A comparative study of CIGS solar cells based on Zn (O, S) buffer layers and CIGS solar cells based on CdS buffer layers

A. CHADEL[*], B. BENYOUCEF, M. CHADEL
URMER Research unit, Tlemcen University BP. 119, Tlemcen, Algeria

Thin film solar cell based on copper-indium-gallium-diselenide Cu(In,Ga)Se$_2$ contain a thin cadmium sulfide (CdS) buffer layer. For environmental and industrial reasons, its replacement by a Cd-free material deposited under vacuum is among the challenges of the research community. In this work, we replaced the CdS buffer layer by the oxysulfure of zinc (Zn(O,S)) which has a higher band gap and thus allows greater blue photon collection to achieve higher photon current. In this work we used a simulation code we replace the CdS with Zn (O, S) for different thickness of each layer. We have shown that the solar cell based on CIGS / Zn (O, S) / ZnO can obtain an equivalent efficiency of the solar cell based on CIGS / CdS / ZnO for all thicknesses are studying the absorbent layer and the layer window.

1. Introduction

Copper-indium-gallium-diselenide (CIGS) thin film solar cell has achieved the highest conversion efficiency [1] compared to other Cu-chalcopyrite thin film solar cells as well as CdTe and amorphous Si thin film solar cells. CIGS Solar cells, constituted by a pile of thin layers [2], contain in particular a fine layer called buffer layer between the absorber and before the contact, necessary for the obtaining of high efficiencies on conversion. This buffer layer is generally consisted of sulphide the cadmium (CdS) and presents three major problems from an environmental point of view, cadmium is a carcinogenic element [3], which although is present in very small quantity as a plug layer and being able to be recycled at the end of the lifetime panels, its represents a potential danger during its storage on the production sites

Concerning the efficiency on the device, band-gap energy of the CdS (2,4 eV)can seem penalizing and preventing the generation of carriers in the absorber from photons of higher energy.

At the industrial level, the synthesis of the CdS is made by CBD [4] (Chemical bath deposition) and entraine a break of the space on the production line, as well as costs caused by the storage of dangerous reactives (cadmium, thio-urea, ammonia water) and the treatment of toxic waste

One of the materials candidates for the replacement of the CdS, allowing the obtaining of equivalent efficiency on conversion, is the oxysulfure of zinc (Zn (O, S).

2. Materials and methods

2.1 Why Zn(O,S) buffer layer in CIGS

Zn(O,S), a Cd-free and abundant material with higher band gap (varying with oxygen content from 2.8 to 3.6 eV), is an attractive candidate. Fig. 1 shows the corresponding enhancement of photocurrent and conversion efficiency of Zn(O,S)/CIGS cells. The two cells in Fig. 1 were fabricated by using the same CIGS absorber but different buffer layer (CBD-CdS and sputtered-Zn(O,S), respectively) at NREL. Zn(O,S), thus, is likely to achieve better conduction-band offset when Ga expands the band gap of CIGS absorber, so as to obtain a higher efficiency CIGS cells [5], [6]. Finally, compared to chemical bath deposition and atomic layer deposition, the sputtering deposition of Zn(O,S) buffer layer is the most attractive process in terms of its suitability for inline, high throughput, and low-cost processing of junction [7].
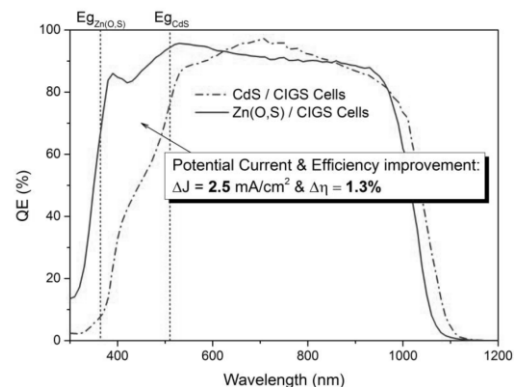

Fig. 1. Quantum efficiency comparison between CdS/CIGS and Zn(O,S)/CIGS solar cells.

