



# The Energy Levels Splitting Calculated for the Heavy and Light Holes in a $\text{Cd}_{1-x}\text{Zn}_x\text{S}$ Double Quantum Dot

Zoubeida Khéfacha<sup>1</sup>, Nabil Safta<sup>2,\*</sup>, Mohamed Dachraoui<sup>3</sup>

<sup>1</sup>Departement of Chemistry, Faculty of Sciences, University of Monastir, Monastir, Tunisia

<sup>2</sup>Unity of Quantum Physics, Faculty of Sciences, University of Monastir, Monastir, Tunisia

<sup>3</sup>Laboratory of Analytical Chemistry and Electrochemistry, Faculty of Sciences, University of Tunis El Manar, Tunis, Tunisia

## Email address:

saftanabil@yahoo.fr (N. Safta)

\*Corresponding author

## To cite this article:

Zoubeida Khéfacha, Nabil Safta, Mohamed Dachraoui. The Energy Levels Splitting Calculated for the Heavy and Light Holes in a  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  Double Quantum Dot. *American Journal of Nano Research and Applications*. Vol. 5, No. 3, 2017, pp. 32-36.

doi: 10.11648/j.nano.20170503.11

**Received:** March 23, 2017; **Accepted:** April 19, 2017; **Published:** June 14, 2017

---

**Abstract:** This work reports on a theoretical investigation of a double  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  quantum dot embedded in an insulating material. The quantum dots are assumed to have a flattened cylindrical geometry with a finite barrier at the boundary. The energy levels splitting has been computed, using the tight binding approximation, in the case of the heavy and light holes, as a function of zinc composition for different inter-quantum dot separations. An analysis of the results shows that, for the light holes, the coupling is maximum when  $x=0.8$ . Moreover, it has been demonstrated the strong localization character of the heavy holes in this nanostructure.

**Keywords:** Double Quantum Dot,  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$ , Heavy and Light Holes, Tight Binding Approximation, Non Volatile Memories

---

## 1. Introduction

In the last decades, the high potentialities of  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  films do not cease to be proved in many useful devices [1-3]. This is principally due to their utility as window materials in heterojunction solar cells with a p-type absorber such as  $\text{CuInSe}_2$ ,  $\text{CuIn}_x\text{Ga}_{1-x}\text{Se}_2$  or  $\text{CuSnS}_z\text{Se}_{1-z}$  [4-9].

Concerning  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  quantum dots (QDs), their considerable advantage has been demonstrated in both fundamental and applied research [10-24].

From a fundamental view point,  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs have particular properties like size quantization, zero – dimensional electronic states, non linear optical behaviour, coupling between QDs etc [10-20].

In technological applications,  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs are of great importance as well. We can evoke red-light-emitting diodes (LEDs) fabricated using  $\text{CdSe}/\text{Cd}_{1-x}\text{Zn}_x\text{S}$  quantum dots (QDs) [21], blue (~440 nm) liquid laser with an ultra-low threshold achieved by engineering unconventional ternary  $\text{CdZnS}/\text{ZnS}$  alloyed-core/shell QDs [22] and fluorescent  $\text{CdS}$  QDs utilized for the direct detection of fusion proteins [23]. Furthermore,

$\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs have become one of the most promising materials in solar cell area [24]. In this context, our actual defy is to use  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs grown on nominal and vicinal Si surfaces [25-27] in order to find adequate structures for novel nanodevices such as the non - volatile memories.

Concerning the growth of  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs, there are several methods like the inverted micelles [28], the selective area – growth technique [29], the single source molecular precursors [30], the colloidal method [31] and the Sol gel technique [4].

To describe the  $\text{Cd}_{1-x}\text{Zn}_x\text{S}$  QDs, we have considered, on a one hand, the spherical geometry and two types of potentials, a potential with an infinite barrier [32] and a potential with a finite barrier at the boundary [33, 34].

For the first case [32], by taking account on the excitonic binding energy, we have calculated the band gap energy as a function of radius. The obtained results showed a good agreement with several experimental data.

