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Research Article

Effect of Buffer Layers Cu_2O and KF Between Molybdenum and CIGS in the Electrical Parameters of CIGS Thin Film Solar Cells

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Abstract

In this paper we have study the AZO/ZnO/CdS/CIGS/Mo/SLG heterojunction. We have study precisely the effect of Cu_2O insertion between CIGS layer and Mo left contact. For this, we fix the Cu_2O thickness at 100 nm. After this, we replace Cu_2O by KF material with the same thickness. The use of those materials is motivated by their photovoltaic properties, their metallic content but also their non toxicity compared to PbS. By using SCAPS_1D software we have stimulated the effect of those buffer layers materials in electrical parameters as efficiency of solar cell, file factor, open-circuit voltage and short-circuit current density. Then, the efficiencies are around 24, 64% and 24.80% respectively for Cu_2O and KF. We note that the efficiency increases at 21% to 24%. This introduction allows to establish a record efficiency for this kind of structure We note the same behavior for the file factor at 78.91% to 79.74% and 80.10% respectively for Cu_2O and KF. These high electrical performances have obtained by using an Aluminum left contact and Molybdenum back contact. The functional temperature variation allows to obtain 26.20% and 25.99% efficiency for KF and Cu_2O at 278.16 K. This functional temperature variation shows that by using phase change materials, we can attempt a record efficiency of 26%. This result is an improvement of 2% compared to ambient temperature. At the same time, this study shows that we have a big photovoltaic potential in the winter and in temperate area, near the pole area. This allows to find more recoiling technologies in order to improve more the efficiency of photovoltaic solar cells.

Keywords

KF, Cu_2O, Buffer Layers, CIGS, Functional Temperature, SCAPS_1D

1. Introduction

In the recent decades, many researches in photovoltaic solar cells are about thin film solar cells as CIGS. With the news depositions technics and the results of simulations researches, a record efficiency is obtained 23% [11] and 24% [3, 18]. For more optimization of electricals parameters, we are putting Cu_2O layer between Mo and CIGS absorber layer that we replace by KF. We use 100 nm as Cu_2O and KF thickness. A Molybdenum work function of 5.62 ev [7] is using as left contact and 4.28 ev [11] Aluminum work function as right contact. At the first part we simulate the two CIGS thin CIGS solar cells with Cu_2O and KF and in the second part we varying functional solar cell temperature to study the effects in

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electricals parameters of CIGS solar cell.

2. Numerical Modal

Even so the majority of CIGS thin film solar cells are experimental; the simulations have an important role in researches. They allow to optimize quickly the solar cells performances with no expensive spend by using the power of computer calculation. The SCAPS_1D simulations software is developpe by Gent Belgium researchers at physics department (electronic and semi-conductors). It uses the semi-conductor's basis equations:

$$\vec{\nabla}.(\epsilon\vec{\nabla}\varphi) = -q(p - n + N_D - N_{A-}) \quad (1)$$

$$\vec{\nabla}.\vec{J_n} = q(R - G) + q\frac{\partial n}{\partial t} \quad (2)$$

$$\vec{\nabla}.\vec{J_p} = q(R - G) + q\frac{\partial p}{\partial t} \quad (3)$$

ϵ: dialectical permittivity
φ: electrical potential
q: electrical charge
p: holes density
n: electrons density
R: holes and electrons pair recombination rate
G: holes and electrons generation rate

By placing Cu_2O between CIGS and molybdenum; we obten the following heterojunction structure AZO/n-ZnO/n-CdS/p-CIGS/Cu_2O/Mo indicate in this figure:

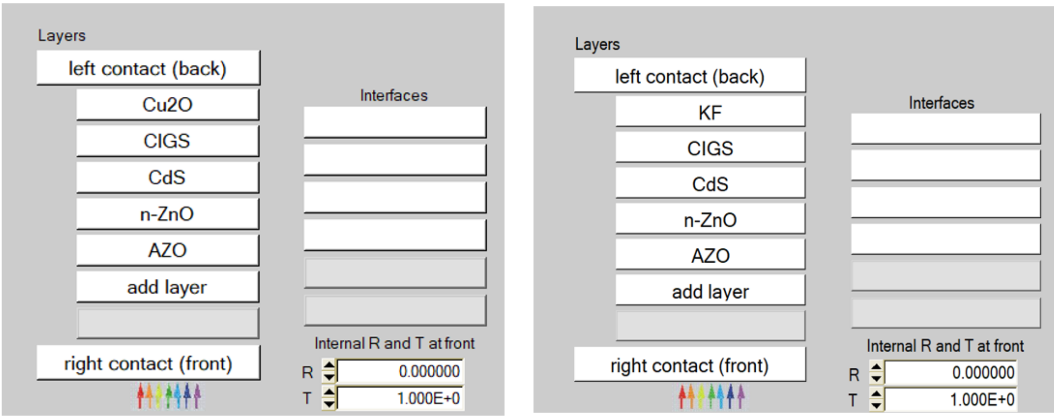

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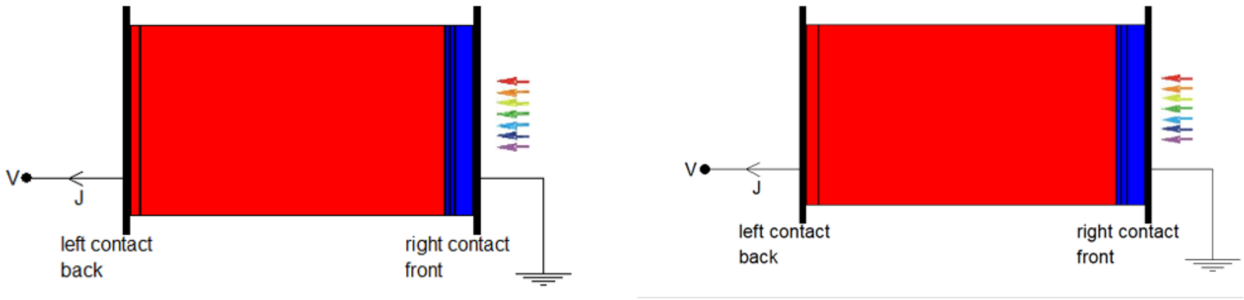
Figure 1. *Representation in SCAPS_1D of CIGS solar with Cu_2O in a et KF in b buffer layers.*



a **b**

Figure 2. *Structure of n-ZnO/n-CdS/p-CIGS/Cu_2O/Mo in a et n-ZnO/n-CdS/p-CIGS/KF/Mo in b solar cell heterojunction.*

The parameters values that we use for our simulations are summarizing in this the following tab:

Table 1. *Opto-electronics parameters [1-22].*

Materials	Cu_2O	KF	p-CIGS	n-CdS	n-ZnO	AZO
Thickness (µm)	0,100	0,100	2,5	0,040	0,080	150
Band gap energy	2,17	1,5	1,15	2,4	3,4	3,4
Electronic affinity	3,200	4,170	4,530	4,400	4,600	4,600
Relative dielectric permittivity	7,110	6,050	13,600	10	9,000	9,000
Effective state of density CB ($1/cm^3$)	$2{,}02.10^{17}$	$2{,}2.10^{18}$	$2{,}20.10^{18}$	$2{,}20.10^{18}$	$2{,}00.10^{18}$	$2{,}00.10^{18}$
Effective state of density CV ($1/cm^3$)	$1{,}8.10^{19}$	$1{,}8.10^{19}$	$1{,}8.10^{19}$	$1{,}8.10^{19}$	$1{,}8.10^{19}$	$1{,}8.10^{19}$
Electrons thermal velocity (cm/s)	10^7	10^7	10^7	10^7	10^7	10^7
Holes thermal velocity (cm/s)	10^7	10^7	10^7	10^7	10^7	10^7
Electrons mobility (cm^2/Vs)	2.10^2	1.10^2	1.10^2	1.10^2	1.10^2	1.10^2
Holes mobility cm^2/Vs)	8.10^1	$2.5.10^1$	$2.5.10^1$	$2.5.10^1$	5.10^1	5.10^1
Donnor density (1/cm3)		---------	1.10^{17}	$1.1O^{17}$	$1{,}00.10^{18}$	$1{,}00.10^{21}$
Acceptor density (1/cm3)	$1{,}00.10^{18}$	$5{,}5.10^{16}$	1.10^{17}	--------	-----------	---------
Total default density	$1{,}00.10^{14}$	$1{,}0.10^{14}$	$1{,}00.10^{14}$	$1{,}00.10^{16}$	$1{,}00.10^{15}$	$1{,}00.10^{15}$