2.2 Solar cell structure

The solar cell with Copper indium gallium dieseline Cu (In, Ga) Se$_2$ (CIGS) consists typically of a layer of Mo deposited on a glass substratum with lime sodium as contact defers for the solar cells. Cu(In,Ga)Se$_2$ is deposited on the back electrode of Mo as photovoltaic material absorber. The heterojunction is then achieved by the deposit of chemical bath (CBD) of CdS or by Sputtered-deposited (PVD) of Zn (O, S) and by the deposit of spraying(pulverizing) of an intrinsic nominally not doped layer of ZnO, then a layer strongly doped by ZnO. Which has an energy of gap for 3.3 eV is transparent for the main part of the solar spectrum which is thus noted as layer of window of solar cells.
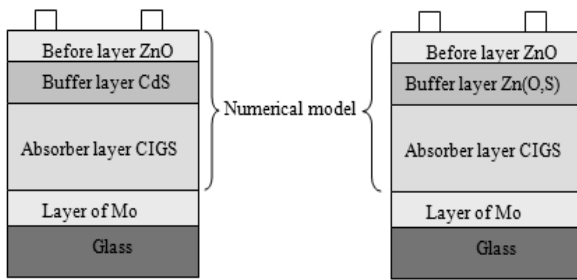

Fig. 2. Schematic structure of the simulated solar cell.

2.3 Solar cell characteristics

The current-voltage *(J-V)* characteristic of the cell is given by the following equation [8]:

$$J = J_{ph} - J_0 \left(e^{\frac{V}{QU_t}} - 1 \right)$$

Where: the saturation current density J_0 is extrapolated according to equation. [9]:

$$J_0 = J_{00} e^{\frac{-E_g}{QKT}}$$

Where: J_{00} is a constant which depend to temperature.

The diode ideality factor Q and J_{00} are extracted from the reference [10].

From the *J-V* characteristic, we can easily deduce the short-circuit density *Jsc*, the open circuit voltage *Vco* and the maximum power *Pm* given respectively by:

$$J_{sc} = J_{ph} \; ; \quad V_{CO} = QU_t. \ln\left(\frac{J_{ph}}{J_0}\right) ; P_m = (J.V)_{max}$$

And hence, the fill factor and the conversion efficiency are deduced by the following equations:

$$FF = \frac{P_m}{J_{sc}.V_{co}} \qquad ; \qquad \eta = \frac{P_m}{P_i}$$

2.4 Simulation parameters

The results of our bibliographic research has inspired us the variation range of parameters, where: wn varies from 10 to 100 nm [11], wp varies from 1 to 4μm [11].

The Material and device parameters used in the simulation are shown in the Table 1.

Table 1. Parameter values adopted for the solar cell in the simulation.

Parameter	CIGS	CdS	Zn(O,S)	ZnO
Layer thickness W[nm]	3000	50	50	200
Relative permittivity $\varepsilon/\varepsilon_0$	13,6	10	9	9
Electron mobility μ_e [cm²/Vs]	100	100	100	100
Hole mobility μ_h [cm²/Vs]	25	25	25	25
Acceptor or Donor concentration[cm^{-3}]	P:2×10^{16}	N:10^{17}	N:10^{17}	N:10^{18}
band gap Energy Eg [eV]	1,15	2,4	$3,3 - 3,6$	3,3
Effective density of states N$_C$ [cm^{-3}]	$2,2 \times 10^{18}$	$2,2 \times 10^{18}$	$2,2 \times 10^{18}$	$2,2 \times 10^{18}$
Effective density of states N$_V$ [cm^{-3}]	$1,8 \times 10^{19}$	$1,8 \times 10^{19}$	$1,8 \times 10^{19}$	$1,8 \times 10^{19}$

