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OPTIMIZATION OF HIGH PERFORMANCE CIGS SOLAR CELLS WITH DIFFERENT BUFFER LAYERS

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Abstract- *Copper Indium Galium Selenide ($CuIn_{1-x}Ga_xSe_2$ or CIGS) solar cells with different buffer materials have been simulated in order to propose an alternative to Cadmium Sulphide (CdS) as the buffer material in this work. Numerical modeling, simulation and optimization of high performance layers of CIGS solar cells were carried out. The prime goal was to reduce the toxic cadmium containing solar cells deteriorous for the environment. Materials like Zinc Sulphide (ZnS), Zinc Selenide (ZnSe) and Indium Sulphide (In_2S_3) were proposed along with CdS for high performance CIGS solar cells. This proposed model showed simulated conversion efficiency of 23.77% for CdS, 26.85% for ZnS, 26.31% for ZnSe, 26.7 % for In_2S_3. Results obtained in this work with ZnS, ZnSe and In_2S_3 as alternative buffer layers for CIGS solar cells has opened a new arena of research in this field. These have been proposed as viable alternatives to the toxic CdS as buffer material for CIGS solar cells.*

Keywords: $Cu(In,Ga)Se_2$ (CIGS) solar cell, AMPS-1D simulation, open circuit voltage (Voc), short circuit current (Jsc), fill factor (FF).

1. INTRODUCTION

The term buffer layer typically refers to a layer sandwiched between two single-crystal materials to accomodate difference in their crystallographic structures(lattice constants) [4]. Buffer layer is an intermediate layer film between the absorber and window layers with two main objectives, to provide structural stability to the device and to fix the electrostatic conditions inside the absorber layer. Meanwhile, it will have to make good p-n junction with the p-type absorber layer for the electrical conduction and to allow the transmission of photons into the absorber layer to generate electron-hole pair . One of the most promising cells today is copper-indium-gallium-diselenide (CIGS) [1]. Atomic layer deposition (ALD) can be used to improve the efficiency of CIGS solar cells by more than 1 percentage point. This is achieved by depositing a dense and conformal zinc oxisulfide Zn(O,S) buffer layer. Criteria for buffer layer selection are

- To make a good junction partner with a p-CIGS absorber, a buffer material should be n-type, or possibly intrinsic (i-type) [9].
- Buffers with high resistivity are preferred to reduce the possibility of shunting of a junction. Matching the absorber and the buffer lattice constants should also be considered when choosing a buffer [11].
- One other major criterion in selection of a buffer material is its band gap (Eg). Eg needs to be sufficiently wide that as few photons as possible are absorbed in the buffer [11].
- Another important buffer-material selection criterion is its electron affinity [9].

The CIGS cell structure that is made up of a p-CIGS absorber layer, the buffer layer and a window layer made of n- ZnO:Al. The entire structure is placed on a soda-lime glass substrate through a Nickel (Ni) back contact. CdS is normally used as the buffer layer but other materials- ZnS, ZnSe, In_2S_3 were used for the simulation [6].

Table 1: Semiconductor parameters used for the simulation [8]

Parameters	CIGS	CdS	ZnS	ZnSe	In_2S_3	ZnO
Thickness	1.0	0.06	0.06	0.06	0.06	0.1
Bandgap (eV)	1.5	2.4	3.54	2.7	2.1	3.3
Electron affinity(eV)	4.1	3.8	4.4	4.09	4.7	4.0
Dielectric permittivity	13.6	10.0	10.0	10.0	13.5	9.0
CB density of state	2.2 $x10^{18}$	$1.5x10^{18}$	$1.5x10^{18}$	1.5 $x10^{18}$	1.8 $x10^{19}$	2.22 $x10^{18}$
VB density of state	1.78 $x10^{18}$	1.8 $x10^{18}$	1.8 $x10^{18}$	1.8 $x10^{19}$	4.0 $x10^{13}$	1.78 $x10^{19}$
Donor density, N_D	0	1.0 $x10^{19}$	1.0 $x10^{18}$	1.0 $x10^{16}$	1.0 $x10^{20}$	1.0 $x10^{18}$
Acceptor Density, A_D	6.0 $x10^{16}$	0	0	0	0	0
Thermal velocity	1.0 $x10^{7}$	1.0 $x10^{7}$	1.0 $x10^{7}$	1.0 $x10^{7}$	1.0 $x10^{7}$	1.0 $x10^{17}$

