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Research Article

Comparative Study of Perovskite Thin Film Solar Cells: Effect of Perovskite Absorber Layer Thickness Variations in Electrical Parameters

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Abstract

In this work, we have study the FTO/ZnO/$CH_3NH_3SnI_3$/Cu_2O/Au/SLG; FTO/ZnO/$CsPbI_3$/Cu_2O/Au/SLG and FTO/$CsSnI_3$/Cu_2O/Au/SLG heterojunction. For that, we have studied the impact of the thickness in the electrical parameters of $CsPbI_3$ in the first time; $CH_3NH_3SnI_3$ in the second time and $CsSnI_3$ in the third time. After thickness variation, we have optimized and done a comparative study of those three perovskites solar cells in energetics, environmental and economic aspects. The absorbers thin films are varying between 500 nm and 2500 nm by using SCAPS_1D software to study the impact of this variation in the solar cell efficiency, the fill factor, the open circuit voltage and the short circuit current density. This work allows us to obtain 26.08% of efficiency and 81.07% for fill factor with 900 nm optimum thickness of $CH_3NH_3SnI_3$ thin film perovskite solar cell. With the $CsPbI_3$ we have obtain 23.21% for the efficiency and 83.26% for fill factor at 1657 nm optimum thickness. And with $CsSnI_3$, an efficiency of 24.76% and 81.04% are obtain at 1131 nm optimum thickness. The energetic comparison shows that the $CH_3NH_3SnI_3$ have the best efficiency but $CsPbI_3$ have the best quality. The efficiency of $CsSnI_3$ is better than the $CsPbI_3$. The $CH_3NH_3SnI_3$ is a volatile substance. If we can find a way to stabilized the tin in CsSnI3 perovskite solar cell, it represents a best choice than CsPbI3 which is toxic and $CH_3NH_3SnI_3$ which is volatile. Our comparative study allows us to show that we can substitute tin by Antimoine, Bismuth or Germanium and varying other parameters to resolve the stability, reduce toxicity aspect and optimize more the electrical parameters. This study shows also that we can use less material and optimize more the electrical performances of the perovskite solar cells.

Keywords

Thin Film Solar Cell, Perovskite, Absorber Layer, Thickness, Electrical Parameters

1. Introduction

In the last decades, many research in photovoltaics solar cells are oriented in thin films solar cells of which perovskites solar cells. With the results of the new depositions and simulations, we have attempted a high efficiency of 25% [1] and then 26% [2]. To improve more the solar cell quality and efficiency, we have study in the first time the impact of $CH_3NH_3SnI_3$ absorber layer thickness in the efficiency, the fill factor. In the second time we have study the $CsPbI_3$ thickness

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variation and in the third time the $CsSnI_3$ thickness variation in the efficiency, the fill factor, the open circuit voltage and the short circuit current density. We have finished by doing an environmental, economic and energetic comparison. The perovskite absorber buffer layers are varying between 500 nm to 2500 nm. In this work, we have used the 5.2 eV as gold work function [7] for back contact and 4.28 eV [8] as Aluminum front contact.

2. Numerical Model

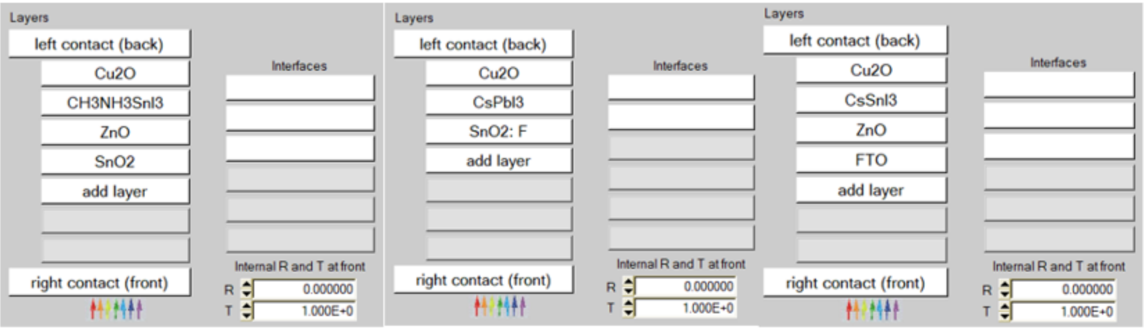
Even so the majority of thin film solar cells as perovskites are experimental; the simulations have an important role in researches. They allow to optimize quickly the solar cells performances with no expensive spend by using the power of computer calculation. The SCAPS_1D simulations software is developed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

$$\vec{\nabla}.\left(\epsilon\vec{\nabla}\varphi\right) = -q(p - n + N_{D^+} - N_{A^-}) \tag{1}$$

