

# Optimization of the Properties of the Back Surface Field of a Cu(In,Ga)Se<sub>2</sub> Thin Film Solar Cell

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**Abstract** The use of the back surface field BSF within the thin film cells isn't elaborated in a current state of research. In this article we try to adapt it to the Cu(In,Ga)Se<sub>2</sub> thin film solar cells. The theoretical study is based on the resolution in one dimension of the equations which govern the behaviour of a photovoltaic cell. The spectrum used is the AM 1.5. The experimental method takes into account all physical phenomena which happen in the solar cell. The comparison of the macroscopic electric parameters of the two cells with BSF and without BSF enabled us to obtain a conversion efficiency of 21.95% for the cell with BSF whereas it is equal to 20.78% for the cell without BSF. The use of the BSF presents a broad maximum absorption band which extends from 0.4μm to 1μm through the study of the quantum efficiency of the cell. The spectral response of the layer reaches a value of 0.7A.W<sup>-1</sup> for an incidental wavelength of approximately 1000nm which corresponds to the gap of the absorber of the solar cell of 1.2eV. The improvement of the thickness of the p+ CIGS up-doped, indicates an optimal thickness of 0.5μm. We find for this thickness an open circuit voltage of 0.71V, a short-circuit current density of 37.409mA.cm<sup>-2</sup> and a conversion efficiency of 21.95%. The optimization of the doping concentration acceptors of the p+ CIGS, shows that the optimal concentration corresponds to 10E18cm<sup>-3</sup>. We find with this acceptors density an open circuit voltage of 0.69V, a short circuit current density of 37.40mA.cm<sup>-2</sup> and a conversion efficiency of 21.74%.

**Keywords:** thin film, Back Surface Field, Cu(In,Ga)Se<sub>2</sub>, electric parameters

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## 1. Introduction

The research on thin film solar cells is under perpetual development. The new conversion efficiencies reached in laboratory are about 22%. The German Center of R&D on solar energy and hydrogen ZSW has just revealed a CIGS solar cell with a conversion efficiency of 22,6%, confirmed by the Fraunhofer Institute for solar systems ISE. [1]

Indeed the performances of the solar cells depend mainly on their structure and their method of elaboration. Several parameters of cells are improved with an aim of raising the efficiency of the cell. Our research team devotes itself to the determination of the electric parameters of the thin film solar cells. [2,3]

In this article we carry out a theoretical study which is based on the improvement of the electric parameters of a Cu(In,Ga)Se<sub>2</sub> thin film solar cell with Back Surface Field (BSF). The BSF is created by a up-doped CIGS layer back surface of the cell. This field is created by a gradient of concentration which increases the diffusion of the minority carriers. However in the bibliography the BSF is more studied for the solar cells containing Silicon. [4,5]

The search for use of this BSF on the thin film cells is not very thorough in current state of research. However our theoretical study tries to adapt it to the CIGS thin film

solar cells. We propose to start by a comparative study of the macroscopic electric parameters of this type of cell with BSF and without BSF to evaluate the interest to use this BSF. Afterwards we will improve the parameters of this BSF by studying the impact of the thickness of the up-doped layer and of its doping concentration acceptors on the tension open-circuit voltage Voc, the short-circuit current density Jsc, the fill factor FF, the conversion efficiency Eff, the internal and the external quantum efficiency IQE and EQE respectively.