For the second case [33, 34], by restricting the study to the ground state for both electrons and holes, we have calculated, in a first step, the shape of the confinement potentials, the

quantized energies, their related envelope wave – functions and the QDs sizes [33]. In addition, we have computed the binding energy of bound excitons and the oscillator strength of interband transitions as well [33]. We have calculated, in a second step, for both electrons and holes, the excited bound states [34]. All these calculations have been made versus the zinc composition.

Nevertheless, the spherical geometry does not lend simply to calculate the band edges of coupled QDs, especially along different quantization directions. Thus, we have suggested, on another hand, the flattened cylindrical geometry with a finite potential barrier at the boundary [35-45]. Using this model, we have investigated, in a first step, the electronic properties of a single Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot [35]. More precisely, we have calculated the shape of the confining potential, the subband energies and their eigen envelope wave functions.

We have studied, in a second step, the electronic properties of the super lattices based on Cd<sub>1-x</sub>Zn<sub>x</sub>S embedded in an insulating material with use of several potential models and different methods (Kronig – Penney method, sinusoidal and triangular potentials, Tight Binding approximation...) [36-43]. Thus, our interest has especially been focused on the computation of the ground miniband width and the longitudinal effective mass for the carriers.

On the other hand, we have recently studied the coupling effect in the case of a double Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot embedded in an insulating material. More precisely, our interest has been focused on the investigation of the energy levels splitting in the case of electrons. This study has evidenced that for intermediate zinc compositions ( $x = 0.4 - 0.6$ ) the coupling between QDs is maximum [45].

The purpose of the present work is to extend the last study to the heavy and light holes. The paper is organized as follows: after an introduction, we present the modeling, the obtained results and discussions. The conclusion derived from this study is presented in the last section.

## 2. Modeling

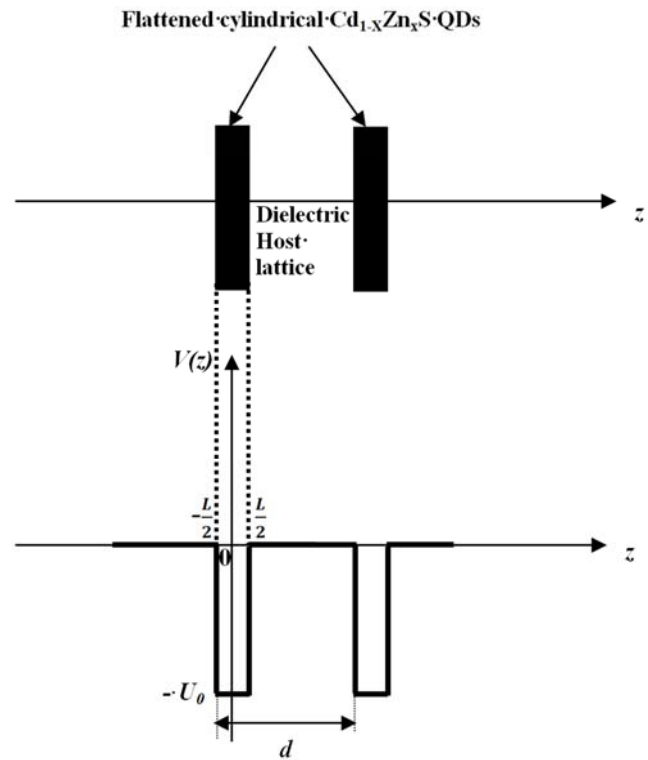
The system under investigation is a double Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot (DQD) inserted in an insulating material. Every QD is assumed to have a flattened cylindrical geometry of height  $L$  in such a way that the quantum confinement along transversal directions can be ignored. The inter-QD separation is labeled  $d$ . Fig. 1. a represents the geometry used to describe this system. The common confined direction is denoted by  $z$ . Here, the Cd<sub>1-x</sub>Zn<sub>x</sub>S flattened cylinders QDs behave as wells of width  $L$  while the host dielectric lattice corresponds to a barrier with a height  $U_0$ . For sake of simplicity, the electron and hole states are assumed to be uncorrelated. The problem to solve is, then, reduced to those of one particle in a one dimensional potential. In this work,

we adopt the potential  $V(z)$  depicted in Fig. 1. b.