3. Results et Discussions

The both electrical parameters which are more important are efficiency and file factor. The efficiency is the rapport between the electrical power supply by the solar cell and the power supply by the light used. The file factor is the rapport between the product open-circuit voltage and the short-circuit current density and the light power used. The others electrical parameters that we use to assess the solar cell performances are open-circuit voltage, short-circuit current density. The current density-voltage characteristics of photovoltaic solar cell under illumination is describe by the diode equation:

$$J_V = J_0\left(e^{\frac{q(V-R_SJ)}{AKT}} - 1\right) + \frac{V-R_SJ}{R_P} - J_{ph} \tag{4}$$

with J the current density, V the voltage, J_0 the saturation current density; q: the electron charge, R_s series resistance, R_p shunt resistance, A diode ideal factor. K Boltzmann constant, T the temperature and J_{ph} the photo-current.

This equation is used for the littles minorities charges carriers' diffusion length. This dependance in J in the right term of the characteristic equation which cause the non-linear equation can be remove if series resistance is missing and in infinite shunt resistance. Then, this equation becomes:

$$J_V = J_0\left(e^{\frac{qV}{AKT}} - 1\right) - J_{ph} \tag{5}$$

By this equation, we obtain the short-circuit current density if V = 0 and the open-circuit voltage when J = 0.

$$J_{cc} = -J_{ph} \tag{6}$$

$$V_{co} = \frac{AKT}{q}\ln\left(\frac{J_{ph}}{J_0} + 1\right) \tag{7}$$

As define preciously, we calculate the efficiency and file factor as this:

$$? = \frac{J_{max}.V_{max}}{P_s} = \frac{J_{cc}.V_{co}.FF}{P_s} \tag{8}$$

$$FF = \frac{J_{cc}.V_{co}}{P_s} \tag{9}$$

The quantum efficiency is the rapport between the number of holes-electrons and the photons number arrivate in the solar cell surface. It is given by:

$$QE(\lambda) = \frac{J(\lambda)}{q.\varphi(\lambda)} \tag{10}$$

3.1. Effect of Buffer Layers in Electrical Parameters

The Figure 2 show the J-V characteristics of CIGS solar cells with Cu_2O or KF buffer layers and without buffer layer.

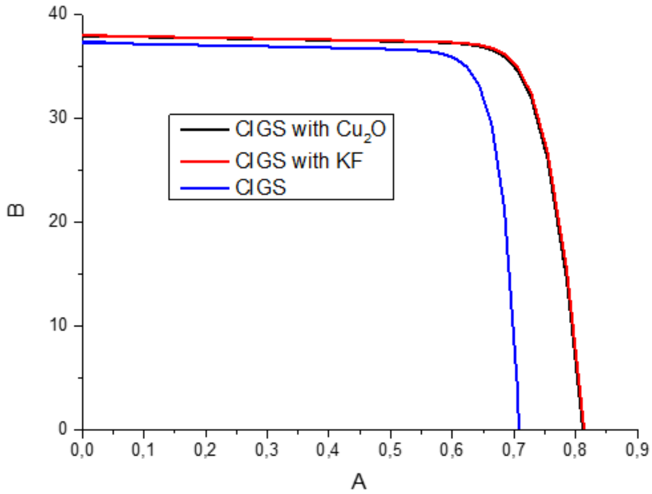


Figure 3. J-Characteristics of CIGS solar cell with Cu_2O or KF buffer layer and without buffer layer.

Then, the electrical parameters without and with Cu_2O or KF buffer layers are summarizing in the following tab:

Table 2. Electrical parameters obtain after simulation.