2. MODELING AND SIMULATION

2.1 Buffer Layer CdS Optimization

After determining optimum parameters for absorber layer the buffer layer was optimized. The buffer layer was optimized by using following the steps-

1. Thickness optimization of Buffer layer, CdS
2. CdS Carrier density (N_D) optimization

2.1.1 Thickness Optimization of Buffer Layer, CdS

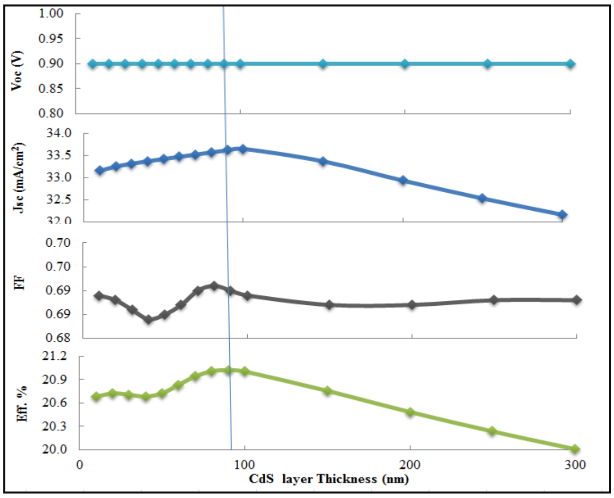

Fig. 1. CdS thickness (nm) optimization

Overall efficiency decreases with increase in thickness above 90nm. 90 nm is chosen to be the optimum thickness for buffer layer, CdS because it is comparatively easier to manufacture than ultra thin CdS of 50nm thickness and it provides maximum efficiency.

2.1.2 CdS Carrier Density (N_D) Optimization

Within 0 to default value 10^{20} cm^{-3} range Voc decreases with increasing N_D and *Jsc* increases with increase in N_D. So Efficiency increases until default value. Above 10^{19} cm^{-3} efficiency increase is extremely small. It increases into 23.772% at $1x10^{19}$ cm^{-3}. Increase beyond 10^{19} cm^{-3} decreases Fill factor. Therefore, 10^{19} cm^{3} is the optimum value of N_D for CdS.

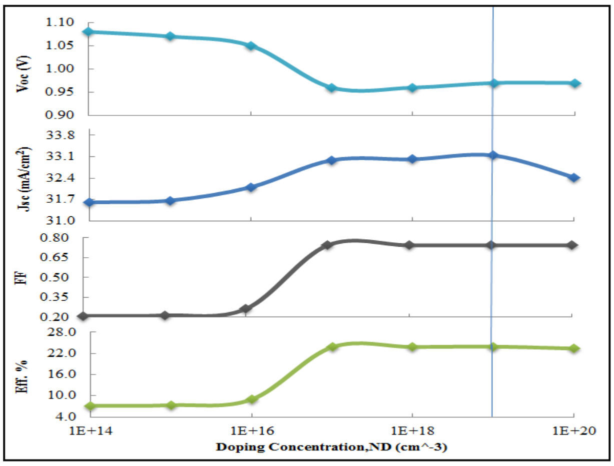

Fig. 2.CdS carrier density (N_D) optimization

2.2 Insertion of ZnS Buffer Layer in CIGS Solar Cell

By changing buffer layer CdS of CIGS solar cell with ZnS buffer layer we can optimize buffer layer by the variation of thickness of doping concentration N_D this later.

2.2.1 ZnS Buffer Layer Thickness Optimization

The thickness of ZnS buffer layer changing from 20nm-200nm. Here we can observe *Voc*, *Jsc*, fill factor is increasing and after thickness 60 these values are constant. And optimized thickness is selected 60nm.