## 2. Experimental Method

The theoretical study is based on the resolution in one dimension of the equations which govern the behaviour of a photovoltaic cell. These equations start with the resolution of the Poisson's equation (1) and the transport equations of the electrons and the holes (2) and (3).

$$p(x,t) - n(x,t) + N_D - N_A = \frac{\varepsilon_0 \varepsilon_r}{q} \frac{\partial^2 \phi(x,t)}{\partial x^2} - \sum_{defects} \rho_i(x,t) \quad (1)$$

$$G_n(x,t) - R_n(x,t) = \frac{\partial}{\partial t} n(x,t) - \frac{1}{q} \frac{\partial j_n(x,t)}{\partial x} \quad (2)$$

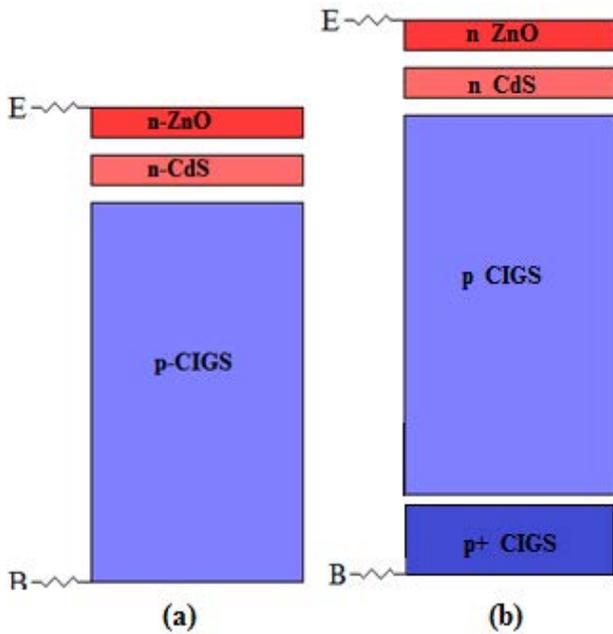
$$G_p(x,t) - R_p(x,t) = \frac{\partial}{\partial t} p(x,t) + \frac{1}{q} \frac{\partial j_p(x,t)}{\partial x} \quad (3)$$

n and p are the densities of electron and holes respectively,  $\phi$  the electric potential,  $\epsilon_0$  vacuum permittivity and  $\epsilon_r$  the relative permittivity. Let us note also  $N_A$  and  $N_D$  the concentrations of the acceptors and donors respectively. The expression of the electrons current density  $J_n$  and the holes current density  $J_p$  are given by the equations (4) and (5).

$$J_n(x,t) = \mu_n n(x,t) \frac{\partial \phi(x,t)}{\partial x} - \frac{\mu_n kT}{q} \frac{\partial n(x,t)}{\partial x} \quad (4)$$

$$J_p(x,t) = -\mu_p p(x,t) \frac{\partial \phi(x,t)}{\partial x} - \frac{\mu_p kT}{q} \frac{\partial n(x,t)}{\partial x} \quad (5)$$

The structures of the cells used for this study are presented by the Figure 1.



**Figure 1.** Configurations of the Cu(In,Ga)Se<sub>2</sub> solar cells (a) without BSF (b) with BSF

The spectral absorption coefficient of each layer is defined by considering an absorption Beer-Lambert. The flow of generation of the carriers is given by using standard illumination AM 1.5. Losses by recombination band-to-band, the Auger recombinations, and Schokley-Red-Hall recombinations are taken into account. For that the energy distribution of the densities of defects and the coefficients of capture of electron and holes are defined. For the interfaces we consider a transport of current by drift-diffusion. This method of transport is based on a layer of interface whose levels of Fermi are related to the other parameters by the following expressions:

$$q\phi(x) - E_{Fn}(x) = q\chi(x) + kT \ln \frac{n(x)}{N_c(x)} \quad (6)$$

$$q\phi(x) - E_{Fp}(x) - E_g(x) = q\chi(x) - kT \ln \frac{p(x)}{N_v(x)} \quad (7)$$

The metal-semiconductor contacts are taken into account by Mott-Schottky contacts. The parameters of the layers which make the cell and enabled us to make the comparison of the two types of cell are given by Table 1.

The generation of the carriers is calculated compared to a spectral flow of incidental photons which is given to the beginning of our work.

