RESEARCHERID
THOMSON REUTERS

ISSN: 2277-9655
[Diagne *, 7(9): September, 2018] Impact Factor: 5.164
IC™ Value: 3.00 CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXTERNAL QUANTUM EFFICIENCY OF A SOLAR CELL ZnO / CdTe: EFFECTS OF EXCITONS BY THE METHOD OF CALCULATING THE DIELECTRIC FUNCTION

M. Diagne[1*], W. Diallo[1] , N. Mbengue[1], F. Dia[1], O. A. Niasse[1], B. Ba[1]

[1] Laboratoire des Semiconducteurs et d'énergie solaire matériaux et systèmes (LASES-SOLMATS), Université Cheikh Anta Diop de Dakar, Faculté des Sciences et Technique, Département de ¨Physique.

DOI: 10.5281/zenodo.1435552

ABSTRACT

The quantum efficiency of the solar cell ZnO / CdTe is studied by simulating through this article. Thus for the return is made to make use of the absorption coefficients of the two semiconductors. . Their expressions are given by the dielectric function ε. The effect of excitons longer present in the ultraviolet band possible to explain the appearance of the quantum efficiency of the solar cell ZnO / CdTe. This enables us with the various transitions well given excitons, optimize the solar cell.

Keywords: Exciton-Heterojunction-Zinc-oxide-telluride-quantum-absorption-coefficient Transition Band-cadmium-energy efficiency.

1. INTRODUCTION

In recent decades, the thin layers of zinc oxide ZnO have attracted great interest as transparent conductive oxides. This is due to the compromise between optical and electrical properties of zinc oxide, its thermal and chemical stability very high. In addition, it has a gap 3.3ev and an exciton binding energy of 60Mev. [1]
In this work, we studied a theoretical model for calculating the quantum efficiency of solar cells ZnO / CdTe. However the determination of the coefficients of absorption and reflection and excitonic transitions semiconductors still pose problems in the study of materials. []. Through this study, we present
determining patterns of the absorption coefficient and reflection of external quantum efficiency, by considering the contribution of excitonic transitions different covering bandwidth of 1.1 to 5.7 eV, expressions of the absorption coefficient proposed by various authors, including Adachi et al. [1].

2. MATERIALS AND METHODS

In this study the calculations are performed considering that the transportation of excess minority carriers is made only in the direction perpendicular to the junction then used to express the results in one-dimensional space. This is realistic in that it corresponds to the fact that the lateral dimensions of the cell are much larger than its thickness.

Thus, the external quantum efficiency is calculated from a one-dimensional model shown in Figure below

Calculation assumptions cell performance.
If we consider a situation of non-equilibrium, from the general transport equation in one dimension, we have for the electrons in the p region the following equation:

Error!Error!(1)

For the holes in the region n, the equation governing the transport phenomena is:

Error!Error!(2)

or :
(n_p - n_{P0}) and (p_n – p_{n0}): density of electrons in the p region and the hole density in zone.
Dn and Dp: electron scattering coefficients and holes,
m_n and m_p: are the mobilities of electrons and holes,

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

E (x): the electric field in the material,
τ_n and τ_p: lifetimes of electrons and holes,
n_{po} , p_{no} and are the densities of minority carriers in equilibrium,
Gn and Gp: the generation rate of electrons and holes.

To solve these equations, one must make simplifying assumptions considering the case where one of the materials is doped, thereby to decouple the two equations by neglecting the term, and the electric field in the near-neutral n and p of the cell.