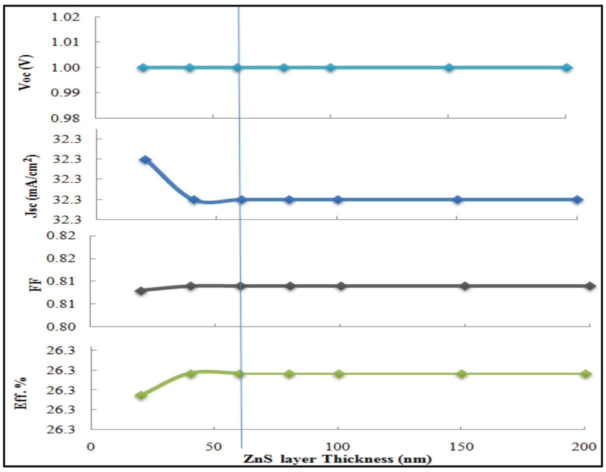

Fig. 3. Performance of ZnS layer thickness(nm) optimization

2.2.2 ZnS Buffer Layer Doping Concentration (N_D) Optimization

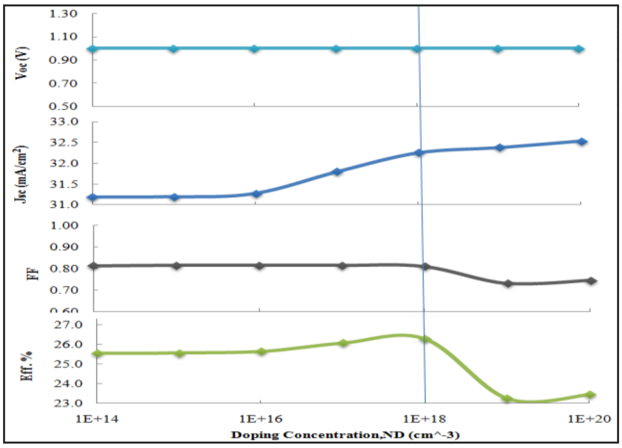

Fig. 4.Performance for ZnS doping concentration optimization

2.3 Insertion of ZnSe Buffer Layer in CIGS Solar Cell

By changing buffer layer CdS of CIGS solar cell with ZnSe buffer layer we can optimize buffer layer by the variation of thickness and doping concentration N_D.

2.3.1 ZnSe Buffer Layer Thickness Optimization

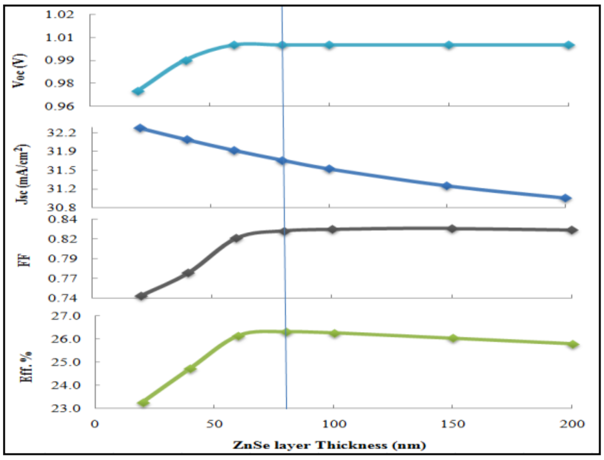

Fig. 5.Performance for ZnSe layer thickness (nm) optimization

The thickness of ZnSe buffer layer changing from 20nm-200nm. Here we can observe *Voc*, *Jsc*, fill factor is increasing and after thickness 80 these values are constant. And optimized thickness is selected 80nm. 80 nm is selected because it is easier to fabricate. It can not be fabricated at 40 nm and below it. At 80 nm efficiency is almost highest as well as fill factor is almost highest. Short circuit current density, *Jsc* is decreasing and open circuit voltage, *Voc* is constant after 80 nm.

2.3.2 ZnSe Buffer Layer Doping Concentration (N_D) Optimization

The doping concentration of ZnSe buffer layer changing from $1x10^{14}$-$1x10^{20}$. Here *Voc*, *Jsc*, fill factor is increasing. And after doping concentration $1x10^{16}$ efficiency is decreasing. Hence here optimized N_D is $1x10^{16}$.