**Table 1. electric parameters of the layers of the solar cell**

Layers	N ZnO	N CdS	P CIGS	P <sup>+</sup> CIGS
Thickness (μm)	0.05	0.05	3	1
Bandgap (eV)	3.30	2.4	1.1	1.1
Electron affinity (eV)	4.45	4.2	4.5	4.5
Dielectric permittivity (relative)	9.00	0	13.6	13.6
effective conduction band density of states (cm <sup>-3</sup> )	2.È18	2.È18	2.È18	2.È18
Effective valence band density of states (cm <sup>-3</sup> )	1.8E19	1.8E19	1.8E18	18E18
Thermal electron velocity (cm.s <sup>-1</sup> )	1E7	1E7	1E7	1E7
Thermal Hole velocity (cm.s <sup>-1</sup> )	1E7	1E7	1E7	1E7
Electron mobility (cm <sup>2</sup> Vs)	100	100	100	100
Hole mobility (cm <sup>2</sup> Vs)	25	25	25	25
Doping concentration donators (cm <sup>-3</sup> )	1E18	1E16	10	10
Doping concentration acceptors (cm <sup>-3</sup> )	1	1	1E16	1E18

In Table 2 we present the parameters of interface semiconductor-metal or semiconductor-semiconductor.

**Table 2. Interface properties taken into account**

Contact	Typical interfaces	Characteristics
Front contact	Face ideal N contact	ZnO absorption loss Front surfaces textured Metal work function 3.9eV ZnO external Reflection
ZnO (N) - CdS (N)	Mott-Schottky-contact	Surface recombination velocities Sn=10E7 cm.s <sup>-1</sup> Sp=10E7 cm.s <sup>-1</sup>
CdS (N) - CIGS (P)	Drift transistor-Diffusion Interfaces	No additional interface defect
CIGS (P) - CIGS (P <sup>+</sup> )	No interfaces	No additional interface defect
Back contact	Back ideal P contact	Metal work function 5.6eV No back absorption No back reflection

For better determining the effect of the BSF, in our calculations we neglect series resistances ( $R_s=0$ ) and shunt resistances  $R_{sh}$  are infinite and a null parallel capacitance.

The electric parameters, which enable us to evaluate the interest of the use of an absorber with BSF and the optimization of this last, are the open-circuit voltage Voc, the short circuit current density Jsc, the factor of quality

FF, the conversion efficiency Eff and quantum efficiency EQ.  $V_{oc}$ ,  $J_{sc}$  and the Maximum Power Point are given starting from the J-V characteristic. Starting from these points values we calculate the form factor and conversion efficiency by using the following relations:

$$FF = \frac{I_{MPP} \times V_{MPP}}{I_{SC} \times V_{OC}} \quad (8)$$

$$E_{ff} = \frac{FF \times I_{SC} \times V_{OC}}{P_{Incident}} \quad (9)$$

The expression which makes it possible to evaluate quantum efficiency is given by the equation (10).

$$QE(\lambda) = \frac{\text{number of electrons in the external circuit}}{\text{number of photons}} \quad (10)$$

However we study as well external quantum efficiency EQE as internal quantum efficiency IQE. To calculate EQE we consider all the incidental photons whereas to calculate IQE we consider the photons absorbed by the cell

### 3. Results and Discussion

#### 3.1. Presentation of the general parameters of the cell with the BSF

The spectrum used is that of AM 1.5. The Figure 2 presents the spectrum of luminous flux used. We note the positions of the gaps of CdS buffer layer and CIGS absorber layer. The coverage of the spectrum shows the importance of the number of incidental photons. The spectrum is more significant in the fields of UV, visible and close IR.