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

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

ε: dielectrically permittivity
V: electrical potential
q: electrical charge
p: holes density
n: electrons density
R: holes and electrons pair recombination rate
G: holes and electrons generation rate
This figure shows the heterojunctions use in the simulation:



Layers
left contact (back)
Cu2O
CH3NH3SnI3
ZnO
SnO2
add layer
right contact (front)
Interfaces
Internal R and T at front
R 0.000000
T 1.000E+0

Layers
left contact (back)
Cu2O
CsPbI3
SnO2: F
add layer
right contact (front)
Interfaces
Internal R and T at front
R 0.000000
T 1.000E+0

Layers
left contact (back)
Cu2O
CsSnI3
ZnO
FTO
add layer
right contact (front)
Interfaces
Internal R and T at front
R 0.000000
T 1.000E+0

a b c

Figure 1. *Representation in SCAPS_1D of perovskites solar cells, with $CH_3NH_3SnI_3$ absorber in a, $CsPbI_3$ absorber in b and $CsSnI_3$ absorber in c.*

Figure 2. *Structure of perovskites solar cells heterojunction.*

The parameter's values than we use for our simulations are summarizing in the following tab:

Table 1. *Opto-electronics parameters of perovskites solar cells layers [1-22].*

Parameters	**SnO_2: F**	**ZnO**	**$CsSnI_3$**	**$CsPbI_3$**	**$CH_3NH_3SnI_3$**	**Cu_2O**
Epaisseur(nm)	300	50	Variable	Variable	Variable	200
Eg(ev)	3.5	3.2	1.27	1.73	1.3	2.17
χ(ev)	4	4.26	3.95	3.95	4.17	3.2
ε_r	9	9	6.00	6.00	8.2	7.11
Nc(cm^{-3})	$2.20.10^{18}$	$2.00.10^{18}$	$1.58\ 10^{19}$	$1.10.10^{18}$	$1.00.10^{18}$	$2.02.10^{17}$
Nv(cm^{-3})	$1.80.10^{19}$	$1.80.\ 10^{19}$	$1.47\ 10^{18}$	$8.00.10^{19}$	$1.00.10^{18}$	$1.10.10^{19}$
µc(cm2/Vs)	20	200	4.47	16	1.60	200
µh(cm2/Vs	10	5	4.47	16	1.60	80
N_D(cm^{-3})	$2.00\ 10^{19}$	$1.50\ 10^{17}$	-	-	-	-
N_A(cm^{-3})	-	-	$1.00.10^{17}$	$1.00.10^{19}$	$1.50\ 10^{16}$	$2.00\ 10^{19}$
N_t($1/cm^3$)	10^{14}	10^{14}	10^{14}	10^{14}	10^{14}	10^{14}

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 described by the diode equation:

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

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 minorities carriers diffusion length. This dependance in J in the right termed of the characteristic equation which cause the nonlinear equation can be removed if series resistance is missing and in infinite shunt resistance. Then, this equation becomes:

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

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

$$J_{cc} = -J_{ph} \qquad (6)$$

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

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

$$\eta = \frac{J_{max}.V_{max}}{P_s} = \frac{J_{cc}.V_{co}.FF}{P_s} \qquad (8)$$

$$FF = \frac{J_{cc}.V_{co}}{P_s} \qquad (9)$$

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

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

3.1. Effect of $CH_3NH_3SnI_3$ Absorber Layer Thickness in Electrical Parameters

In this part we study the impact of absorber layer in energetics performances. The Figure 3 show the influence of the $CH_3NH_3SnI_3$ absorber thickness in the efficiency and the fill factor and the Figure 4 show the impact in the short circuit current density and the open circuit voltage.