Thus in steady state equations of continuity in the base and the emitter are represented by equations 3 and 4.

$$D_n \frac{d^2(n_p - n_{p0})}{dx^2} + \alpha F(1-R)\exp(-\alpha x) - \frac{n_p - n_{p0}}{\tau_n} = 0 \quad (3)$$

$$D_P \frac{d^2(p_n - p_{n0})}{dx^2} - \frac{(p_n - p_{n0})}{\tau_n} + G(\lambda) = 0 \quad (4)$$

Equations (3) and (4) are second order differential equations; the final expressions of their general solutions are given respectively by the equations (5) and (6).

$$n_p - n_{p0} = \frac{\alpha F(\lambda[1-R(\lambda)])\tau_n}{\alpha^2 L_n{}^2 - 1} \exp[\alpha(x_j - w)] \times A \quad (5)$$

With (6)

$$A = \left\{ \cosh\left(\frac{X - X_j - W}{L_n}\right) - \exp[-\alpha(x - x_j - w)] \frac{\frac{S_n L_n}{D_n}\left(\cosh\left(\frac{H}{L_n}\right) - \exp(-\alpha H) + \alpha L_n \exp(-\alpha H)\right)}{\frac{S_n L_n}{D_n}\sinh\left(\frac{H}{L_n}\right) + \cosh\left(\frac{H}{L_n}\right)} \sinh\left(\frac{X - X_j - W}{L_n}\right) \right\}$$

$$p_n - p_{n0} = \frac{\alpha F(1-R)\tau_n}{\alpha^2 L_p{}^2 - 1}\left[\frac{\left(\frac{S_p L_p}{D_p} + \alpha L_p\right)\sinh\left(\frac{X_j - X}{L_p}\right) + \left(\frac{S_p L_p}{D_p}\sinh\frac{X}{L_p} + \cosh\frac{X}{L_p}\right)\exp(-\alpha x_j)}{\frac{S_p L_p}{D_p}\sinh\frac{X_j}{L_p}} - \exp(-\alpha x) \right] \quad (7)$$

The external quantum efficiency is deduced from the photocurrent density by the following formula:

$$SR(RQE) = \frac{J_{ph}}{qF(\lambda)} \quad (8)$$

Where Jph represents the photocurrent density in short circuit.
This density is given by the expressions 8, 9 and 10 respectively, the emitter, the base and the space charge zone.

$$Je_{ph} = \frac{qF(1-R)\alpha L_P}{\alpha^2 L_n{}^2 - 1}\left\{ \frac{\frac{S_P L_P}{D_n} + \alpha L_P - \left(\frac{S_P L_P}{D_P}\cosh\frac{X_J}{L_P} + \sinh\frac{X}{L_P}\exp(-\alpha x)\right)}{\frac{S_P L_P}{D_P}\sinh\frac{X_J}{L_P} + \cosh\frac{X_J}{L_P}} - \alpha L_P(-\alpha x) \right\} \quad (9)$$

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

$$Jn_{ph} = \frac{qF(1-R)\alpha L_n}{\alpha^2 L^2{}_n - 1}\exp[-\alpha(x_j + w)]\left\{\alpha L_n - \frac{\frac{S_n L_n}{D_n}\left(\cosh\frac{He}{L_n} - \exp(-\alpha He) + \sinh\frac{He}{L_n} + \alpha L_n \exp(-\alpha He)\right)}{\frac{S_n L_n}{D_n}\sinh\frac{He}{L_n} + \cosh\frac{He}{L_n}}\right\} \quad (10)$$

$$J_{ZCE} = qF(1-R)[1-\exp(-\alpha W)]\exp(-X_J) \quad (11)$$

Thus, the total external quantum efficiency due to the contribution of the different areas of the cell is given by:

$$QE = QE_b + QE_e + QE_{scr} \quad (12)$$

With

$$SR_b = \frac{(1-R)\alpha_n L_n}{\alpha_n{}^2 L_n{}^2 - 1}\exp[-\alpha_n(X_j + W)]\left\{\frac{\frac{S_n L_n}{D_n}\left(\cosh\frac{Hb}{L_n} - \exp(-\alpha Hb) + \sinh\frac{Hb}{L_n} + \alpha L_n \exp(-\alpha Hb)\right)}{\frac{S_n L_n}{D_n}\sinh\frac{Hb}{L_n} + \cosh\frac{Hb}{L_n}}\right\} \quad (13)$$