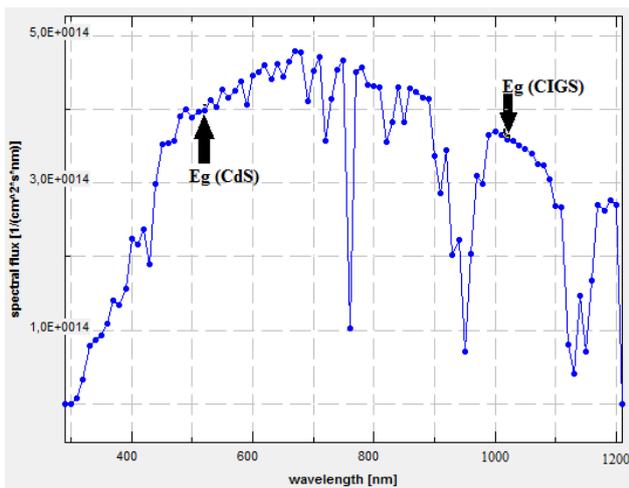


Figure 2. Spectrum Incident

All the studied parameters depend in an intrinsic way to the absorption coefficients on the materials which constitute the cell. The Figure 3 presents the variation of the absorption coefficients of the CdS buffer layer and that of CIGS absorber. The CIGS being a material with direct bandgap with a high absorption coefficient ( $\alpha > 3E5cm^{-1}$ ) and absorbs more the wavelengths lower than  $0.43\mu m$ .

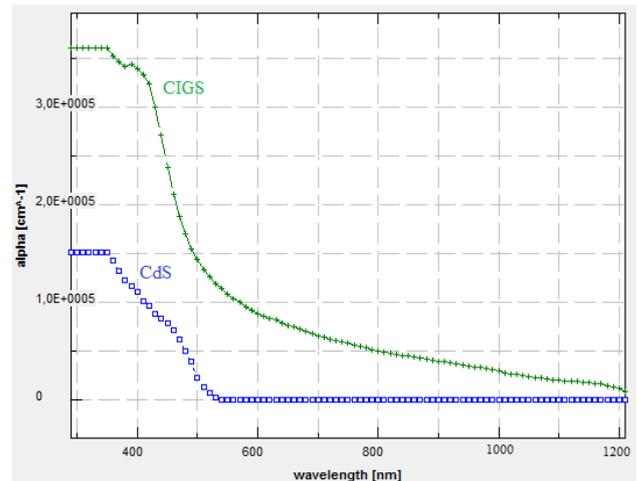


Figure 3. Absorption coefficients of CdS and CIGS layers

#### 3.2. Comparative study of the characteristics of the CIGS solar cells with BSF and without BSF

##### 3.2.1. Comparison of the macroscopic electric parameters of the cells with the BSF and without the BSF

The characteristics voltage of the studied cells show similarities from 0 to 0.5V. This attests the proximity of the short-circuit current densities of the two cells. In the proximity of the Maximum Power Point we note a shift which translates the performance brought by the BSF. This last makes it possible to have a power of cell of 0.221mW for the cell with BSF and 0.208mW for the cell without BSF. The shift of the two characteristics to the intersection with the x-axis gives a difference in open circuit voltages. As indicated by Table 3 the open circuit voltage  $V_{oc}$  of the solar cell with BSF reached 708.6mV while that of the cell without BSF is only of 663.3mV.