3. Results and discussion

3.1 Optimization of thickness of different layers

The effect of the variation of the thickness absorber layer of 0.4μm to 4μm and the doping concentration for the CIGS on the efficiency solar cell is illustrated on the Fig. 3. We note when the thickness and the doping concentration increase the efficiency of the solar cell increase. As the p-type layer is increased more photons with longer wavelength can be collected in the absorber layer. The characteristics of the semiconductor materials are strongly influenced by the impurities. They are added to increase the electrical conductivity or the control of the duration of life, but these often these impurities or imperfections in the network, from a certain threshold, act as factors loss, therefore a high concentration of defects discriminates the carrier transport, thereby reducing the conversion efficiency. We note that the performance obtained for the two structures CIGS/CdS, CIGS/Zn(O,S) is equivalent to each point.
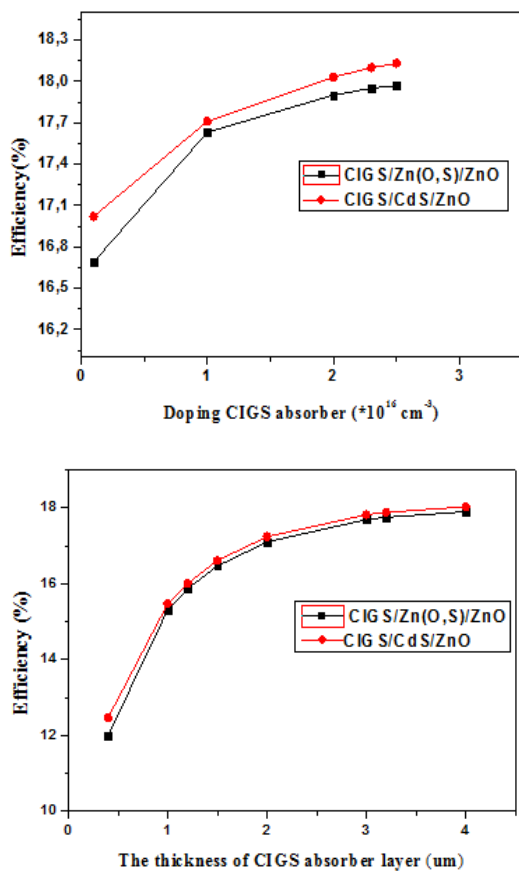

Fig. 3. Effects of the variation of the thickness and the doping concentration for the absorber layer on the performance of the solar cell.
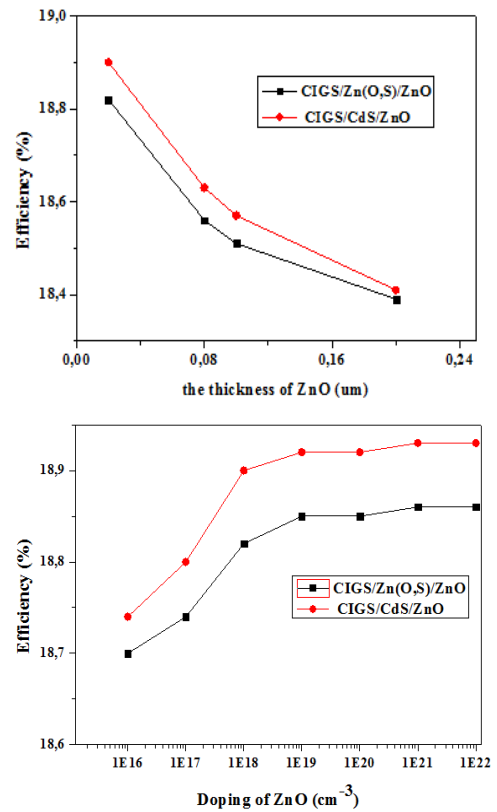

