ANALYSIS OF CIGS AND CdTe SOLAR CELL CONCENTRATORS

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Operating solar cells under concentrated illumination offers main advantages, low cost of manufacture and high solar cell efficiency. These performance levels make CIGS and CdTe thin film technologies an attractive option for concentrator solar cells. Three concentrator cells are simulated in this work; the efficiency has increased about 22.2% with only 10 suns in CdTe concentrator solar cell and has reached 25% in CIGS concentrator solar cell. This increase could be attributed to the presence of a graded absorber layer and best result is obtained when the difference between front and back band-gaps in this layer is large.

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1. Introduction

During the past three decades, extensive research and development efforts have been devoted to finding new materials and fabrication processes with higher potential of cost reduction than that of crystalline silicon technology.

One of the most promising ways to achieve economical competitiveness of photovoltaic was to turn to thin film technologies. Thin film approaches are usually thought of as those utilizing active semiconductor material of approximately 10 µm or less in thickness, such-that with chalcopyrite CIGS absorber materials and CdTe solar cells. The present highest laboratory efficiencies in thin film technology are 21.7% for CIGS solar cells [10]. 20.4% [3], 21.0% [11] and 21.5% for CdTe laboratory solar cell [9].

An alternative approach to reduce the cost of photovoltaic energy is using concentrator technologies to partly replace relatively expensive semiconductor material; there are two common approaches to concentrators, one uses either line focus lenses or reflectors with concentration ratios in the order of 2-20, and other uses point focus lenses with concentration ratios up to 1000.

Although the motivation for research has been focused on low cost, flat plate applications, these performance levels make thin films technologies such as CIGS and CdTe attractive options for concentrator solar cells. The highest achieved efficiency with CIGS concentrator solar cell was 23.3% under 14.7sun [9].

2. Simulations

In this work, we compare the behaviour of the photovoltaic performance of three cells under concentrated illumination with and without cooling. These cells were previously studied without concentrated illumination, theTCO/$Cd_{1-x}Zn_xS$/CdTe cell with an efficiency of 21.15% [1], the ZnO/CdS/CIGS solar cells with new experimental record efficiency of 21.7% [10] and an optimized ZnO/CdS/CIGS solar cell where the maximum efficiency was 24.34% for a graded band gap with Eg=1.41eV at the front and Eg=1.54eV at the back of the absorber CIGS layer [2] using the software SCAPS.

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The inputs materials parameters used are gathered in table 1 below and were extracted from literature, either experimental or theoretical data values [7,4 and 12].

Table 1. Some of thin films electronic parameters used in various simulations

Layer properties	ZnO	SnO_2	CdS	CdTe	CIGS	ZnS
χ Electron affinity (eV)	4	4	3.8	3.9	4.1	3.9
ε/ε0 Dielectric permittivity (relative)	9	9	10	9.4	13.6	9.6
µe Electron mobility (cm^2/Vs)	100	100	100	320	100	165
µh Hole mobility (cm2/Vs)	13	25	25	40	25	5
$N_{D/A}$ shallow donor/acceptor density (cm^{-3})	N_D : $5.6x10^{20}$	N_D : $1.0x10^{19}$	N_D : $1.1x10^{18}$	N_A : $3.5x10^{15}$	N_A : $2x10^{16}$	N_D : $1x10^{18}$
Eg Bandgap (eV)	3.3	3.6	2.4	1.5	1.13	3.66
Nc CB density of states (cm^{-3})	$2.2x10^{18}$	$2.2x10^{18}$	$2.2x10^{18}$	$8.0x10^{17}$	$2.2x10^{18}$	$1.3x10^{18}$
Nv VB density of states (cm^{-3})	$1.8x10^{19}$	$1.8x10^{19}$	$1.8x10^{19}$	$1.8x10^{19}$	$1.8x10^{19}$	$9.0x10^{18}$
Gaussian-distributed defect states						
N_{DG},N_{AG} (cm^{-3})	D : 10^{17}	D : 10^{15}	A : 10^{18}	D : $2x10^{12}$	D : 10^{13}	A : 10^{18}
EA,ED (ev)	Mid-gap	Mid-gap	Mid-gap	Mid-gap	Mid-gap	Mid-gap
WG (ev)	0.1	0.1	0.1	0.1	0.1	0.1
.σ_e (cm^2)	10^{-12}	10^{-12}	10^{-17}	10^{-12}	5.10^{-13}	10^{-17}
.σ_h (cm^2)	10^{-15}	10^{-15}	10^{-12}	10^{-15}	10^{-15}	10^{-12}