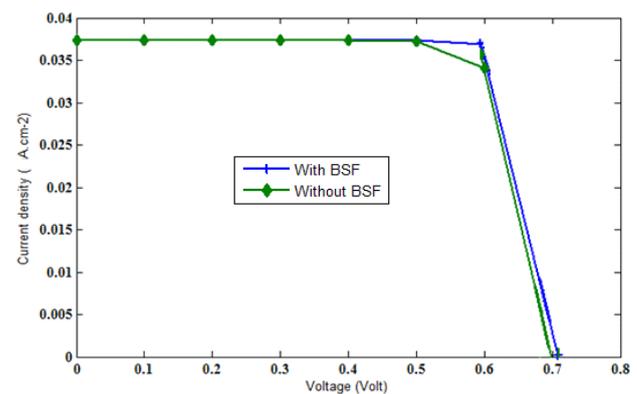


Figure 4. Characteristics J-V of CIGS solar cells with BSF and without BSF

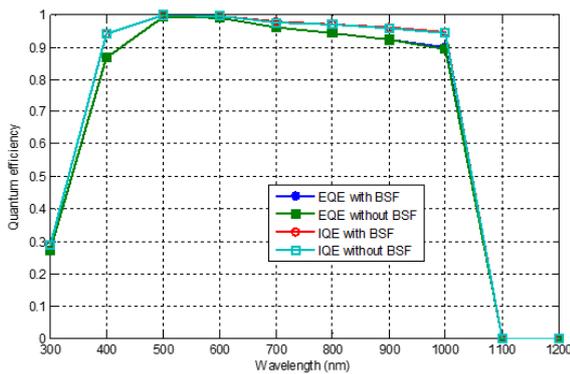
The significant form factors of about 83.82% for the cell without BSF and 82.79% for the cell with BSF show the quality of the studied cells. This performance results in conversion efficiency of 20.78% for the cell without BSF and 21.95% for the cell with BSF. The improvement of 1.17% comes from the beneficial contribution of the BSF.

**Table 3. Numerical values of the macroscopic electric parameters**

CIGS Solar cell	Open circuit voltage Voc (mV)	Shorts circuit current density Jsc (mA.cm <sup>-2</sup> )	Fill Factor FF (%)	Conversion efficiency EFF (%)
Without BSF	663.3	37.38	83.82	20.78
With BSF	708.6	37.41	82.79	21.95

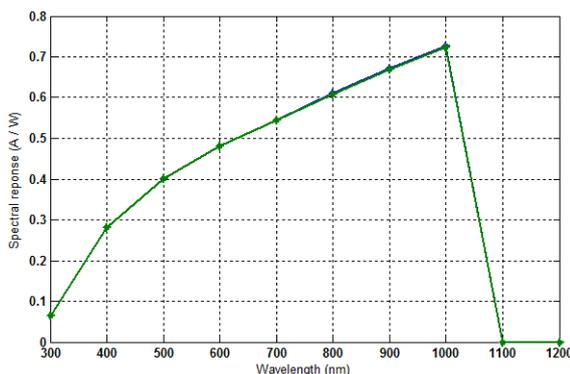
**3.2.2. Comparison of the quantum efficiency of the solar cells with BSF and without BSF**

The profiles of the quantum efficiency of the cells presented by the Figure 5 show a superposition on all the range of wavelength going from 300nm to 1200nm. External Quantum Efficiencies EQE which represent the relationship between the number of incidental photons and the number of collected carriers reached a maximum value of 99.2% with approximately 500nm. The Internal Quantum Efficiencies which represents the number of photons absorbed on the number of collected carriers reached a maximum value of 100% with approximately 500nm. This value limiting of 100% is reached because the photons absorbed by the collectors are not taken into account. Only those which take part in the photogeneration were considered.



**Figure 5.** Quantum efficiencies of solar cells with BSF and without BSF

The width of the zone of maximum absorption extends from 0.4μm to 1μm. This improves the electric parameters of the cell because the photogenerated carriers are more significant. The spectral response of the CIGS cell indicates a maximum value of 0.7A/W for a wavelength of approximately 1000nm. This value corresponds to an energy equal to the bandgap of the CIGS thin film. The use or not of the BSF does not give a remarkable difference on the spectral answer.