For this potential, the electron and hole states can be calculated using the effective Hamiltonian:

$$H_{e,h} = \frac{-\hbar^2}{2m_{e,h}^*} \frac{d^2}{dz_{e,h}^2} + V_{e,h}(z_{e,h}) \quad (1)$$

where  $\hbar$  is the Plank's constant and  $m^*$  is the effective mass of carriers. The subscripts  $e$  and  $h$  refer to electrons and holes respectively. In deriving the Hamiltonian  $H_{e,h}$ , we have considered the effective mass theory (EMT) and the band parabolicity approximation (BPA). The difference of the effective mass between the well and the barrier has been disregarded.



**Figure 1.** (a) A schematic diagram of a double Cd<sub>1-x</sub>Zn<sub>x</sub>S QD according to the flattened cylindrical geometry – (b) The potential used in this work.

We have resolved the Schrodinger equation using the Tight Binding Approximation. Our interest is focused on the energy levels splitting in the case of the ground state. This parameter will be noted  $\Delta E_{e,h}$ . If we neglect the wave function overlap, our calculation shows that:

$$\Delta E_{e,h} = 2\beta_{e,h}$$

where

$$\beta_{e,h} = -\frac{2U_{0e,h} A_{e,h} B_{e,h} e^{-\rho_{e,h}\left(\frac{d-L}{2}\right)}}{\rho_{e,h}^2 + k_{e,h}^2} \left( \rho_{e,h} \cos\left(\frac{k_{e,h}L}{2}\right) \operatorname{sh}\left(\frac{\rho_{e,h}L}{2}\right) + k_{e,h} \sin\left(\frac{k_{e,h}L}{2}\right) \operatorname{ch}\left(\frac{\rho_{e,h}L}{2}\right) \right)$$

with

$$A_{e,h} = \left[ \frac{L}{2} + \frac{\cos^2\left(\frac{k_{e,h}L}{2}\right)}{\rho_{e,h}} + \frac{\sin(k_{e,h}L)}{2k_{e,h}} \right]^{\frac{1}{2}}$$

$$B_{e,h} = A_{e,h} \cos\left(\frac{k_{e,h}L}{2}\right)$$

$$k_{e,h} = \sqrt{\frac{2m_{e,h}^*E_{1e,h}}{\hbar^2}}; \quad \rho_{e,h} = \sqrt{\frac{2m_{e,h}^*(U_{0e,h} - E_{1e,h})}{\hbar^2}}$$

$E_l$  corresponds to the ground state energy associated with an isolated flattened cylindrical quantum dot of  $Cd_{1-x}Zn_xS$ .  $E_l$  is calculated in such a way that the zero energy is taken at the bottom of the QD well.

### 3. Results and Discussion

We have computed, for the heavy holes and light holes, the energy levels splitting as a function of the ZnS molar fraction, for inter quantum dot separations going from  $d = 1.5$  nm to  $d = 2.5$  nm. Values of parameters used in this computation are summarized in Table 1. All these parameters are taken from the Ref [35]. Values of the effective masses of the heavy and light holes for  $Cd_{1-x}Zn_xS$  with different Zn compositions have been deduced using the Vegard's law.

**Table 1.** Parameters used to calculate the energy levels splitting in the case of the heavy and light holes for a double  $Cd_{1-x}Zn_xS$  QD. ( $m_0$  is the free electron mass).

x	$\frac{m_{hh}^*}{m_0}$	$\frac{m_{lh}^*}{m_0}$	$U_{0h}$ (eV)	L(nm)	$E_{1hh}$ (eV)	$E_{1lh}$ (eV)
0.0	5.00	0.70	0.25	1.00	0.040	0.129
0.2			0.25	1.00	0.049	0.136
0.4			0.50	1.00	0.060	0.216
0.6			0.50	1.00	0.070	0.238
0.8			0.50	1.00	0.083	0.266
1.0	1.76	0.23	2.00	1.00	0.145	0.538

Typical results are reported in Table 2 and Table 3.