Numerical simulations of the structures were carried out using SCAPS-1D which is among the tools used to model the CdTe and CIGS/CIS thin film solar cells and proved to give good analysis of such devices [6,8]. The SCAPS calculations were carried out for moderately concentrated light, with C ranging from 1 to 10 suns because of the limits of the software SCAPS accuracy due to its inability of solving semiconductor equations at high injection level.

In low injection level the photo-generated carriers density Δn is very low compared to equilibrium free carriers density (Δn, Δp<< p, n) and in high injection level the photo-generated carrier density is of the order of equilibrium free carrier density (Δn, Δp≈p, n), where the low injection model used in SCAPS is no longer valid.

The simulation is performed under global AM1.5 solar spectrum. Measurements of photovoltaic parameters are made in the case of zero series and infinite shunt resistances.

3. Simulation results and discussion.

3.1. Validation of the numerical model of the CIGSconcentrator cell.

In order to test SCAPS-1D simulator for its capacity to simulate the CIGS concentrator cells, The starting point for the simulations is the first fabricated CIGS concentrator cell with an efficiency exceeding 20% [5]. The fabricated ZnO/CdS/CIGS structure was a 30-nm-thick CdS layer deposited first by CBD on 2.5um thick $CuInGaSe_2$ films which were grown by NREL's three-stage coevaporation process. On this thin CdS layer, a 50-nm-thick ZnO film was deposited from a pure ZnO target, and was followed by the deposition of a 200-nm-thick, Al-doped ZnO layer.

Table 2 summarises the performance parameters of fabricated CIGS concentrator cells as a function of concentration ratio and the simulated one with a perfect cooling (T=300°K)

Table 2. Performance parameters for an experimental and simulated CIGS concentrated cell

Solar cell	Suns	Voc(mV)	FF (%)	.η (%)
Experimental [5]	1	647	76.30	17.90
Simulated by SCAPS	1	712	81.11	19.41
Experimental [5]	9.46	722	80.60	21.10
Simulated by SCAPS	10	785	81.09	21.46

In table 2, our SCAPS simulations are compared with experimental results of CIGS concentrator cells [5]. The obtained results were in good agreement with experimental measurements higher efficiencies in simulated CIGS concentrator cells is caused by zero series resistance and perfect cooling (T=300°K) used in software SCAPS.

3.2. Comparaison of the CdTe and CIGS concentrator solar cells.

Schematic representations of the three simulated cells are shown in Fig1 and Fig2, first the TCO/$Cd_{1-x}Zn_xS$ /CdTe cell in Fig.1, the baseline case of the most recent CIGS solar cell [10] with conversion efficiencies up to 21.7% fabricated by P. Jackson et al with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back of the absorber CIGS layer and the optimized ZnO/CdS/CIGS solar cell [2] with Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV at the back of the absorber CIGS layer in fig 2. Only semiconductor layers are reproduced in numerical models. The metallic contacts at the top and bottom are defined by their work functions and surface recombination velocities.

The three cell are simulated with perfect cooling (T=300°K) and without cooling.

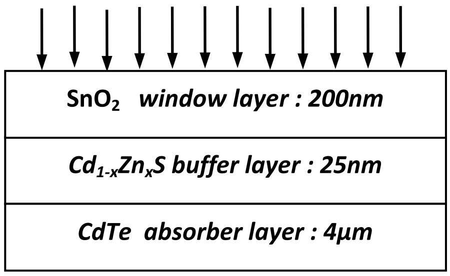


Fig. 1. Schematic diagram of a TCO/ $Cd_{1-x}Zn_xS$ /CdTe solar cell.