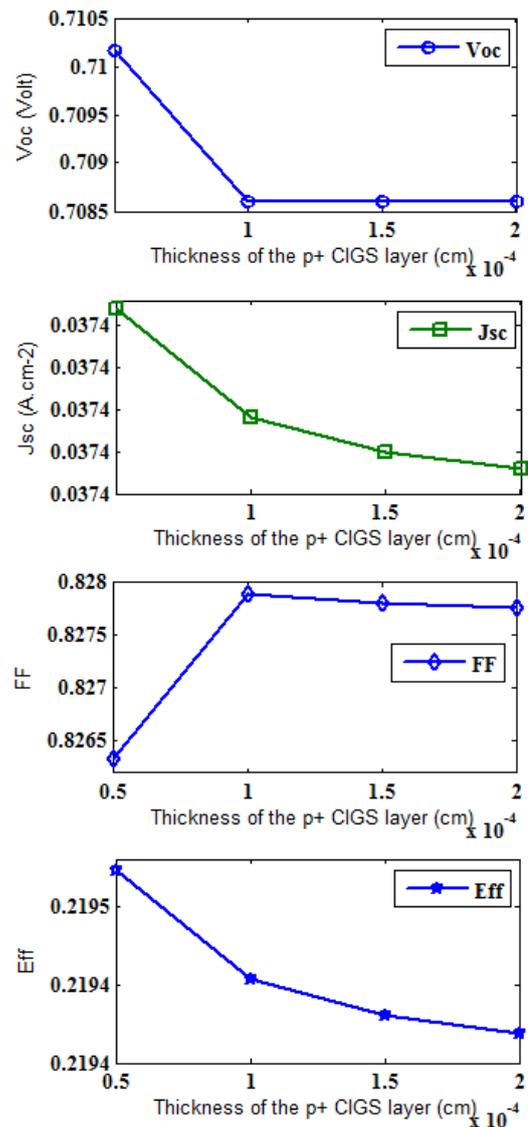
**Figure 6.** Spectral Response of the CIGS solar cell with BSF and without BSF

Considering the beneficial effects of the use of the BSF, we try to improve the macroscopic electric parameters of the cell by varying on the one hand the thickness of the thin layer in CIGS (p+), and other shares its doping concentration acceptors.

**3.2.3. Improvement of the thickness of the up-doped layer**

In this part, we vary the thickness of up-doped CIGS layer of 0.5μm with 2μm. the variations of the macroscopic electric parameters are introduced by the Figure 7. The Voc varies slightly with the thickness of up-doped CIGS layer, it passes just from 0.710V to 0.708V and remains more significant for a thickness of 0.5μm. The short-circuit current density decreases with the thickness but in a way little meaning. The form factor remains higher than 82.6% and the conversion efficiency remains close to 21.9%. However this efficiency decreases with the increase of the thickness.

The Table 4 shows in view of these values that the optimal thickness of the up-doped layer to use is 500nm because it gives a maximum conversion efficiency of 21.95%.



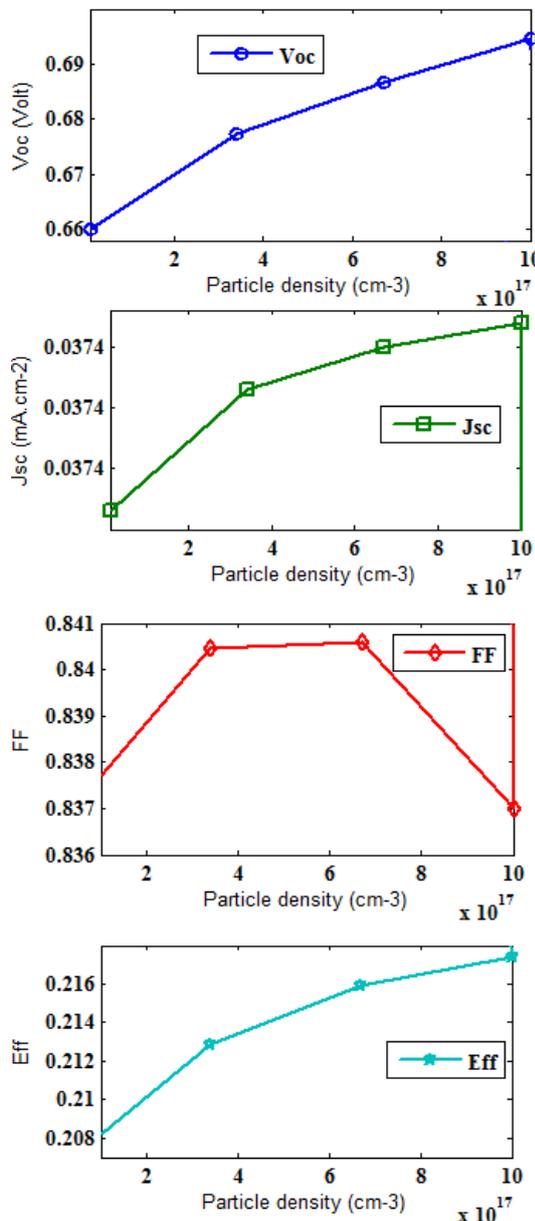
**Figure 7.** Variation of the macroscopic electric parameters according to the thickness of the layer of doped CIGS p+