$$SR_e = \frac{(1-R)\alpha_p L_p}{\alpha_p{}^2 L_p{}^2 - 1}\left\{\frac{\frac{S_P L_p}{D_p} + \alpha_p L_p - \exp(-\alpha_p X_j)\left(\frac{S_P L_p}{D_p}\cosh\frac{X_j}{L_p} + \sinh\frac{X_j}{L_p}\right)}{\frac{S_P L_p}{D_p}\sinh\frac{X_j}{L_p} + \cosh\frac{X_j}{L_p}} - \alpha_p L_p \exp(-\alpha_p X_j)\right\} \quad (14)$$

$$SR_{ZCE} = (1-R)[1-\exp(-\alpha W)]\exp(-X_j) \quad (15)$$

3. RESULTS AND DISCUSSIONS:

3.1 Refractive Index

The figure 1 below shows the change in the refractive index of the ZnO layer of the heterojunction window according to the incident photon energy is calculated from the data Adachi [4]. Indeed we find that the curve of variation of the refractive index has three parts. Between a first and 1.9ev 3.3ev where the refractive index gradually increases as a function of energy up to a maximum value of 2.3 (solid form) [5]. All photons that arrive in this area are absorbed as the material is transparent in this energy range. Then a second part between 3.3ev 3.6ev and where there is a rapid decrease of the maximum value to 1.8 and finally reduction of the latter to 1.69. We also see a peak between the second and third part

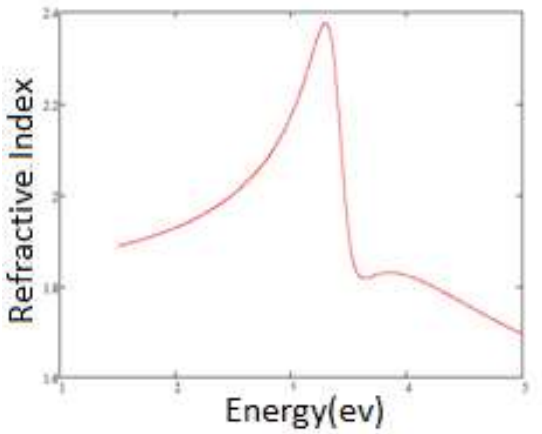

Fig. 2. Variation of the refractive index of ZnO based on the energy of incident photons

3.2 Reflection Coefficient

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The property which zincs oxide having a low extinction coefficient is used in the manufacture of heterojunction where zinc oxide acts as a window layer.

The reflectivity R (E) of the two materials of the solar cell ZnO / CdTe depends on the extinction coefficient (E) and the index n (E) of refraction and is given by the following expression: where (E) n and (E) depends on the excitation energy.

2a and 2b show the variations, versus the wavelength of the reflection coefficients ZnO and CdTe without excitons for different contributions of each transition and with the contribution of all transitions. They are given by the expression.

$$R(E)=\frac{\left[n(E)-1\right]^2+\kappa(E)^2}{\left[n(E)+1\right]^2+\kappa(E)^2} \qquad (15)$$

κ (E) and n (E) deping of excitation energy.

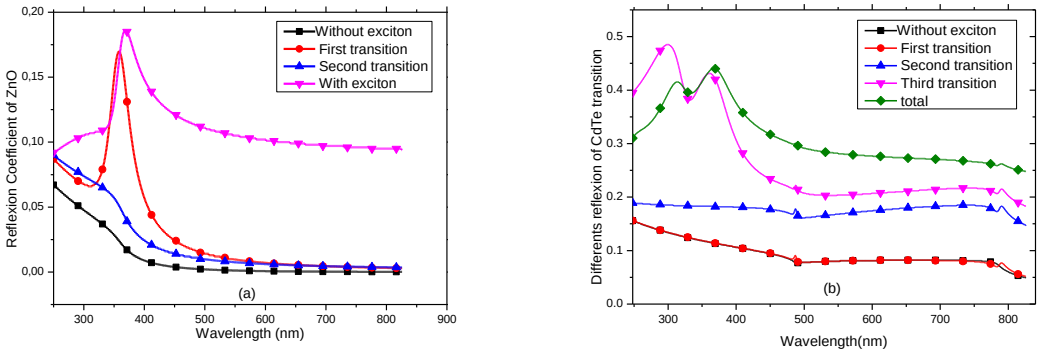

Fig. 3(a-b). ZnO and CdTe variation of the reflection coefficient for the different transitions of excitons according to the wavelength.