Parameters	Voc (V)	Jsc (mA/cm^2)	FF (%)	η (%)	Buffer layer thickness (nm)
CIGS without buffer layer	0.7433	37.312140	78.91	21.89	
CIGS with Cu_2O	0.8240	37.969319	79.74	24.64	100
CIGS with KF	0.8264	38.007845	80.10	24.80	100

By integrating Cu_2O or KF buffer layer between CIGS absorber and Molybdenum contact; we note that the efficiency increase at 21.89% to 24.64% and 24.80%. We note the same variation for the file factor at 78.91% to 79.74% and 80.10% respectively for CIGS solar cells with Cu_2O and KF. We note the same behavior to the open-circuit voltage and the short-circuit current density. This efficiency increasement can be explain by the fact that the Cu_2O or KF buffers layer facilitate the charges collections by reducing the Schotley resistance and recombination's centers. The little increasment of the file factor can be explain by interface lattices reduction but also adherence improvement. Barman and al. [3] study using PbS as buffer layer with CIGS band gap of 1.3 ev allow them to obtain 24.22% as efficiency.

3.2. Effect of Buffer Layers in Quantum Efficiency of CIGS Solar Cells

The quantum efficiencies graphs in wave length dependance show that 90% of photons are absorbed in the range of 310 to 1100 nm. Despite this big efficiency, we note a low decrease belong 800 nm. This one show that Cu_2O or KF presence improve the efficiency of absorption of the cell between 800 to 1100 nm.

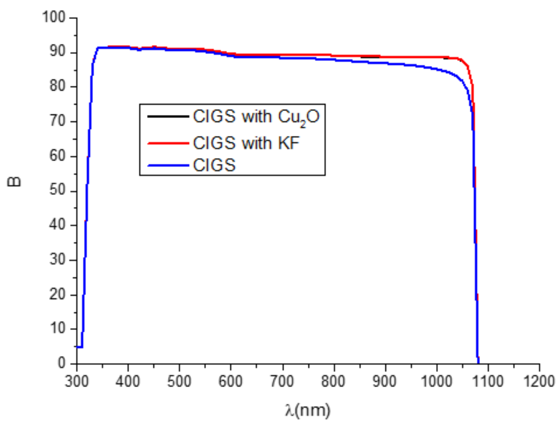


Figure 4. Quantum efficiency of CIGS solar cell without and with Cu_2O or KF buffer layers in wave length dependence.

3.3. Effect of Functional Temperature in Electrical Parameters with Cu_2O as Buffer Layer

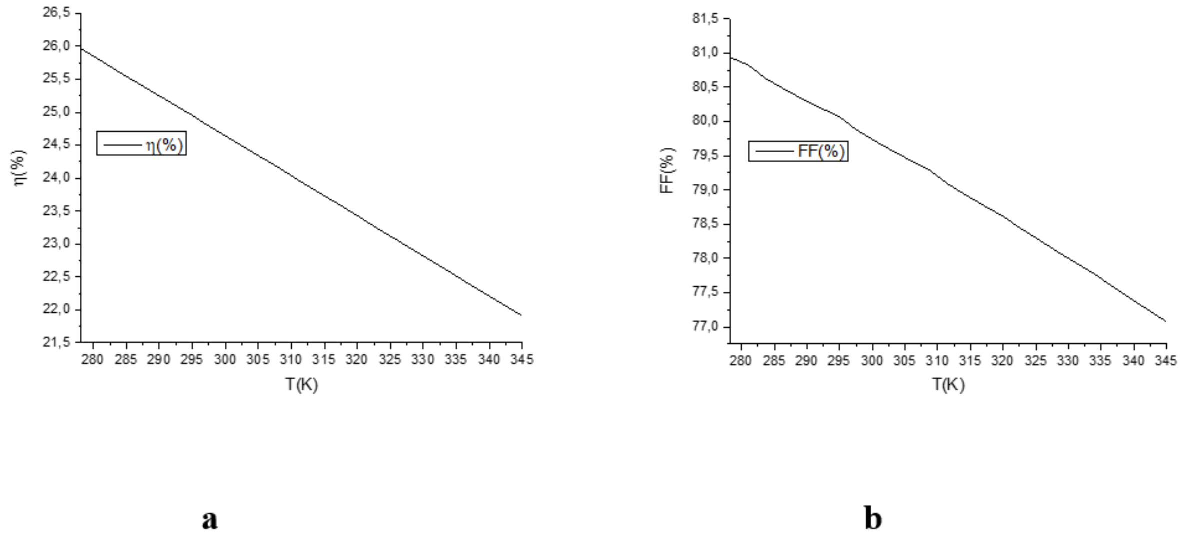


Figure 5. Effect of functional solar cell temperature in the solar cell efficiency in a and file factor in b of CIGS thin film solar cell with Cu_2O as buffer layer between Mo and CIGS absorber buffer layer.