**Table 4. Numerical values of the macroscopic electric parameters according to the thickness of p+ CIGS doped layer**

Thickness ( $\mu\text{m}$ )	Voc (Volt)	Jsc ( $\text{mA}\cdot\text{cm}^{-2}$ )	FF (%)	EFF (%)
0.5	0.7101	37.40877	82.632	21.952
1.0	0.7085	37.40864	82.799	21.945
1.5	0.7085	37.40860	82.780	21.943
2.0	0.7085	37.40858	82.776	21.941

### 3.2.4. Improvement of the rate of doping of the up-doped layer

The doping of the CIGS layer at the back contact has a direct effect on the intensity of the BSF. In this part we search the optimal doping by studying the variation of the macroscopic electric parameters according to the doping concentration acceptors of the p+ CIGS layer. This last varies from  $10\text{E}16\text{cm}^{-3}$  to  $10\text{E}18\text{cm}^{-3}$ . Knowing that when one reaches a very high doping like  $10\text{E}19$ , the properties of the doped layer deteriorated, we limit the doping to  $10\text{E}18\text{cm}^{-3}$ . [6]

**Figure 8.** Variation of the macroscopic electric parameters according to the doping concentration acceptors of the CIGS p+ doped layer

We note that the study is carried out with a p+ CIGS thickness of  $0.5\mu\text{m}$ . The Figure 8 indicates to us the improvement of the open circuit voltage which passes from  $0.66\text{V}$  to  $0.69\text{V}$ . The increase in the doping concentration acceptors improves the open circuit voltage Voc. The same effect is noted on the short-circuit current density which passes from  $37.37\text{mA}\cdot\text{cm}^{-2}$  to  $37.40\text{mA}\cdot\text{cm}^{-2}$ . The Form Factor remains higher or equal to  $83.7\%$  whatever the doping. This attests the quality of the solar cell. This form factor decrease when we approaches  $10\text{E}18\text{cm}^{-3}$  what makes logical the choice to use this value like maximum doping. The conversion efficiency, main criterion of excellence of the cell is improved with the increase of doping. It passes from  $20.64\%$  to  $21.74\%$  such as indicating by Table 5. This study shows us that the optimal doping of the up-doped which establishes the BSF is of  $10\text{E}18\text{cm}^{-3}$ .

**Table 5. Numerical values of the macroscopic electric parameters according to the doping concentration acceptors of CIGS surdoped layer**

Doping concentration acceptors ( $\text{cm}^{-3}$ )	Voc (Volt)	Jsc ( $\text{mA}\cdot\text{cm}^{-2}$ )	FF (%)	Eff (%)
$1\text{E}16$	0.660	37.373	83.67	20.64
$3.\text{E}17$	0.677	37.393	84.05	21.29
$6.7\text{E}17$	0.687	37.400	84.06	21.59
$1\text{E}18$	0.694	37.404	83.70	21.74