Fig. 4. Effects of the variation of the thickness and the doping concentration for window layer on the performance of the solar cell.
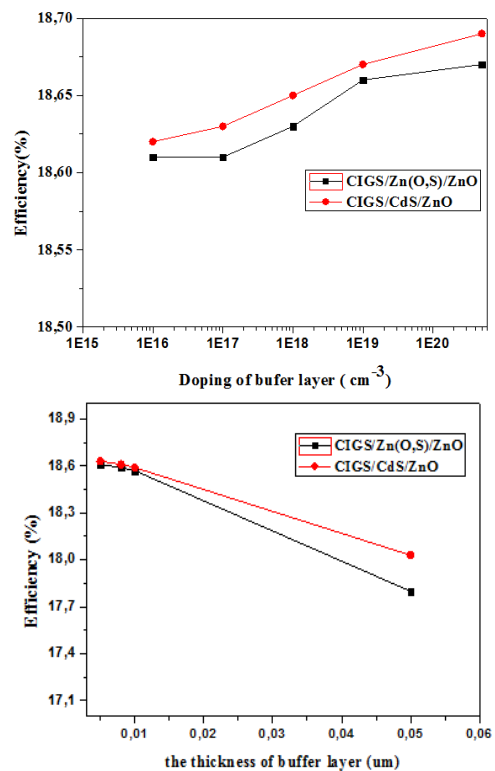

Fig. 5. Effects of the variation of the thickness and the doping concentration for buffer layer on the performance of the solar cell.

You should choose a threshold CIGS with thickness of 4 um and a concentration $2,5 \times 10^{16}$ cm^{-3} to have the maximal electric performance

3.2 The layer effect of window ZnO:

The Fig. 4 represents the variation of the electrical performance in function of the layer's thickness and the doping concentration for the window layer ZnO between. From the Fig. 4, the efficiency increases slightly with increasing doping concentration of the window layer. So to have a performance improvement, we should use a window layer ZnO heavily doped. We note that the performance obtained for the two structures CIGS/CdS, CIGS/Zn(O,S) is equivalent to each point

The thickness of the ZnO should be choose with 0,02 um and a concentration of 10^{22} cm^{-3} to have the maximal electric performance.

3.3 The layer effect of buffer

The effect of the variation for the thickness and the doping concentration for the buffer layer from the efficiency solar cell is illustrated on the Fig. 5. The variation of the thickness of the buffer layer with the efficiency shows that there is a reduction in efficiency with increasing thickness. This is explained by a significant absorption of photons in this layer. The absorption in the buffer layer reduces the number of photons incidents which have an energy hv> Eg(buffer layer). All photons having a wavelength greater than that associated with the gap of the semiconductor wavelength cannot generate electron-hole pair and therefore, are lost as heat. This affects the creation of electron-hole pairs contributing to the overall photocurrent where the decrease in efficiency. The objective is to recover the lost photons to improve performance conversion of the solar cell. Since the light absorbed in this layer does not contribute significantly in the photocurrent collected, it is desirable that this layer is of minimal thickness.

That Fig. 5 represent the variation of the electrical performance in terms of the doping from 10^{16} till 5×10^{20} cm^{-3} with the thickness of the buffer layer 0,005 um. We note when the doping for the buffer layer increase the efficiency increase. when the doping of the buffer layer increases, the potential barrier in the heterojunction CdS / CIGS or Zn(O,S)/CIGS decreases, allowing an increase of the space charge region, thereby improving the collection of photo-generated carriers and thus increasing the conversion efficiency. We note that the performance obtained for the two structures CIGS/CdS, CIGS/Zn(O,S) is equivalent to each point

Following these results, we can say that for improved performance for CIGS, we must use a buffer layer heavily doped and thickness is in the order of 0,005 um.

4. Conclusion

In this work, an analytical model is used to simulate a (CIGS)-based thin film solar cells. From the simulation results, it is found that the contribution of the space charge region in the photocurrent density is dominant compared to those of the neutral regions. However, the increases of the buffer layer thickness only reduce the cell performance. In contrast, the optimum thickness of the absorber layer is around 3 μm for 4um.

The solar cell based on CIGS/Zn(O,S)/ZnO to get electrics performance equivalent to the solar cell which is based on CIGS/CdS/ZnO, so we can replace the buffer layer of cadmium sulfide (CdS) with oxysulfide of zinc (Zn (O,S)) by the moment that this last one is not toxic, it is field on the CIGS with the co-sputtering (PVD) which is less expensive than the chemical bath deposition of CBD and it has a very big gap energy of 3,7 ev.

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*Corresponding author: a-chadel@hotmail.com