By varying the functional solar cell temperature between 278.16 to 345 K, we note that the efficiency decreases at 25.99% to 22%. We note the same behavior for the file factor at 80.89% to 77%. This can be explained by the fact that the increasement of temperature provocate the cell dilatation. This dilatation provocate increasement of recombination centers and the cell degradation.

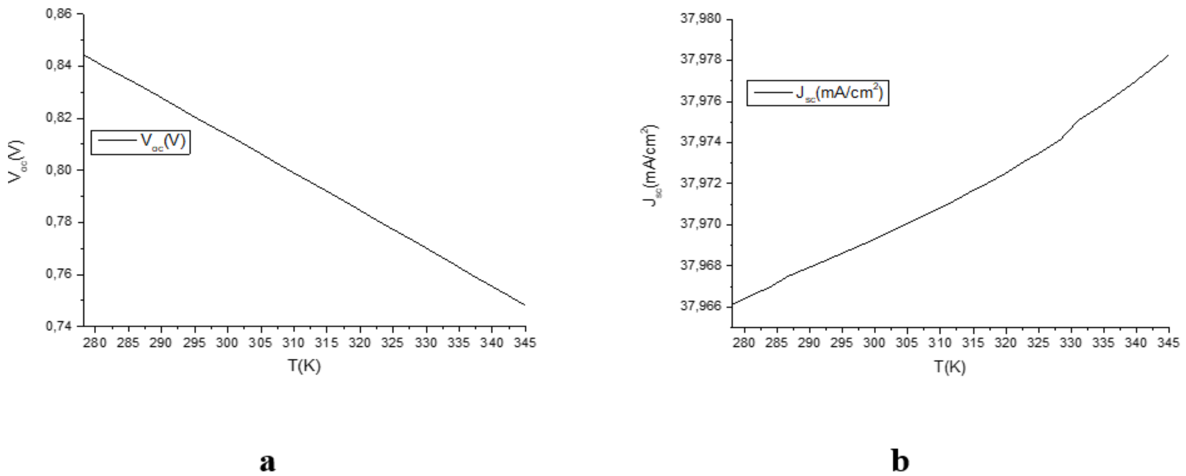


Figure 6. Effect of functional solar cell temperature in open-circuit voltage in a and short-circuit current density in b with Cu_2O as buffer layer.

By varying the functional solar cell temperature between 278,16 to 345K, we note that the open-circuit voltage decreases at 0.84 to 0.75V. The short-circuit current density increase at 37.966 mA/cm2 to 37.980 mA/cm2. The decreasement of open-circuit can be explain by the charges bocage caused by cell dilatation. The increasement of short-circuit current density can be explain by diffusion phenomenon caused by thermic agitation caused by temperature increasement.