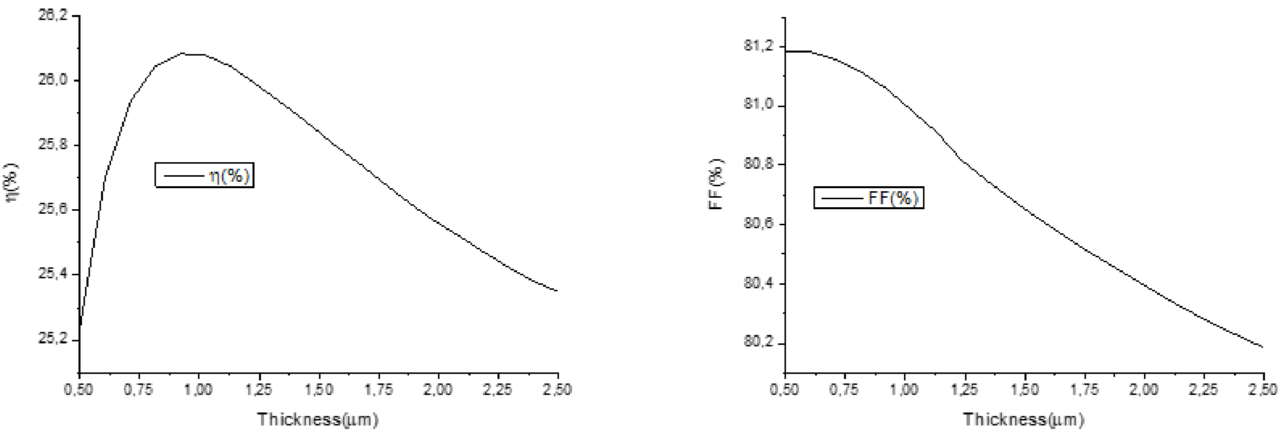


Figure 3*. Fill factor and efficiency variation as a function of thickness.*

By varying the absorber layer thickness between 500 nm and 2500 nm, we note an increasement of the efficiency and an decrease of the fill factor. The increasement of the efficiency attempted a pic of 26.08% and corresponding fill factor at 900 nm thickness. This increasement of efficiency can be explained by absorber layer thickness increasement which allow the number of absorbers photons and then holes-electrons generation. This thickness of 900 nm is an optimum value which allow more adherence, less defaults and an optimal holes-electrons generation. Beyond this value, we note more recombination before collection. This value is confirmate by Abdelhadji SLAMI and al [1].

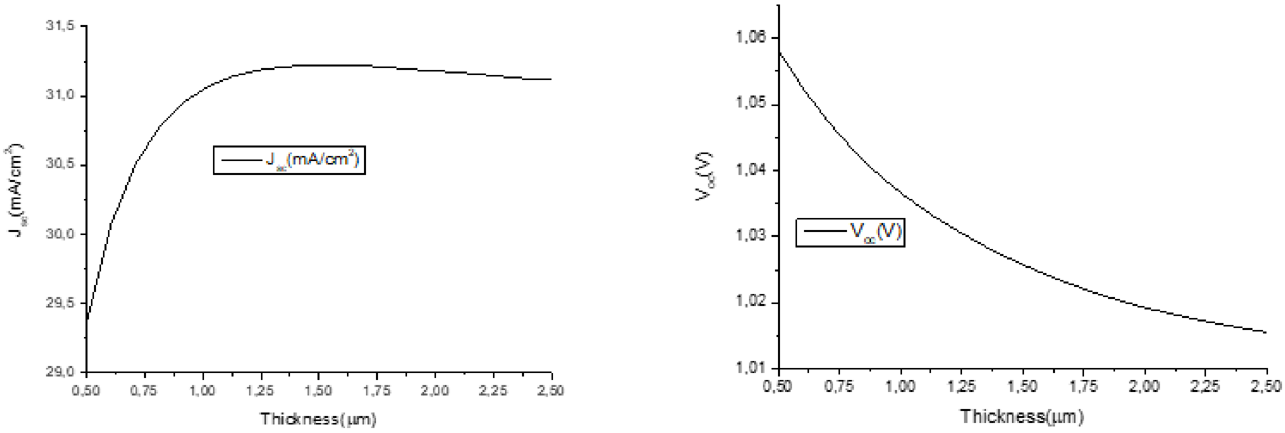


Figure 4*. Open circuit voltage and short circuit current density variation as a function of thickness.*

The absorber thickness variation between 500 nm and 2500 nm leads an exponential increasement of the short circuit current density at 29.5 to 31.2 mA/cm^2 and an exponential decrease of the open circuit voltage at 1.065 to 1,02 V. This increasement of current density can be explain by the fact that the thickness increasement allow more holes-electrons generation because we have more absorbed photons. But the absorber thickness improvement leads more carriers recombination.