Concerning the light holes, this study showed: (i)  $\Delta E_{lh}$  decreases when  $d$  increases independently of the Zn composition. Consequently, the coupling decreases with the inter – quantum dot separation (ii) for  $Cd_{1-x}Zn_xS$  QDs with  $x = 0; 0.2$  and  $0.4$ ,  $\Delta E_{lh}$  is low especially when  $d$  is high. Thus, the coupling is weak at high values of  $d$  (iii) for  $x = 0.8$ ,  $\Delta E_{lh}$  is maximum for all the inter-quantum dot separations studied. In this case, the coupling between the QDs is highest. These results are probably due to the barrier potential height  $U_{0h}$ , the bulk effective mass  $m_{lh}^*$  and the energy  $E_{1lh}$  values (iv)

For  $Cd_{1-x}Zn_xS$  QDs with  $x = 0.6$ , the magnitude order of  $\Delta E_{lh}$  is not far from the one of  $x = 0.8$ (v) concerning  $x = 1.0$ ,  $\Delta E_{lh}$  significantly declines as a function of the inter – quantum dot separation.

As for the heavy holes, we can make the following observations: (i) The energy levels splitting decreases with  $d$  for all the compositions studied,

(ii)  $\Delta E_{hh}$  is very low in all the cases studied.

These results can be explained in terms of the effective mass. Indeed, there is a large difference between the light hole and heavy hole effective masses in CdS, ZnS and in their alloys.

This reflects the strong localization character of the heavy holes for all the inter – quantum dot separations and independently to the composition.

**Table 2.** The energy levels splitting ( $10^{-3}$  eV), as calculated for the heavy holes versus the zinc composition for different inter-QD separations.

d(nm)	1.5	1.7	1.9	2.1	2.3	2.5
x						
0.0	2.732	0.957	0.185	0.117	0.041	0.144
0.2	3.814	1.529	0.585	2.253	0.086	0.033
0.4	1.798	0.486	0.131	0.035	0.096	0.002
0.6	3.266	1.010	3.124	0.096	0.029	0.009
0.8	8.155	2.156	0.773	0.277	0.099	0.035
1.0	0.943	0.014	0.023	0.018	0.001	0.001

**Table 3.** The energy levels splitting (eV), as calculated for the light holes versus the zinc composition for different inter-QD separations.

d(nm)	1.5	1.7	1.9	2.1	2.3	2.5
x						
0.0	0.067	0.050	0.035	0.027	0.020	0.015
0.2	0.095	0.057	0.044	0.033	0.026	0.019
0.4	0.093	0.063	0.042	0.029	0.019	0.013
0.6	0.118	0.087	0.585	0.041	0.029	0.021
0.8	0.156	0.108	0.082	0.061	0.045	0.035
1.0	0.150	0.086	0.047	0.026	0.014	0.008

The comparison with results obtained for electrons [45] shows that the  $\Delta E_{lh}$  values are not far from those of electrons (Table 4).

**Table 4.** The energy levels splitting (eV), as calculated for the electrons versus the zinc composition for different inter-QD separations[41].

d(nm)	1.5	1.7	1.9	2.1	2.3	2.5
x						
0.0	0.023	0.027	0.026	0.025	0.024	0.023
0.2	0.105	0.094	0.084	0.075	0.067	0.060
0.4	0.176	0.145	0.121	0.100	0.083	0.069
0.6	0.203	0.151	0.112	0.083	0.061	0.045
0.8	0.172	0.104	0.062	0.038	0.022	0.013
1.0	0.120	0.063	0.032	0.017	0.085	0.004

### 4. Conclusion

We studied the coupling in a double quantum dot made by  $Cd_{1-x}Zn_xS$ . To describe the QDs, we have suggested the flattened cylindrical geometry with a finite potential barrier at the boundary. Using the Tight Binding Approximation, we

have computed for the heavy and light holes the energy levels splitting. Calculations have been made as a function of Zn composition for different inter – quantum dot separations.