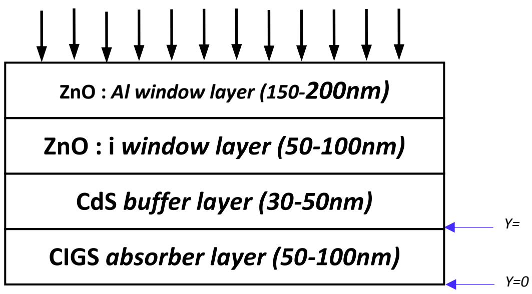


Fig. 2. Schematic diagram of a ZnO/CdS/CIGS solar cell.

In Fig. 3,efficiencies of the three concentrator cells versus sun ratio are presented, where the efficiency increase is observed in the two cells with a value of 1%;from 21.15 % to 22.2% in CdTe solar cell and from 24.34% to 25.50% in the optimized ZnO/CdS/CIGS solar cell where front band-gap Eg(y=d)=1.41eV and back band-gap Eg(y=0)=1.54eV in its absorbing layer; on the other hand that of the fabricated CIGS solar cell where the difference between front band-gap Eg(y=d)=1.14eV and back band-gap Eg(y=0)=1.31eV in its absorbing layer is large, the efficiency is increased with a value of ≈2.5%, from 22.69% to 25.26%.

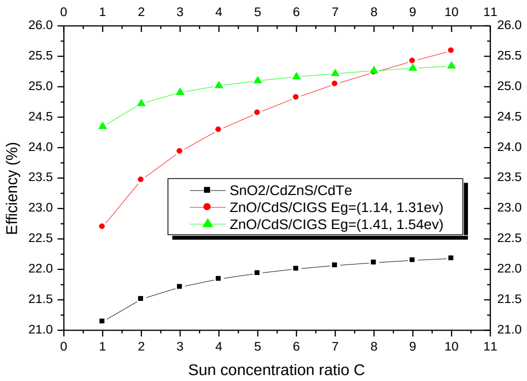


Fig. 3. the efficiency of the three concentrator solar cells TCO/$Cd_{1-x}Zn_xS$ /CdTe cell, ZnO/CdS/CIGS with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back of the absorber CIGS layer ZnO/CdS/CIGS solar cell with Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV at the back of the absorber CIGS layer with perfect cooling (T=300°K).

The same pace of the efficiency increase in the two cells CdTe solar cell and the optimized ZnO/CdS/CIGS solar cell with Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV is caused by the same percentage of the Voc increase versus the sun concentration ratio fig5 and fig7 against that of the fabricated solar cell with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back as in fig6. On the other hand the short circuit current is amplified ten times at C=10 compared to C=1 for the three cells.

The difference in percentage of the efficiency increase can be due to the electric field created by the difference in gap energy in the absorbing layer CIGS which is of a value of [Eg(y=0)=1.31eV]-[Eg(y=d)=1.1eV]=0.17ev of the manufactured cell more than that of the optimized cell which is of a value of 0.1ev.

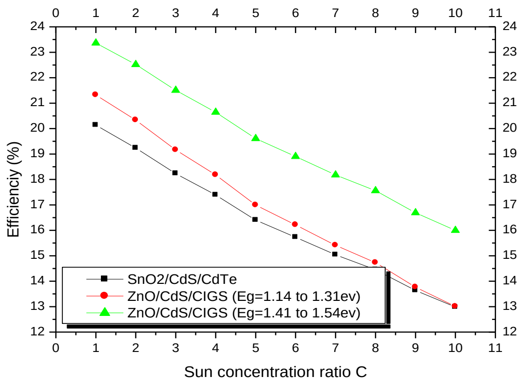


Fig. 4. the efficiency of the three concentrator solar cells TCO/$Cd_{1-x}Zn_xS$ /CdTe cell, ZnO/CdS/CIGS with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back of the absorber CIGS layer ZnO/CdS/CIGS solar cell with Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV at the back of the CIGS absorber layer without cooling versus sun ratio.