3.2. Effect of $CsPbI_3$ Absorber Layer Thickness in Electrical Parameters

In this part we study the impact of absorber layer in energetics performances. The Figure 5 show the influence of the $CsPbI_3$ absorber thickness in the efficiency and the fill factor and the Figure 6 show the impact in the short circuit current density and the open circuit voltage.

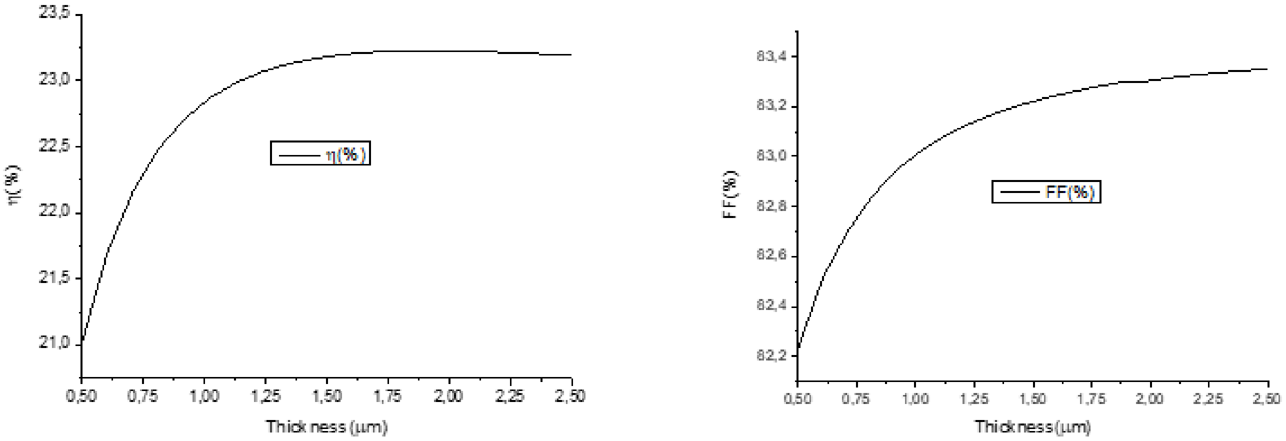


Figure 5. *Fill Factor and efficiency variation as a function of thickness.*

By varying the absorber layer thickness between 500 nm and 2500 nm, we note an increasement of the efficiency and an increasement of the fill factor. The increasement of the efficiency attempted a pic of 23.21% and corresponding fill factor of 83,26% at 1657 nm thickness. This increasement of efficiency can be explain by absorber layer thickness increasement which allow the number of absorbers photons and then holes-electrons generation. This thickness of 1657 nm is an optimum value which allow more adherence, less defaults and an optimal holes-electrons generation. Beyond this value, we note more recombination before collection.