## 4. Conclusion

The work carried out in this article makes it possible to confirm the beneficial effects of the use of a BSF in the CIGS thin film solar cells. The comparison of the macroscopic electric parameters of the two cells with BSF and without BSF enabled us to obtain a conversion efficiency of  $21.95\%$  for the cell with BSF instead of  $20.78\%$  for the cell without BSF. The use of the BSF does not have a remarkable impact on internal and external quantum efficiencies which nevertheless presents a broad maximum absorption band which extends from  $0.4\mu\text{m}$  to  $1\mu\text{m}$ . The spectral response of the layer reaches a value of  $0.7\text{A}\cdot\text{W}^{-1}$  for an incidental wavelength of approximately  $1000\text{nm}$ . This wavelength is accompanied indeed by an energy corresponding to the gap of the absorber of the solar cell. The improvement thickness of layer in up-doped CIGS p+ layer, indicates an optimal thickness of  $0.5\mu\text{m}$ . Indeed to us we find for this thickness Voc= $0.71\text{V}$ , Jsc= $37.409\text{mA}\cdot\text{cm}^{-2}$  and Eff= $21.95\%$ . The optimization of the doping concentration acceptors of the layer p+ CIGS thickness  $0.5\mu\text{m}$ , shows us that the optimal rate corresponds to  $10\text{E}18\text{cm}^{-3}$ . We find with this concentration an open circuit voltage of  $0.69\text{V}$ , a short-circuit current density of  $37.40\text{mA}\cdot\text{cm}^{-2}$  and a conversion efficiency of  $21.74\%$ . This article contributes to the technology of the thin film CIGS solar cell with the original use of a back surdoped layer having a thickness  $0.5\mu\text{m}$  and a doping acceptors density of  $10\text{E}18\text{cm}^{-3}$ .

## References

- [1] Available: <http://www.lechodusolaire.fr/cellules-solaires-cigs-226-de-rendement-de-conversion-zsw/>. [Accessed Sept. 18, 2017]

- [2] Alain Kassine Ehemba, Ibrahima Wade, Mouhamadou Mamour Soce, Djimba Niane, Moustapha Dieng, "Study of the consequences of the front external reflection on the electric parameters of a thin film  $\text{Cu(In,Ga)Se}_2$  solar cell", Research Journal of Engineering Sciences, Vol 05, Issue 10, pp. 01-06, 2016.
- [3] Demba Diallo, Alain Kassine Ehemba, Amsata Ndiaye, Mouhamadou Mamour Soce, Moustapha Dieng, "The influence of the thickness of the CdS emitter layer on the performance of a CIGS solar cell with acceptor defects", International Journal of Engineering and Applied Sciences, Vol. 4, Issue 1, pp. 1-4, 2017.
- [4] Vinh Ai Daoa, Jongkyu Heoa, Hyungwook Choia, Yongkuk Kima, Seungman Parka, Sungwook Junga, Nariangadu Lakshminarayan, Junsin Yia,c, "Simulation and study of the influence of the buffer intrinsic layer, back-surface field, densities of interface defects, resistivity of p-type silicon substrate and transparent conductive oxide on heterojunction with intrinsic thin-layer (HIT) solar cell", Solar Energy, Vol. 84, pp. 777-783, 2010.
- [5] "Simplified fabrication of back surface electric field silicon cells and novel characteristics of such cells", in Ninth Photovoltaic Specialists Conference sponsored by the Institute of Electrical and Electronics Engineers Silver Spring, Joseph Mandelkorn and John H. Lamneck.
- [6] Alain Kassine Ehemba, Moustapha Dieng, Demba Diallo, Gerome Sambou, "Influence of the donor doping density in CdS and Zn(O,S) buffer layers on the external quantum efficiency of  $\text{Cu(In,Ga)Se}_2$  thin film solar cell", International Journal of Engineering Trends and Technology, Vol. 28, Issue 6, pp. 280-286, 2015.