The results show that the reflection coefficient is lower than at the ground state that is to say without excitons for both materials. We also note that for lower wavelengths gap of ZnO reflectivity increases with the contribution of excitonic transitions. We also see the appearance of peaks on the curves with excitons, which shows the effect of excitons on the reflectivity for that because there's no free excitons peaks. The analysis also shows that for CdTe the contribution of the first transition is substantially equal to that of the ground state. We also note that for higher wavelengths 370nm the reflectivity of CdTe increases with excitonic transitions which show the contribution of excitons on the material.

3. 3 Absorption Coefficient

To carry out the study in modeling of electrical and photovoltaic properties of the heterojunction ZnO / CdTe, the absorption coefficient of the materials that heterojunction must be known. Thus our calculations are based on the expression proposed by Adachi zinc oxide and AERakhshani for CdTe.

These expressions are analytical types and gives the absorption coefficient as a function of energy for each contribution of excitonic transitions.

The absorption coefficient is related to the extinction coefficient K by the formula where is the wavelength of the light in vacuum.

Thus we were able to identify in Figures 3a and 3b, the variation of the absorption coefficient of the two materials as a function of the wavelength, without excitons and for different contributions of each transition.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

These curves are obtained by the expression of. Le coefficient d'absorption α est lié au coefficient d'extinction K par la formule

$$\alpha(E) = \frac{4\pi}{\lambda} \cdot \kappa(E) \qquad (15)$$

où λ est la longueur d'onde de la lumière dans le vide.

Ainsi nous avons pu relever sur les figures 3a et 3b, les variations du coefficient d'absorption α des deux matériaux en fonction de la longueur d'onde, sans exciton et pour différentes contributions de chaque transition .Ces courbes sont obtenues par l'expression de α .

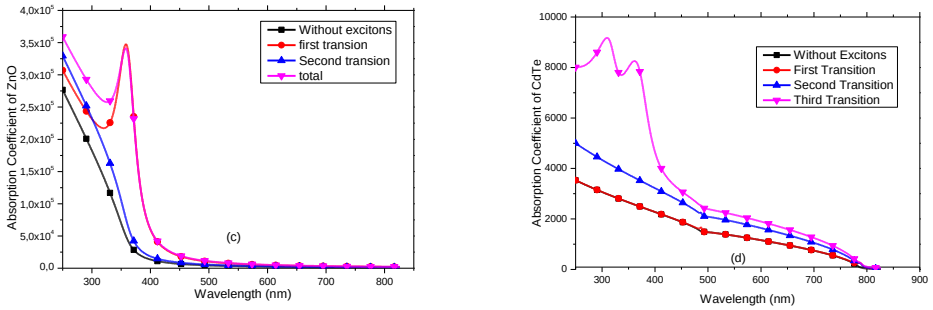

Fig.4. variation CdTe absorption coefficient for the different transitions of excitons according to the wavelength

We note that our curves extend over a wavelength range between 250nm and 900nm. If we consider the range between 250 nm and 330 nm, we observe for both materials as absorbency, gradually decreases for the first and all the excitonic contributions for the ZnO and gradually increases as the third contribution of excitonic transitions for CdTe. In addition to zinc oxide is noted that augment absorption from 330 nm to the wavelength gap where his gradually decreases to 500 nm to cancel. We also note the appearance of peaks for the two materials in the presence of excitons. These peaks could be explained by the presence of impurities on the different transitions of the two materials, which was confirmed by the study of Rakhshani et al for CdTe and Adachi et al for ZnO.

The study that we conducted shows that the absorption coefficient with exciton, CdTe is the active area of our cell has a maximum value of minimum 4.107cm-1 and 107 cm-1 between 400nm and 730nm which part well for good absorption of a cell.