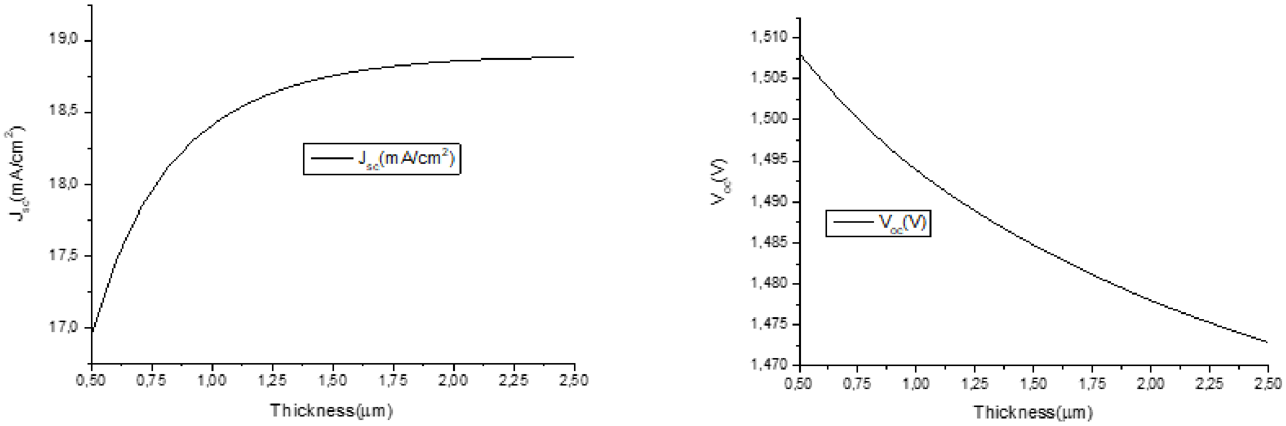


Figure 6. *Open circuit voltage and short circuit current density variation as a function of thickness.*

The absorber thickness variation between 500 nm and 2500 nm leads an exponential increasement of the short circuit current density at 16.9 to 18.7 mA/cm^2 and an exponential decrease of the open circuit voltage at 1.510 to 1,475 V. This increasement of current density can be explain by the fact that the thickness increasement allow more holes-electrons generation because we have more absorbed photons. But the absorber thickness improvement leads more carriers recombinaitions.

3.3. Effect of $CsSnI_3$ Absorber Layer Thickness in Electricals Parameters of $CsSnI_3$ Perovskite Solar Cell

In this part we study the impact of absorber layer in energetics performances. The Figure 7 show the influence of the $CsSnI_3$ absorber thickness in the efficiency and the fill factor and the Figure 8 show the impact in the short circuit current density and the open circuit voltage.

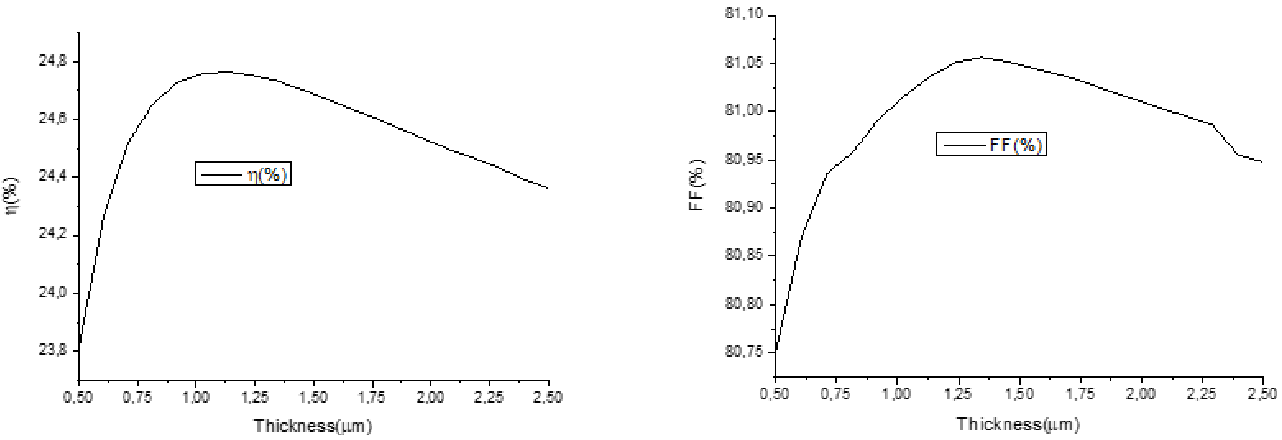


Figure 7. *Fill Factor and efficiency variation as a function of thickness.*

By varying the absorber layer thickness between 500 nm and 2500 nm, we notice an increasement of the efficiency and an increasement of the fill factor. The increasement of the efficiency attempted a pic of 24.76% and corresponding fill factor at 1131 nm thickness. This increasement of efficiency can be explain by absorber layer thickness increasement which allow the number of absorbers photons and then holes-electrons generation. This thickness of 1131 nm is an optimum value which allow more adherence, less defaults and an optimal holes-electrons generation. Beyond this value, we note more recombination before collection. This optimum value are in the same order than the results of Mukadarr Sk and al [9]. They are found 1000 nm as optimum value of CsSnI3 by combining KSnI3 and $CsSnI_3$ as double absorber layer; MZO and ITO as ETL layer and NiO_x as HTM layer.