Fig. 4 represents the efficiency of the three cells without cooling versus the sun concentration ratio; it is shown that the decrease of the efficiency is of the same percentage approximately 7% for the two cells which have a high energy gap approximately 1.5ev. On the other hand the efficiency decrease of the CIGS cell with low energy gap is a little high with the increase in the sun ratio, it is caused by the increase of its short circuit current fig.6 a value of 37.4 to 374mA/cm^2 more than the other solar cells currents 25.24 to 252.69 mA/cm^2 and 29.10 to 291.80mA/cm^2 as show in fig5 and fig7 respectively where the Joule effect plays its role.

This is confirmed at high temperature, solar cell with wide band-gap can function where it is capable of more energy output and loses less of its output than that of a low-band-gap cell.

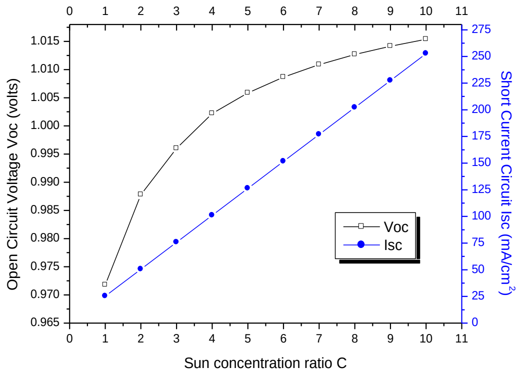


Fig. 5. Jsc and Voc of TCO/$Cd_{1-x}Zn_xS$/CdTe cell for different sun ratio.

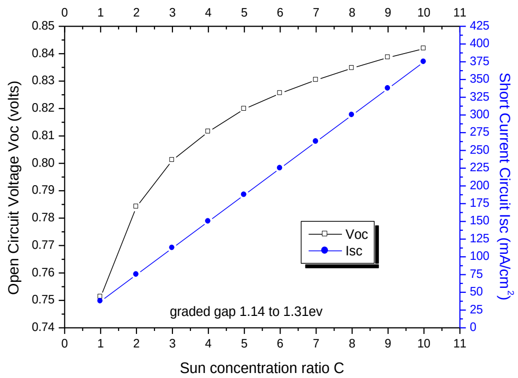
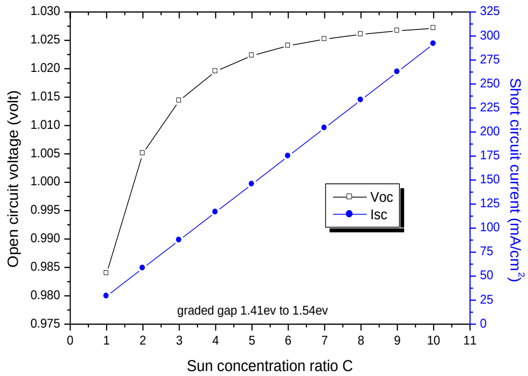


Fig. 6. Jsc and Voc of ZnO/CdS/CIGS solar cell with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back of the absorber CIGS layer for different concentrator sun Ratio



Fig, 7. Jsc and Voc of ZnO/CdS/CIGS solar cell Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV at the back of the absorber CIGS layer for different concentrator sun ratio

4. Conclusions

In the present work, the efficiency of TCO/ $Cd_{1-x}Zn_xS$ /CdTe concentrator cell has reached 22.20% and up to 25.50% in ZnO/CdS/CIGS concentrator solar cell graded CIGS layer at only 10 suns

we proved that the advantage which can be envisaged is that the solar cells with high band-gap resist better than those with low band-gap therefore they can be better used under concentration than those of low gap

The increase rate of the efficiency in a cell where the difference of energy gap between that of the front and the back is broad in the absorbing layer, is higher than with cells which have a tiny difference between the back and the front of their absorbing layers ≈3% in CIGS concentrator solar cell with Eg(y=d)=1.14eV at the front and Eg(y=0)=1.31eV at the back against 1% in ZnO/CdS/CIGS concentrator solar cell with Eg(y=d)=1.41eV at the front and Eg(y=0)=1.54eV at the back with only 10 sun.

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