An analysis of the obtained results has showed that, for the light holes, the Zn composition  $x = 0.8$  is appropriate to ensure the maximum of coupling between QDs. As for the heavy holes, the results indicated the strong localization character of these carriers in all the cases studied.

In the applied physics, this study is of a great interest for designing novel devices based on Cd<sub>1-x</sub>Zn<sub>x</sub>S QDs particularly the non – volatile memories.

## References

- [1] A. Sakly, N. Safta and A. Ben Lamine. (2004), Interpretation of the bowing phenomenon in Cd<sub>1-x</sub>Zn<sub>x</sub>S alloy” *J. Mater. Sci.-Mater. Electron.* 15: 351.
- [2] N. A. Shah, A. Nazir, W. Mahmood, W. A. Syed, S. Butt, Z. Ali and A. Maqsood. (2012), Physical properties and characterization of Ag doped CdS thin films *J. Alloys Compd.* 512: 27.
- [3] T. P. Kumar, S. Saravanakumar and K. Sankaranayanan. (2011), Effect of annealing on the surface and band gap alignment of CdZnS thin films”, *Appl. Surf. Sci.* 257 (6): 1923.
- [4] B. Bhattacharjee, S. K. Mandal, K. Chakrabarti, D. Ganguli and S. Chaudhuri. (2002), Optical properties of Cd<sub>1-x</sub>Zn<sub>x</sub>S nanocrystallites in sol–gel silica matrix” *J. Phys. D: Appl. Phys.* 35: 2636-2642.
- [5] H. H. Gürel, Ö. Akinci and H. Ünlü. (2008), Tight binding modeling of CdSe/ZnS and CdZnS/CdS II–VI heterostructures for solar cells: Role of d-orbitals” *Thin Solid Films* 516: 7098.
- [6] M. Gunasekaram, M. Ichimura. (2007) Photovoltaic cells based on pulsed electrochemically deposited SnS and photochemically deposited CdS and Cd<sub>1-x</sub>Zn<sub>x</sub>S,” *Sol. Energy Mater. Sol. Cells.* 91: 774.
- [7] Z. Khéfacha, M. Mnari and M. Dachraoui (2002) Caractérisation des couches minces de Cd<sub>1-x</sub>Zn<sub>x</sub>S préparées par dépôt chimique,” *Comptes Rendus Chimie.* 5(3): 149-155.
- [8] Z. Khéfacha, Z. Benzarti, M. Mnari and M. Dachraoui, (2004) “Electrical and optical properties of Cd<sub>1-x</sub>Zn<sub>x</sub>S (0≤x≤0.18) grown by chemical bath deposition”, *Journal of crystal growth.* 260: 400- 409.
- [9] Z. Khéfacha, M. Mnari and M. Dachraoui (2003) Opto – electronical of thin films prepared by chemical bath deposition,” *Physical and Chemical News.* 14:77-84.
- [10] A. J. Peter and C. W. Lee. (2012), Electronic and optical properties of CdS/CdZnS nanocrystals” *Chinese Phys. B* 21: 087302.
- [11] F. Scotognella, G. Lanzani, L. Manna, F. Tassone and M. Zavelani-Rossi. (2012), Study of higher-energy core states in CdSe/CdS octapod nanocrystals by ultrafast spectroscopy” *Eur. Phys. J. B.* 85: 128.
- [12] L. Cao, S. Huang and S. E. (2004), ZnS/CdS/ZnS quantum dot quantum well produced in inverted micelles” *J. colloidInterface Sci.* 273: 478-482.
- [13] H. Kumano, A. Ueta and I. Suemune. (2002), Modified spontaneous emission properties of CdS quantum dots embedded in novel three-dimensional microcavities” *Physica E* 13: 441-445