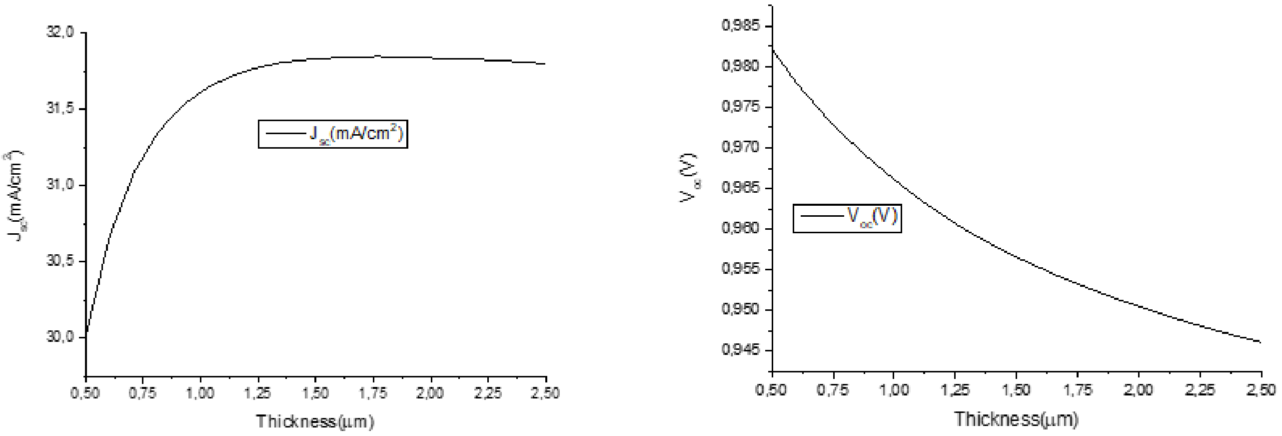


Figure 8. *Open circuit voltage and short circuit current density variation as a function of thickness.*

The absorber thickness variation between 500 nm and 2500 nm leads an exponential increasement of the short circuit current density at 30 to 31.8 mA/cm^2 and an exponential decrease of the open circuit voltage at 0.985 to 0.945 V. This increasement of current density can be explained by the fact that the thickness increasement allows more holes-electrons generation because we have more absorbed photons. But the absorber thickness improvement leads more carriers recombination.

3.4. Electrical Comparison $CH_3NH_3SnI_3$; $CsPbI_3$ and $CsSnI_3$ Perovskite Solar Cells

For more energetics comparison, we have represented the J-V characteristics at optimum thickness value.

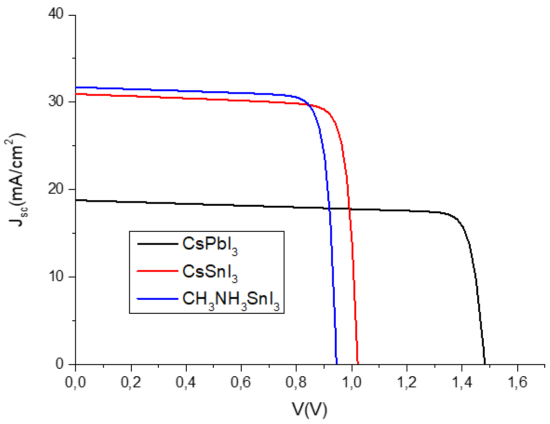


***Figure 9**. J-V characteristics of $CH_3NH_3SnI_3$; $CsPbI_3$ and $CsSnI_3$ perovskite solar cell.*

The J-V characteristeristics show that the CH3NH3SnI3 and the CsSnI3 tin film solar cell have a big short-circuit current density respectively 30.929321 mA/cm2, 31.718822 mA/cm2 compared to CsPbI3 with short-circuit current density around 18.7990 V. But we note that the $CsPbSnI_3$ open-circuit voltage are higher than $CH_3NH_3SnI_3$ open-circuit voltage and $CsSnI_3$ respectively at 1.4824 V; 1,0396 V and 0.9631 V. This one can be explained by the little $CH_3NH_3SnI_3$ optimum thickness around 900nm compared to the $CsSnI_3$ which is 1,131 nm and CsPbI3 around 1,657 nm. In other words, more thickness is high, less we have a generate carriers and more carriers are blocked.