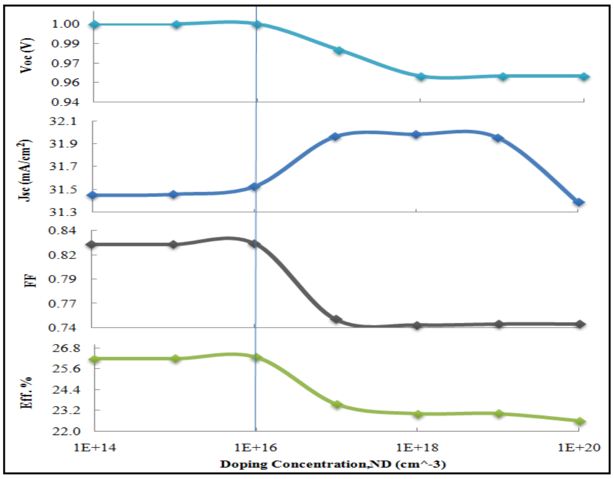

Fig. 6.Performance for ZnSe buffer layer doping concentration (cm^{-3}) optimization

2.4 Insertion of In_2S_3 Buffer Layer in CIGS Solar Cell

By changing buffer layer CdS of CIGS solar cell with InS buffer layer we can optimize buffer layer by the variation of thickness and doping concentration N_D of this. In_2S_3 buffer layer thickness optimization and In_2S_3 buffer layer doping concentration (N_D) optimization are discussed later.

2.4.1 In_2S_3 Buffer Layer Thickness Optimization

The thickness of In_2S_3 buffer layer changing from 20nm-200nm. Here we have observed *Voc*, *Jsc*, fill factor is decreasing. efficiency is also decreasing. And optimized thickness is selected 60nm. Thickness 60 nm is selected to ease the fabrication of ultra thin device. Thickness below 40 nm can not be selected. If the thickness is below 40 nm then it is not possible to fabricate because of less thickness.

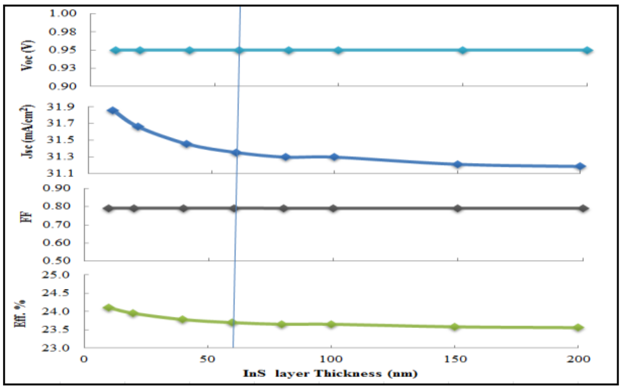

Fig. 7. Performance for In_2S_3 layer thickness (nm)

2.4.2 In_2S_3 Buffer Layer Doping Concentration (N_D) Optimization

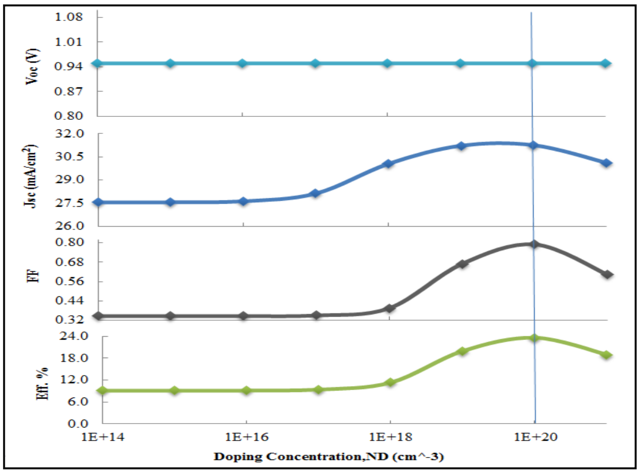

Fig. 8. The doping concentration of In_2S_3 buffer layer optimization

The doping concentration of In_2S_3 buffer layer changing from $1x10^{14}$-$1x10^{20}$. Here *Voc* is constant, *Jsc*, fill factor is increasing. And after doping concentration $1x10^{20}$ efficiency is decreasing. Hence here optimized N_D is $1x10^{20}$ Performance for In_2S_3 doping concentration (cm^{-3}) optimization.

3. RESULT AND DISCUSSION

Final simulated high performance CIGS solar cell with CdS buffer layer has the open circuit voltage, *Voc* is 0.969 Volts and the short circuit current density, *Jsc* is 32.982 mA/cm^2.