3.4 External Quantum Efficiency

The quantum yield is the ratio of the photocurrent collected at each wavelength relative to the number of photons incident on the cell surface. In the theoretical expression of quantum efficiency made above, we can say that the performance function of the wavelength mainly depends on parameters such as the absorption coefficient of the transmitter of the payload area of spaces and base. However it would be interesting to study the contribution of each area of the cell before the total return. The latter are calculated in both cases with and without excitons. This will allow us to offer quantum efficiency curves with and without the effect of excitons.

Quantum Efficiency of the Emitter ZnO

The quantum efficiency of the transmitter is given by the expression (11) theoretical calculations. Thus in the fig. 4 we have represented the variation depending on the wavelength of the incident photons, free excitons and for different contribution of each excitonic transition.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

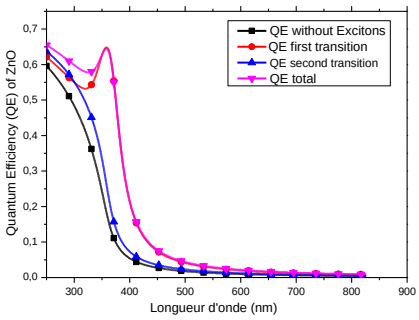

Fig. 5.Variation of the quantum yield of the emitter for various ZnO excitons transitions depending on the wavelength.

Observation shows that these different parts contribute significantly to the spectral response of the ZnO transmitter. However it is noted that the transmitter efficiency decreases gradually over the range 250 to 400nm which corresponds to the high energy photons; while for the rest of the wavelength range of the output is zero, this is due to the fact that in these wavelengths are greater than the wavelength of the gap of ZnO. We also note that performance with excitons is larger than that without excitons and its maximum value is 65%. Thus we can deduce the excitons have a positive effect in the issuer of the heterojunction.

Quantum Efficiency of CdTe Base

The base is the heterojunction CdTe which is the most active part (2) .It in this part of the cell that creates the majority of the minority carriers, responsible for the photovoltaic current in the cell. That is why it is necessary to study its evolution with or without the presence of excitons to better see the influence of excitons. Thus in Figures 5a and 5b we have represented, respectively, the quantum yield of the base without the contribution of excitons corresponding to the fundamental transition and for the contribution of each transition

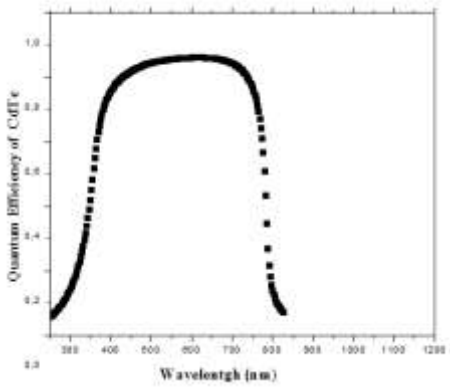

Fig. 6..variation of the quantum efficiency of the CdTe active region without depending on the exciton wavelength

It appears through the figure5a that the quantum efficiency is less than 10% on the lower wavelength range à300nm. However it is noted that this efficiency increases to 80% for 300nm to 378nm to reach its maximum value at 530 nm (94%). It is also seen that the quantum efficiency decreases beyond 700nm to reach a minimum value lower than 10%.

The analysis also shows that the CdTe gives a good yield even if there's no excitons that is to say, the fundamental transition, because the quantum yield present corresponding significant values (80 to 85%) between the wavelengths of the gaps of the ZnO (376 nm), and CdTe (840 nm) .

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

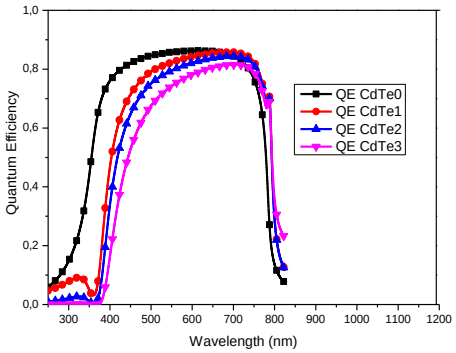

Fig. 7. variation of the quantum efficiency of the CdTe basis for different contributions of each excitons transition depending on the wavelength.