***Table 2**. Electrical parameters of perovskite solar cells.*

Electrical parameters	η(%)	FF(%)	V_{oc}(V)	J_{sc}(mA/cm^2)	Thickness (µm)
CH3NH3SnI3	26.08	81.07	1.0396	30.929321	0.900
$CsPbI_3$	23.21	83.26	1.4824	18.799003	1.657
$CsSnI_3$	24.76	81.04	0.9631	31.718822	1.131

For more solar cells energetics performances comparison, we have represented the quantum energetics graph:

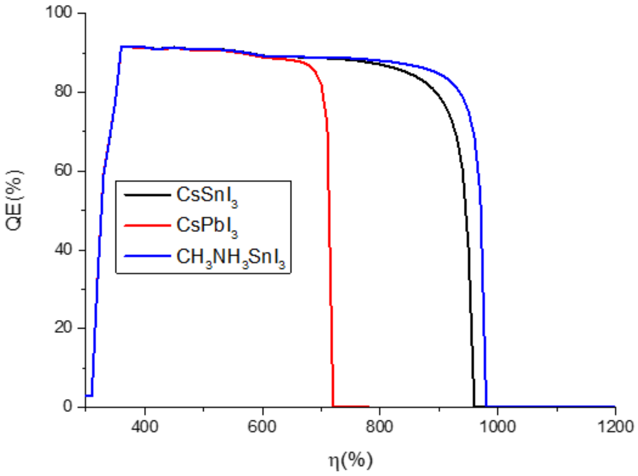


***Figure 10**. Quantum efficiency of $CH_3NH_3SnI_3$; $CsPbI_3$ and $CsSnI_3$ perovskite solar cell.*

This graph shows that with CsPbI3 93% of photons are absorbed between 350 nm to 700 nm. For $CsSnI_3$, 93% of photons are absorbed in the range of 350 to 970 nm. For $CH_3NH_3SnI_3$ perovskite tin film solar cell, 93% of photons are absorbed in the range of 350 to 990 This one can be explained by the fact that the optimum thickness value of $CsPbI_3$ are bigger than the CsSnI3 optimum thickness value which is bigger than the $CH_3NH_3SnI_3$ optimum value and the band gap are respectively 1.3 ev, 1.27 ev and 1.73 ev.

3.5. Economic and Environmental Comparison of $CH_3NH_3SnI_3$; $CsPbI_3$ and $CsSnI_3$ Perovskite Solar Cell

The thickness variation of absorber layer shows that with $CH_3NH_3SnI_3$, we obtain an optimum value of 900 nm. With $CsPbI_3$ perovskite value, we obtain an optimum value of 1,657 nm. With $CsSnI_3$, we have 1,131 nm as optimum value. This value shows that with $CsPbI_3$ we use more material than $CsSnI_3$ and more than $CH_3NH_3SnI_3$. For economic considerations, the $CH_3NH_3SnI_3$ and $CsSnI_3$ are the best choice but $CH_3NH_3SnI_3$ is volatile. That's way the $CsSnI_3$ represent the best choice because it is a perovskite inorganic solar cell and without lead.

4. Conclusion

To summarize, we can retain that the thickness variation allows to improve the quality and the efficiency of perovskite solar cells. This work allows us to attempt a high efficiency and fill factor respectively at the score of 26,08% and 81.07% for $CH3NH3SnI_3$. For $CsSnI_3$, we obtain an efficiency of 24.76%

and 81.04% for fill factor. It implies that the CsPbI3 perovskite solar cell has the best quality. But the energetic and environmental comparisons allow us to choose CsSnI3 as best perovskite solar cell. This requires a stabilization of the tin in CsSnI3. In the future, we can replace Tin by Germanium or Bismuth.

Abbreviations

CH3NH3SnI3	Methylammonium Tin Iodide
CsPbI3	Cesium Lead Triiodide
CsSnI3	Cesium Tin Iodide

Author Contributions

Aliou Diedhiou: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

Gerome Sambou: Formal Analysis, Funding acquisition, Methodology

Alain K Ehemba: Conceptualization, Funding acquisition, Methodology, Resources, Validation

Ibrahima Wade: Conceptualization, Funding acquisition, Methodology, Resources, Validation

Moustapha Dieng: Methodology, Supervision, Resources, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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