- [14] Y. C. Zhang, W. W. Chen and X. Y. Hu. (2007), “In air synthesis of hexagonal Cd<sub>1-x</sub>Zn<sub>x</sub>S nanoparticles from single-source molecular precursors” *Mater. Lett.* 61: 4847-4850
- [15] C. S. Pathak, D. D. Mishra, V. Agarawala, M. K. Mandal. (2012), Mechanochemical synthesis, characterization and optical properties of zinc sulphide nanoparticles” *Indian J. Phys* 86: 777-781.
- [16] S. Roy, A. Gogoi and G. A. Ahmed. (2010), Size dependent optical characterization of semiconductor particle: CdS embedded in polymer matrix *Indian J. Phys.* 84: 1405-1411
- [17] A. U. Ubale and A. N. Bargal. (2010), Characterization of nanostructured photosensitive cadmium sulphide thin films grown by SILAR deposition technique” *Indian J. Phys.* 84: 1497-1507
- [18] K. K. Nanda, S.N. Sarangi, S. Mohanty, S.N. Sahu. (1998), “Optical properties of CdS nanocrystalline films prepared by a precipitation technique” *Thin Solid Films* 322: 21-27.
- [19] N. Safta. (2004), Fluctuations mode of the gap as a function of composition of Cd<sub>1-x</sub>Zn<sub>x</sub>S ternaries” *Ann. Chim. Sci. Mat.* 29 (5) 105-112
- [20] H. Yükselici, P. D. Persans and T. M. Hayes. (1995), Optical studies of the growth of Cd<sub>1-x</sub>Zn<sub>x</sub>S nanocrystals in borosilicate glass *Phys. Rev. B.* 52: 11763.
- [21] N. -K. Cho, J.-W. Yu, Y. H. Kim, and S. J. Kang. (2014) "Effect of oxygen plasma treatment on CdSe/CdZnS quantum-dot light-emitting diodes," *Jpn. J. Appl. Phys.* 53: 032101.
- [22] Y. Wang, K. S. Leck, V. D. Ta, R. Chen, V. Nalla, Y. Gao, T. He, H. V. Demir, and H. Sun. (2014) "Blue liquid lasers from solution of CdZnS/ZnS ternary alloy quantum dots with quasi-continuous pumping," *Adv. Mater.* Doi: 10.1002/adma.201403237.
- [23] J. J. Beato-López, C. Fernández-Ponce, E. Blanco, C. Barrera-Solano, M. Ramírez-del-Solar, M. Domínguez, F. García-Cozar, and R. Litrán.(2012) "Preparation and characterization of fluorescent CdS quantum dots used for the direct detection of GST fusion proteins," *Nanomaterials and Nanotechnology*, 2: 10.
- [24] K. Deepa, S. Senthil, S. Shriprasad, and J. Madhavan, "CdS quantum dots sensitized solar cells (2014)" *International Journal of Chem Tech Research*, 6: 1956–1958.
- [25] N. Safta, J-P. Lacharme and C. A. Sébene (1993) Clean Si(110): a surface with intrinsic or extrinsic defects ?,” *Surf. Sci.* 287/288: 312, 1993.
- [26] N. Safta, J. P. Lacharme, A. Cricenti, A. Taleb-Ibrahimi, Indlekofer, V. Aristov, C. A. Sébenne, G. Le Lay and B. Nesterenko (1995) Core level spectra of clean “2 × 8” vicinal Si(110)”, *Nuclear Instruments and Methods in Physics Research B.* 97: 372.
- [27] A. Cricenti, G. Le Lay, V. Yu Aristov, B. Nesterenko, N. Safta, J.P. Lacharme, C.A. Sébenne, A. Taleb-Ibrahimi and G. Indlekofer (1995) High resolution synchrotron radiation Si 2p core-level spectroscopy of Si(110)1x2”, *Journal of Electron Spectroscopy and related phenomena* . 76: 613-617.