3.4. Functional Temperature of Solar Cells Effect in Electricals Parameters

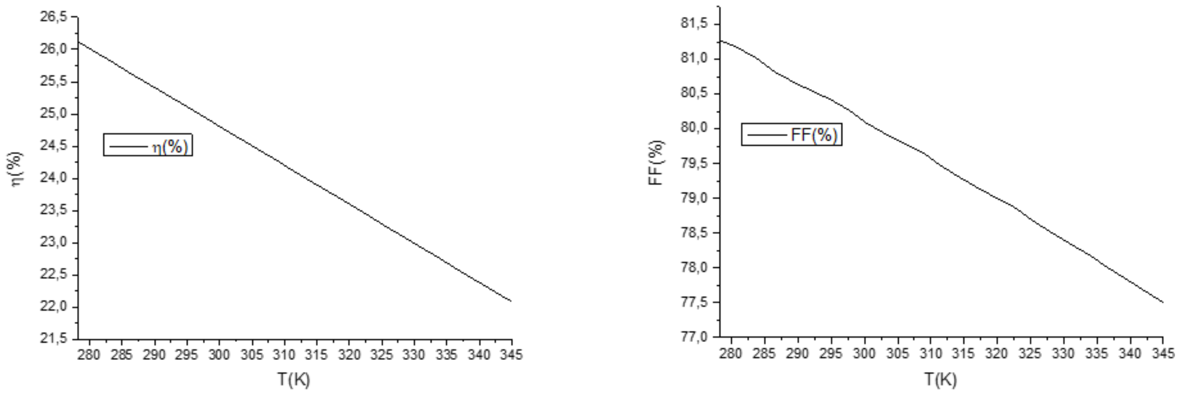


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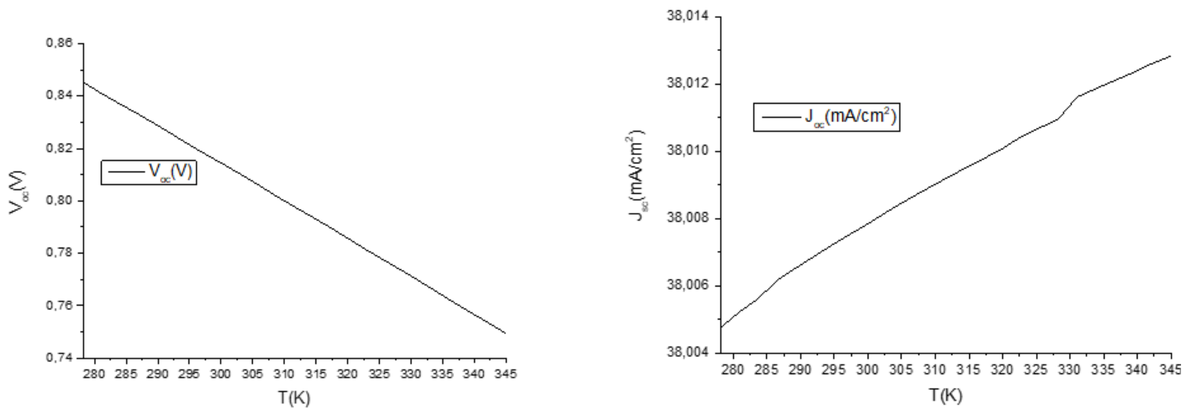
Figure 7. *Effect of functional solar cell temperature in the solar cell efficiency in a and file factor in b of CIGS thin film solar cell with KF as buffer layer between Mo and CIGS absorber buffer layer.*

By varying the functional solar cell temperature between 278.16 to 345 K, we note that the efficiency decreases at 26.20% to 22.10%. We note the same behavior for the file factor at 81.25% to 77.50%. This can be explained by the fact that the increasement of temperature provocate the cell dilatation. This dilatation provocate increasement of recombination centers and the cell degradation.



a b

Figure 8. *Effect of functional solar cell temperature in open-circuit voltage in a and short-circuit current density in b with KF as buffer layer.*

By varying the functional solar cell temperature between 278,16 to 345K, we note that the open-circuit voltage decreases at 0.84 to 0.75V. The short-circuit current density increase at 38.004 mA/cm2 to 38.014 mA/cm2. The decreasement of open-circuit can be explain by the charges bocage caused by cell dilatation. The increasement of short-circuit current density can be explain by diffusion phenomenon caused by thermic agitation caused by temperature increasement.

4. Conclusion

We can return that the use of Cu_2O or KF as buffers layers between CIGS and Molybdenum have an positive effect in CIGS thin films solar cell performance. It allows to improve the efficiency between 21,89% to 24.64% for Cu_2O and 24.80% for KF. We note the same behavior for file factor. It passes at 78.91% to 79.74 and 80.10% respectively for Cu_2O and KF. The functional temperature variation allows to obtain a record efficiency of 26.20% for CIGS solar cell with KF and 25.99% for CIGS solar cell with Cu_2O.