The analysis of this figure shows that for wavelengths below 700nm yield corresponding to the fundamental transition is greater than that calculated taking into account the different contributions of excitonic transitions. This shows that the influence of excitons on this range is negative. We also see that the influence is weak in the visible range, even if it seems they have an effect that increases yield. We also observe that beyond 750nm variations in the performance of the different contributions are combined to 800nm.

Thus we can say that the excitons acts differently on the quantum yield of the base which could be due to the difference between their energy level and their contribution is very important to long wavelengths.

Quantum Efficiency of the Space Charge Region (SCR)

To illustrate the influence of excitons on the performance of the cell, it would be important to study all parties. Thus in the figure6 we have represented the variation of the quantum efficiency of the space charge zone, each excitons and the differenttransitions, depending on the wavelength.

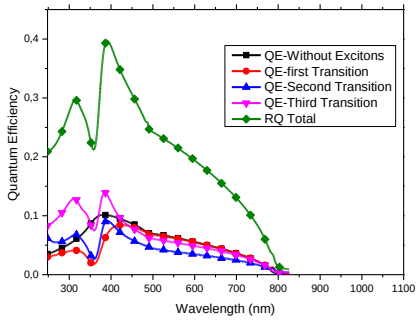

Fig. 8. variation of the quantum efficiency of the cell space charge zone for the different transitions of excitons according to the wavelength.

The analysis brings up two parts with the exception of the variation in performance without the contribution of excitons:

- For A range of wavelength between 250 and 300 nm, it is noted that the external quantum efficiency increases. This increase is due, in that in this wavelength range of the solar spectrum ZnO which is a part of the space charge zone is absorbent.
- For A wavelength range between 300 nm and 800 nm a gradual decrease is observed between 300 and 350nmsuivi a sudden increase from 350 to 378nm and from the latter it decreases to zero.

In the entire range of wavelength we also observe peaks in returns calculated in the presence of excitons. Thus we can say that they are responsible for these peaks.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

As can be even in this figure the presence of excitons increases the quantum yield of 9% to 40% in the visible. This clearly shows the influence of excitons of the quantum efficiency of the solar cell.
These results show that the excitons improve performance in this area.

Total Quantum Efficiency of the Solar Cells ZnO/CdTe

The total quantum yield is the sum of the yields of the three parts of the heterojunction. However we grouped in Figure7 below the curves of variation of the yield as a function of wavelength, with and without excitons.

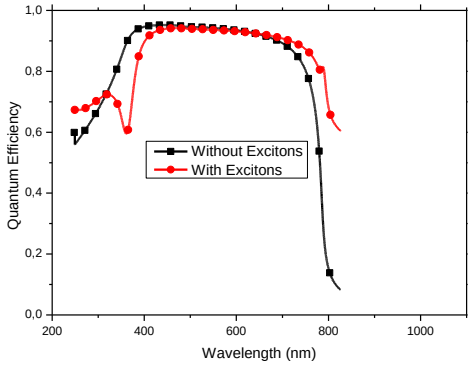

Fig. 9. Variation of the external quantum efficiency of the cell with and without excitons according to the wavelength

The observation shows that the wavelength range between 300 and 400nm efficiency calculated without excitons is higher. Therefore on the remaining wavelength ranges, other than 400 and 600 nm when they are substantially equal; performance with excitons is more important.

In particular we also observe that above the maximum yield the effect of excitons becomes very significant because we find that the response of the cell becomes increasingly important .on also notes the difference between the two yields increases as and as one away from the area of higher wavelength 750nm.

4.CONCLUSION

During this work, we studied some optical parameters namely the refractive index, the reflection coefficient, absorption of the materials forming the heterojunction ZnO / CdTe. For the latter two, we graphically established their variation as a function of wavelength, for different contributions of excitonic transitions of materials. Thereafter we studied the quantum efficiency of each part of the heterojunction taking the same criteria that we took on the optical parameters of materials, before studying the performance of the cell to see the contribution of excitons.

The effect of excitons on the emitter, the base, the space charge region and the cell was studied. The results showed that whereas the excitonic transition can improve the efficiency of the solar cell. Thus, for a good optimization of the cell efficiency ZnO / CdTe apart from other parameters which thicknesses of the emitter and base must be considered excitonic transitions of materials.