- [28] L. Cao, S. Huang, and E. S (2004) "ZnS/CdS/ZnS quantum dot quantum well produced in inverted micelles," *J. Colloid Interface Sci.* 273: 478–482.
- [29] H. Kumano, A. Ueta, and I. Suemune (2002) "Modified spontaneous emission properties of CdS quantum dots embedded in novel three-dimensional microcavities," *Physica E*. 13: 441-445.
- [30] Y. C. Zhang, W. W. Chen, and X. Y. Hu (2007) "In air synthesis of hexagonal Cd<sub>1-x</sub>Zn<sub>x</sub>S nanoparticles from single-source molecular precursors," *Mater. Lett.* 61: 4847-4850.
- [31] K. Tomihira, D. Kim, and M. Nakayama (2005) "Optical properties of ZnS-CdS alloy quantum dots prepared by a colloidal method," *J. Lumin.* 112: 131- 135.
- [32] Z. Khéfacha, N. Safta and M. Dachraoui (2016) The Band Gap Energy Calculated for Cd<sub>1-x</sub>Zn<sub>x</sub>S Quantum Dots grown by the Sol gel Method," *International Journal of Applied Chemistry*. 12: 573-579.
- [33] N. Safta, A. Sakly, H. Mejri and Y. Bouazra. (2006), "Electronic and optical properties of Cd<sub>1-x</sub>Zn<sub>x</sub>S nanocrystals" *Eur. Phys. J. B* 51: 75-78
- [34] A. Sakly, N. Safta, A. Mejri, H. Mejri, A. Ben Lamine (2010), The Excited Electronic States Calculated for Cd<sub>1-x</sub>Zn<sub>x</sub>S Quantum Dots Grown by the Sol-Gel Technique" *Journal of Nanomaterials* 2010, Article ID 746520, 4 pages. doi:10.1155/2010/746520
- [35] N. Safta, A. Sakly, H. Mejri and M. A. Zaïdi (2006), Electronic properties of multi-quantum dot structures in Cd<sub>1-x</sub>Zn<sub>x</sub>S alloy semiconductors" *Eur. Phys. J. B* 53: 35 – 38.
- [36] S. Marzougui, and N. Safta (2015) "The excited electronic states and the oscillator strength calculated for flattened cylindrical Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dots," *International Journal of Chemistry and Materials Research*, 3: 17-26.
- [37] A. Sakly, N. Safta, H. Mejri, A. Ben Lamine (2009), The electronic band parameters calculated by the Kronig–Penney method for Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices" *J. Alloys Compd.* 476: 648–652.
- [38] A. Sakly, N. Safta, H. Mejri, A. Ben Lamine. (2011), The electronic states calculated using the sinusoidal potential for Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices" *J. Alloys Compd.* 509: 2493–2495.
- [39] S. Marzougui, N. Safta. (2014), The electronic band parameters calculated by the Triangular potential model for Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices" *IOSR-JAP* 5 (5): 36-42.
- [40] S. Marzougui, N. Safta. (2014), The electronic band parameters calculated by the Tight Binding Approximation for Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices" *IOSR-JAP* 6 (2): 15-21
- [41] S. Marzougui, N. Safta. (2014), A theoretical study of the electronic properties of Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices" *American Journal of Nanoscience and Nanotechnology* 2 (3): 45-49.
- [42] S. Marzougui and N. Safta (2014) "A theoretical study of the heavy and light hole properties of Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot superlattices." *International Journal of Materials Science and Applications*. 3: 274-278.
- [43] S. Marzougui and N. Safta (2015) " The Electronic Band Parameters Calculated by a Novel Potential Model for Cd<sub>1-x</sub>Zn<sub>x</sub>S Quantum Dot Super lattices," *Research journal of Materials science*. 3: 9-14.
- [44] S. Marzougui and N. Safta (2015) "The electron transmission coefficient calculated for Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dots- Application in the non volatile memories" *International Journal of Applied Engineering Research*. 10 (21): 42275-42278.
- [45] Z. Khéfacha, N. Safta and M. Dachraoui (2017) "The energy levels splitting calculated for electrons in a double Cd<sub>1-x</sub>Zn<sub>x</sub>S quantum dot" To be published.