Abbreviations

KF Potassium Fluoride

Cu_2O	Oxyde of Cuivre
CIGS	Cuivre Indium Gallium di-Seleleniure
SLG	Soda Lime Glass
SCAPS_1D	Solar Cell Capacitance Simulator
PbS	Sulfide of Plomb
ZnO	Zinc Oxide
AZO	Oxide of Zinc and Aluminum

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Adama Zongo1, Daouda Oubda1, Soumaïla Ouédraogo1, Marcel Bawindsom Kébré1, Alain Diasso1, Issiaka Sankara1, Boureima Traore1, François Zougmoré1, Zacharie Koalga1 and Frédéric Ouattara. Optimization of Mo/Cu (In, Ga) Se2/CdS/ZnO Hetero-Junction Solar Cell Performance by Numerical Simulation with SCAPS-1D, Journal of Materials Science and Engineering, 2021, https://doi.org/10.17265/2161-6221/2021.10-12.004, 156-167.

[2] Alain Kassine EHEMBA1, Moustapha DIENG1, Demba DIALLO1, Ibrahima WADE, Gregoire SISSOKO. Minority carriers' diffusion length determination in thin films CuInSe2 solar cells electro deposited on flexible substrate in Kapton, IJISET - International Journal of Innovative Science, Engineering & Technology, 2015, 2, ISSN 2348 - 7968.

[3] B. Barman, P. K. Kalita. Influence of Back surface field Layer on enhancing the efficiency of CIGS solar cell. Solar Energy, 14 January 2021, https://doi.org/10.1016/j.solener.2021.01.032, 216, 329-337.

[4] Caixia Zhang,* Zhiyuan Yang, Hui Deng, Qiong Yan, Weihao Xie, Quanzhen Sun, Xiaowei Sheng, and Shuying Cheng. Numerical Study to Improve the Back Interface Contact of CZTSSe Solar Cells Using Oxygen-Doped Mo (Se1−x, Ox) 2, The Journal of Physical Chemistry C, 2021, https://doi.org/10.1021/acs.jpcc.1c04129, 125, 16746−16752.

[5] Djimba Niane1, Mouhamadou M. Soce1, Jean Jude Domingo1, Ousmane Diagne1 & Moustapha Dieng, Influence of the Thickness of a Layer of Potassium Fluoride Incorporated in the CIGS/CdS Interface on the Macroscopic Electrical Parameters of the Solar Cell, Canadian Center of Science and Education, 2019, https://doi.org/10.5539/apr.v11n1p1,. 11, ISSN 1916-9639.

[6] Djimba Niane, Ousmane Diagne, Alain K. Ehemba, Mouhamadou M. Soce, Moustapha Dieng, Generation and Recombination of a CIGSe Solar Cell under the Influence of the Thickness of a Potassium Fluoride (KF) Layer, American Journal of Materials Science and Engineering, 2018, https://doi.org/10.12691/ajmse-6-2-1, 6, 26-30.

[7] Dario Cozza, Carmen M. Ruiz, David Duche, Jean Jacques Simon, and Ludovic Escoubas, Modeling the Back Contact of Cu2ZnSnSe4 Solar Cells, IEEE JOURNAL OF PHOTOVOLTAICS, 2014, 2156-3381.

[8] Enrico Avancini, Romain Carron, Thomas P. Weiss, Christian Andres, Melanie Bu□rki, Claudia Schreiner, Renato Figi, Yaroslav E. Romanyuk, Stephan Buecheler, and Ayodhya N. Tiwari. Effects of Rubidium Fluoride and Potassium Fluoride Postdeposition Treatments on Cu (In, Ga) Se2 Thin Films and Solar Cell Performance, Chemistry of Materials, 2017, https://dx.doi.org/10.1021/acs.chemmater.7b03412, 29, 9695-970.

[9] Gizem Birant, Jorge Mafalda, Romain Scaffidi, Jessica de Wild, Dilara Gokcen Buldu, Thierry Kohl, Guy Brammertz, Marc Meuris, Jef Poortmans and Bart Vermang. Rear surface passivation of ultra-thin CIGS solar cells using atomic layer deposited HfOx, EPJ Photovoltaics 11, 2020, https://doi.org/10.1051/epjpv/2020007, 10.

[10] J. K. GREPSTAD, P. O. G4RTLAND and B. J. SLAGSVOLD, ANISOTROPIC WORK FUNCTION OF CLEAN AND SMOOTH LOW-INDEX FACES OF ALUMINIUM, North-Holland Publishing Company, 16 February 1976, https://doi.org/10.1016/0039-6028(76)90187-4, 57, 348-362.