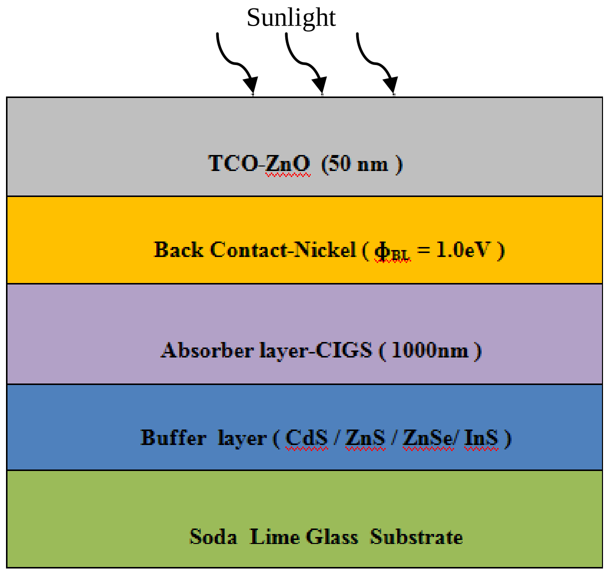

Fig. 9.Final high performance CIGS solar cell structure

However there was a compromise in the fill factor, FF of the cell which is 0.744. The efficiency of the final high performance CIGS solar cell is 23.772% at normal temperature, 298K.

By changing CdS buffer layer with ZnS, ZnSe and In_2S_3 buffer layer we get the efficiency of high performance CIGS solar cell 26.284%, 26.305% and 23.697%.

Table 2 : Comparison of the performance of different buffer layers

Buffer Layers	Efficiency η %	Open Circuit Voltage, *Voc* (volt)	Short Circuit Current Density, *Jsc* (mA/cm^2)	Fill Factor, FF %
CdS	23.772	0.96	32.982	0.744
ZnS	26.284	1	32.255	0.809
ZnSe	26.305	1	31.688	0.825
In_2S_3	23.60	0.95	31.353	0.792

The final result is presented with the comparison of different buffer layers in CIGS solar cell. High efficiency expected for wider bandgap buffer layer due to lower light absorption. Here ZnS and ZnSe has wider bandgap than CdS and In_2S_3 buffer layers, so small percentage of light absorbed in buffer layer and most of the light absorbed in absorber layer CIGS. Hence CIGS solar cells with ZnS or ZnSe buffer layer has high efficiency.

Again the comparison is shown through the I-V characteristics curve of different buffer layers together in a single graph.

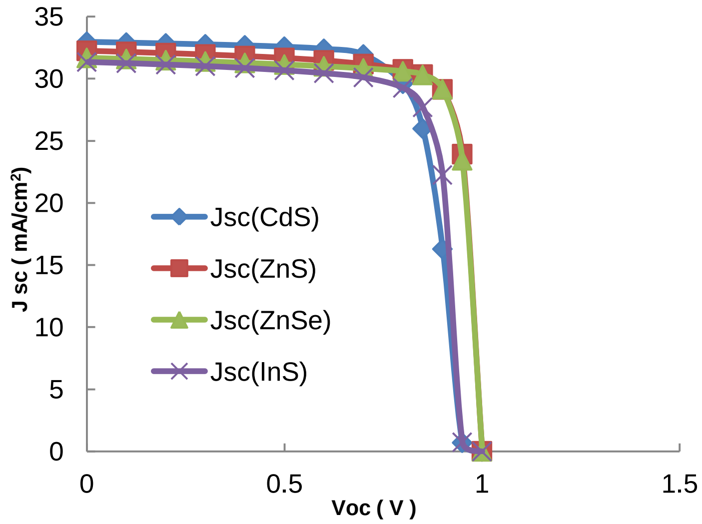

Fig. 10.Comparison of different buffer layers in an I-V characteristics curve

4. CONCLUSION

Materials like Zinc Sulphide (ZnS), Zinc Selenide (ZnSe) and Indium Sulphide (In_2S_3) were tested along with CdS. Results obtained with ZnSe, ZnS and In_2S_3 compare favourably well with that of CdS. Therefore they can be used as viable alternatives to the toxic CdS as buffer material for CIGS solar cells. In CIGS solar cell the main problem lies in high price and scarcity of Indium. That's why ZnS or ZnSe can be the well substitute of CdS because of it's toxic characteristic.

5. ACKNOWLEDGMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
V_{OC}	Open circuit voltage	(V)
J_{SC}	Short circuit current density	(mA/cm^2)
FF	Fill factor	Dimentio-nless