REFERENCES

[1] I. Zerbo, M. Zoungrana, A.D. Seré, F. Ouedraogo, R. Sam, B. Zouma et F. Zougmoré, 2011.Influence d'une onde électromagnétique sur une photopile au silicium sous éclairement multi spectral en régime statique,Revue des Energies Renouvelables Vol. 14 N°3,pp 517 – 532.
[2] O.A. Niasse, B. Mbengue, B. BA, A. Ndiaye et I. Youm,Effets des excitons sur le rendement quantique de la cellule solaire CdS/CdTe par le modèle de la fonction diélectrique, 2009.Revue des Energies Renouvelables Vol. 12 N°3 pp 501 – 512.
[3] S. Girish Kumar and K. S. R. Koteswara Physics and chemistry of CdTe/CdS thin film hétérojunction photovoltaic devices: fundamental and critical aspects .Energy Environ. Sci., 2014, 7, 45–102 | 45
[4] T.K. Subramanyam, B. Srinivasulu Naidu, S. Uthanna. Cryst. Res. Technol. 35, 1193(2000). P.F. Gerhardinger and R.J. McCurdy, Thin Films for Photovoltaic and Related Device.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[5] Hisashi YOSHIKAWA and Sadao ADACHI, 1997.Optical constants of ZnO, J.Appl.phys.Vol.36 pp.6237-6243.
[6] S. Adachi, N. Kimura and N. Suzuki, 'Optica Properties of CdTe: Experimental Modelling',Journal of Applied Physics, Vol. 74, N°5, pp. 3435 – 3441, 1993
[7] T.K. Subramanyam, B. Srinivasulu Naidu, S. Uthanna. Cryst. Res. Technol. 35, 1193(2000).
[8] HAFDALLAH Abdelkader, YNINEB Fayssal, DARANFED Warda, ATTAF Nadhir* et AIDA Mohamed Salah*Revue « Nature & Technologie ». n° 06/Janvier 2012. Pages 25 à 27
[9] Mohammed K.Khalaf, Abdul-Hussain K.Iltaif, Naseer M.Hadi, Rasheed H. Jabaar, Ashuak A. Jabor, Moroog A. Abood, Shatha S.Botress, Ahmed A.Ali.Characteristics of Zinc Oxide Film Prepared by Chemical Spray Deposition as a Gas Sensor.Iraqi Journal of Physics, 2011 Vol. 9, No.14, PP. 25 – 30.
[10] M. Gloeckler and J.R. Sites, 'Apparent Quantum Efficiency Effects in CdTe Solar Cells', Journal of Applied Physics, Vol. 95, N°8, pp. 4438 – 4445, 2004.
[11] D. SORO B. MARí et B. AKA Étude de la composition stœchiométrique des couches minces de CdTe élaborées par électrodéposition pour des applications photovoltaïques Afrique SCIENCE 06(2) (2010) 1 – 8
[12] V. Srikant and D. R. Clarke .On the optical band gap of zinc oxide. J. Appl. Phys., Vol. 83, No. 10, 15 May 1998
[13] E.M. Bachari, G. Baud, S. Ben Amor, M. Jacquet, Thin Solid Films, 165, 348(1999).
[14] Adly A. Hanna, Sahar M.A. Mousa, Marwa A. Sherief, Gehan M.Elkomy, Journal of American Science **6**, 2010, 10.
[15] Brajesh Kumar,Kumari Smita,Luis Cumbal and Alexis Debut.Green Approach for fabrication and application of zinc oxide nanoparticul.Chimistry and Application Handawi Publishing corporation.volume 2014

CITE AN ARTICLE

DIAGNE, M., DIALLO, W., MBENGUE, N., Dia, F., Niasse, O. A., & Ba, B. (2018). EXTERNAL QUANTUM EFFICIENCY OF A SOLAR CELL ZnO / CdTe: EFFECTS OF EXCITONS BY THE METHOD OF CALCULATING THE DIELECTRIC FUNCTION. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY,7*(9), 300-308.