[11] M. Burgelman et al. Advanced electrical stimulation of thin film solar cells, Thin Solid Films, 2013, http://dx.doi.org/10.1016/j.tsf.2012.10.032, 535, 296-301.

[12] Mouhamadou M. Soce, Alain K. Ehemba*, Ousmane Diagne, Djimba Niane, Moustapha Dieng. Influence of the Recombination Assisted by Tunneling Effect and Influence of the Surface Treatment on the Electric Performances of Cu-Rich Solar Cells Based on Cu (In, Ga) Se2, American Journal of Energy Research, 2017, https://doi.org/10.12691/ajer-5-2-4, 5, 51-56.

[13] Motoshi NAKAMURA, Koji Yamaguchi, Yoshinori, Kimoto and al. Cd-Free Cu (Ga, In)(Se, S) 2 Thin-Film solar cell, with record efficiency of of 23.35%. IEEE JOURNAL OF PHOTOVOLTAICS, 2019, https://doi.org/10.1109/JPHOTOV.2019.2937218, 2156-3381.

[14] Nima Khoshsirat and Nurul Amziah Md Yunus. Numerical Simulation of CIGS Thin Film Solar Cells Using SCAPS-1D, 2013 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology, 2013, 978-1-4673-4691-7/13/$31.00 ©2013 IEEE.

[15] Ousmane DIAGNE*, Alain Kassine EHEMBA*, Demba DIALLO*, Ibrahima WADE*, Mouhamadou Mamour SOCE*, Moustapha DIENG. Effect of [Ga]/[In+Ga] Atomic Ratio on Electric Parameters of Cu (In, Ga) Se2 Thin Film Solar Cells, International Journal of Scientific Engineering and Technology, 2016, https://doi.org/10.17950/ijset/v5s5/507, 5, 252-255, ISSN: 2277-1581.

[16] Ousmane Diagne*, Djimba Niane, Alain Kassine Ehemba, Mouhamadou Mamour Soce, Moustapha Dieng, Impact of the Geometry Profil of the Bandgap of the CIGS Absorber Layer on the Electrical Performance of the Thin-film Photocell, American Journal of Energy Research, 2018, 6, https://doi.org/10.12691/ajer-6-1-4, 6, 23-29.

[17] Salhi, B. The Photovoltaic Cell Based on CIGS: Principles and Technologies, Materials, 2022. https://doi.org/10.3390/ma15051908, 15.

[18] Shiqing Chenga,†, Boyan Lib,†, Wei Liua, *, Kaizhi Zhanga, Yunxiang Zhanga, Zhichao Hea, Lie Linb, Shulong Sunc, Yun Suna, Analyzing the causes of limited performance improvement in cigs devices after potassium fluoride post-deposition treatment using SCAPS, Optik - International Journal for Light and Electron Optics 219, 2020, https://doi.org/10.1016/j.ijleo.2020.164757, 164757.

[19] SOCE Mouhamadou Mamour*, DIENG Moustapha **, EHEMBA Alain Kassine**, DIALLO Demba**, WADE Ibrahima. Influence of the doping of the absorber and the charged defects on the electrical performance of CIGS solar cells, International Journal of Scientific and Research Publications, 2015, 5, ISSN 2250-3153.

[20] Tariq AlZoubi 1 and Mohamed Moustafa. Numerical optimization of absorber and CdS buffer layers in CIGS solar cells using SCAPS, International Journal of Smart Grid and Clean Energy, 3 May 2019, https://doi.org/10.12720/sgce.8.3.291-298, 8, 291-298.

[21] Younghwann Kim, Minki Kim, Woonjoon Kim. Effect of the Fukushima nuclear desaster on global public acceptance of nuclear energy. Energy Policy, 2013, http://dx.doi.org/10.1016/j.enpol.2013.06.107, 61, 822-828.

[22] W. Thongkham a, b, A. Pankiew c, K. Yoodee a, b, S. Chatraphorn, Enhancing efficiency of Cu (In, Ga) Se2 solar cells on flexible stainless steel foils using NaF co-evaporation, Solar Energy, 18 March 2013, https://dx.doi.org/10.1016/j.solener.2013.03.010, 92, 189-195.