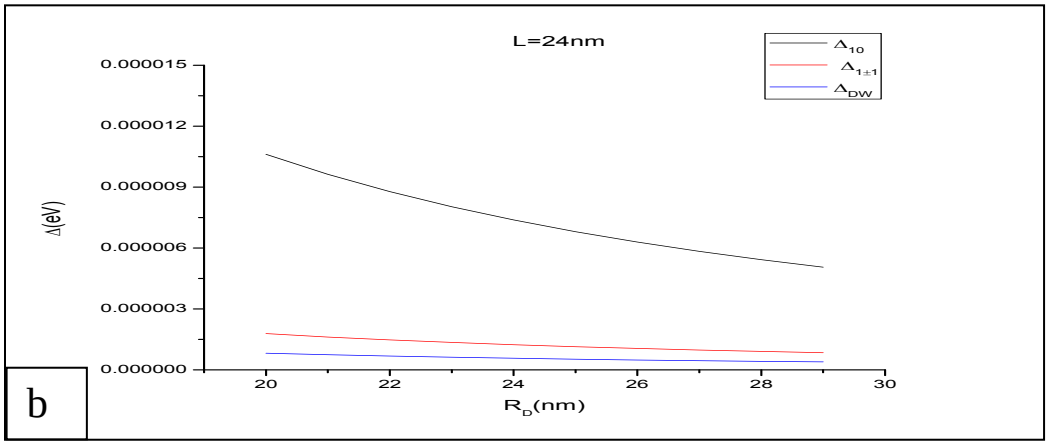


Fig.(9): The broadening functions Δ_{D10} , Δ_{D1+1} and Δ_{D1-1} and Δ_{WD} as a function of R_D with (a):*L=12nm* , (b):*L=24nm*

For certain L , as R_D increases the maxima of the QD density of states is shifted towards the higher negative values of energy .

3 – 4 The Quantum Dot Local Density of States

The quantum well density of states is calculated as a function of energy for *L=12nm* and *L= 24nm* (see Fig.(10)). Many maxima are popped , but all these maxima are not perceptible in comparison with the last maxima which is the nearest to the energy reference *(E = 0)* .

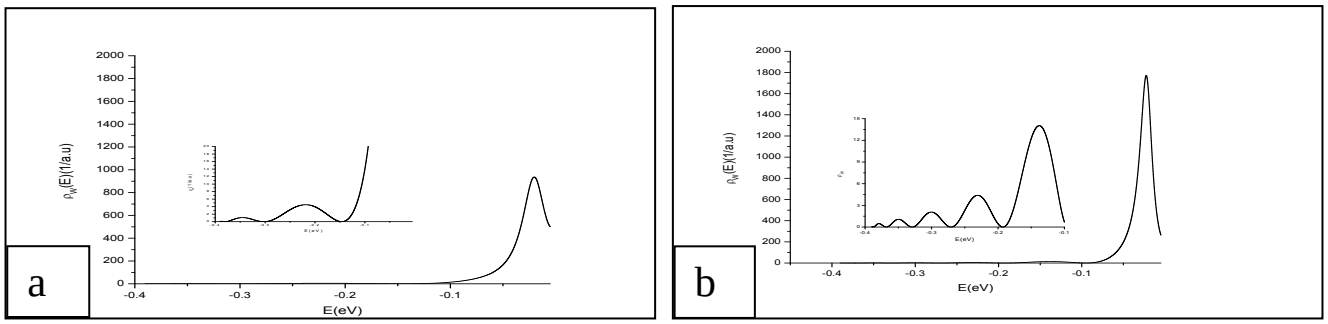


Fig.(10) : The quantum well density of states $\rho_W(E)$ (a): when $L = 12nm$. (b) when $L = 24nm$.

4 – Conclusions

In this work, a study and investigation in the physical features of electron properties of the coupled QD – QW nanostructure system is extendedly presented, where the electronic properties of the system are calculated and discussed.

The theoretical model for coherent tunneling from one quantum dot to another one through quantum well based on the transition – probability formulation. This model is attractive since it analysis the tunneling probability from a zero – dimension in terms of the initial state in the quantum dot to final state in a two-dimension (QW).

In our theoretical model we perform the calculations concern to **the electrical properties firstly** by calculating the energy spectrum of each subsystem. Where, we use the diagrammatic solution of the corresponding eigen value equation to obtain the 4th p-state energy level for the GaAs quantum dot and quantum well. The value of the quantum dot energy level or the

quantum well energy level are determined as a function of the quantum dot radius and the quantum well width respectively. The calculated energy values are within the estimated one and has a reasonable variations with the quantum dot radius and the quantum well width and other parameters.

Secondly, we calculate the tunneling rates due to coupling interaction between the subsystems. The matrix element of the coupling interaction is formulated as a function of all system parameters. The calculated tunneling rates and its variation with the quantum dot energy level (i.e. for the corresponding radius) and the quantum well energy level (i.e. for the corresponding width) are investigated. The coupling interaction between the quantum dot and the quantum well depends on quantum dot radius and quantum well width . The calculated values of tunneling rate Δ_{DW} for $L = 24nm$ is much lesser than that calculated for $L = 12nm$.

The calculated tunneling rates due to coupling interactions between the subsystems started by calculating the local density of states for the 4th p-state of the quantum dot coupled with the quantum well, ρ_{DW}, which is obtained by summing over all the partial density of states for different index i.e. m and l as,

$$\rho_{DW}(E) = \sum_{-l}^{l} \rho_{Dml}(E)$$

with $\rho_{Dml}(E) = \frac{1}{\pi} \frac{\Delta_{ml}}{(E - E_D)^2 + \Delta_{ml}^2}$

When R_D increases the value of E_D is shifted toward the higher negative energy range and so the peak position of ρ_{DW}. The 4th p-state quantum dot tunneling rate due to coupling with quantum well states, Δ_{DW}, decreases with increasing each of R_D and L. However, increasing each of R_D and L increases the maximum value of the peak position as a consequence of decreasing Δ_{DW}.

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الخصائص الالكترونية لنظام نقطة كمية مقترنة ببئر كمي (QD – QW)

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الملخص

تم اشتقاق أنموذج نظري موسع للنفق المتشاكه من نقطة كمية الى بئر كمي ، استندت على صياغة احتمالية الانتقال . هذا الانموذج مثير للاهتمام حيث انه يحلل احتمالية النفق من جزء النظام (0D) الى جزء النظام (2D). في معالجتنا تم اهمال عرض الحاجز بين اجزاء النظام بينما تم اخذ عدم الاستمرارية بالكتلة الفعالة بنظر الاعتبار. حساب طيف طاقة النقطة الكمية والبئر الكمي كدالة لنصف قطر النقطة الكمية والبئر الكمي على التوالي. بعد ذلك تم صياغة عنصر المصفوفة لتفاعل الاقتران بين النقطة الكمية والبئر الكمي بحيث يعتمد على الخصائص الالكترونية للنظام. تم توظيف صيغة عنصر المصفوفة لصياغة معدل النفق بين النقطة الكمية و البئر الكمي. في حسابتنا تم اعتماد نقطة كمية كروية وبتر كمي من شبه الموصل GaAs . كل الخطوات العلمية التي تم عرضها في بحثنا تعد خطوة مهمة و ضرورية لدراسة الخصائص الالكترونية والانتقالية للجهاز قطب ايمن – نقطة كمية – بئر كمي – نقطة كمية – قطب ايسر .

الكلمات المفتاحية : نقطة كمية مقترنة ببئر كمي ، الالكترونيات النانوية