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A Highly Efficient Ultra-thin Film CIGS Solar Cell with SnS BSF Layer

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Abstract : *Numerical analysis of ultra-thin CIGS solar cell is done in this paper. First the baseline cell of CIGS solar cell is optimized by varying different parameter of layers of the cell within the range of limit to give desire efficiency. To reduce the cost of material of CIGS solar cell, the thin film cell thickness is reduced towards ultra-thin film cell i.e. 300nm. But efficiency of the cell also reduced with the thickness. For increasing the efficiency of the cell, SnS layer is added next to CIGS layer which act as BSF layer. Ultra-thin film CIGS solar cell with SnS BSF layer show higher Efficiency.*

Keywords: *Optimization, BSF layer, efficiency, absorbance, quantum efficiency.*

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I. Introduction

A photovoltaic cell is a device that produce electricity using semiconductor materials by conversion of sunlight. When photons of sunlight are absorbed by semiconductor materials, ejects electrons by creating a hole that is filled by surrounding electrons and thus create electron flow. This phenomenon of electron flow by photon absorption is called the photovoltaic effect. The PV's cell directs the electrons in one direction, which forms a current [1][2].

There are many types of photovoltaic cells. Silicon solar cell are first generation solar cell and rapidly use in the productions. But silicon cell has high cost compare to efficiency [3]. Thin film solar cells are second generation solar cell. Thin film solar sell are two types: III-V solar cells and chalcogenide solar cells. GaAs is the III-V thin film solar cell and CIGS, CdTe , CZTS are the Chalcogenide thin film solar cells.

The copper–indium–gallium–diselenide (CIGS) thin-film solar cell is well known in photovoltaic technology due to its high performance, low cost and stability [4]. In CIGS solar cell, most important layer is Cu(In1-xGax)Se2 which is absorber layer of the cell. The value x can be changed x=0 i.e. pure CuInSe2 to x=1 i.e. pure CuGaSe2 [5][6]. The band-gap of CIGS is continuously adjustable from 1.01eV for pure CuInSe2 to 1.7eV for pure CuGaSe¬2. The energy bandgap of Cu(In1-xGax)Se2 can vary according to the equation: Eg=1.011+0.421x+0.244x^2 Where x=Ga/(Ga+In) [7]

The variation of absorber layer bandgap change the optical characteristics of the layer. The thickness of the absorber layer is also important due to production cost and efficiency of the cell [6].

II. Modeling and Analysis

A. Baseline Cell:

M. Gloeckler et al. CIGS solar cell is taken in this paper as a baseline solar cell. The cell structure is shown in Fig. 1. There are 5 layer: TCO(Al:ZnO), Buffer layer(CdS), Absorber layer(CIGS), Back contact(Mo) and Substrate (Soda Lime Glass). The properties of baseline cell shown in Table 1 [8].

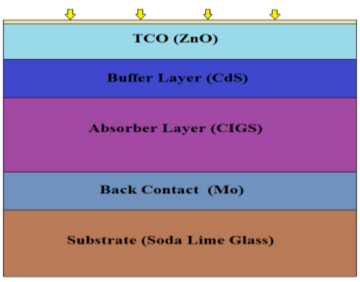

Fig.1. CIGS cell structure

Table 1. Properties of CIGS baseline cell [8].

Parameters and Units	ZnO	CdS	CIGS
Thickness(nm)	200	50	3000
Electron Affinity(eV)	4.5	4.4	4.5
BandGap(eV)	3.3	2.4	1.15
Dielectric Permittivity(relative)	9	10	13.6
CB Effective Density of States(cm^{-3})	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}
VB Effective Density of States(cm^{-3})	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}
Electron Mobility (cm^2/Vs)	100	100	100
Hole Mobility(cm^2/Vs)	25	25	25
Shallow uniform donor density N_D(cm^{-3})	1×10^{18}	1×10^{18}	0
Shallow uniform acceptor density N_D(cm^{-3})	0	0	2×10^{16}
Electron thermal velocity (cm/s)	1×10^{7}	1×10^{7}	1×10^{7}
Hole thermal velocity (cm/s)	1×10^{7}	1×10^{7}	1×10^{7}

Gaussian mid-gap defect are take in baseline cell defects [8]. 110 plane Molybdenum metal take as back contact which work function is high[9]. This work function of this plane is such that it reduces the Shockley barrier of metal semiconductor junction. The base line solar cell show 18.8% efficiency [8].

B. Optimization of CIGS Solar Cell:

SCAPS 1 D simulation software from Dr. Marc Burgelman is used for Numerical modeling & optimization of CIGS solar cell. By changing different parameter of different layers on SCAPS CIGS solar cell is optimized. First the bandgap of CIGS cell vary according to the equations Eg=1.011+0.421x+0.244x^2 , where x=Ga/(Ga+In) [7]. As the bandgap of absorber layer change, the absorber layer optical properties also change. Optical properties used here from SCAPS software of Paulson absorbtion data[10]. Band gap is changed for x=0, 0.31, 0.45, 0.66 and 1. The output of bandgap change is shown in Fig. 2. The Fig.2 shows that highest efficiency is possible for x=0.45 where bandgap of CIGS is 1.25.

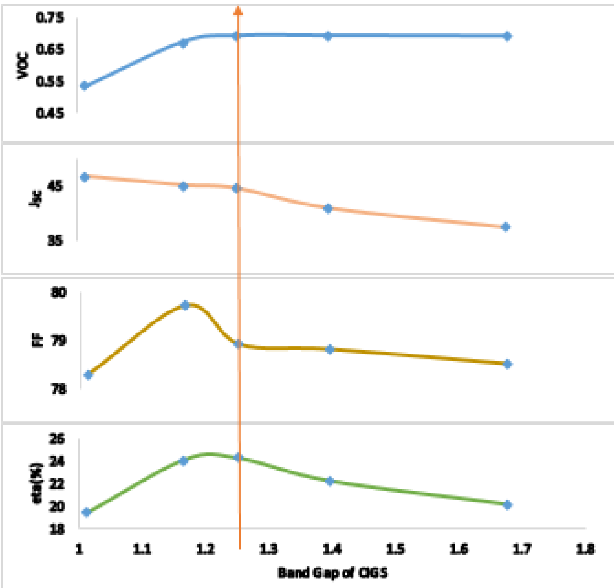

Fig. 2. Output of bandgap of CIGS layer change

After optimization of CIGS bandgap, thickness of TCO layer i.e. ZnO is varied from 20nm to 200 nm which is shown in Fig.3. From Fig.3, it is said that less thickness of ZnO layer show more efficiency. But lower thickness create production complication. For that thickness of ZnO is optimized at 30nm. Then shallow uniform donor density is varied from 1e16 to 5e19 cm-3 which is shown in Fig.4. Though efficiency is higher at higher donor density, it is difficult to make higher density. So, donor density is optimized at 5e18 cm^{-3}.

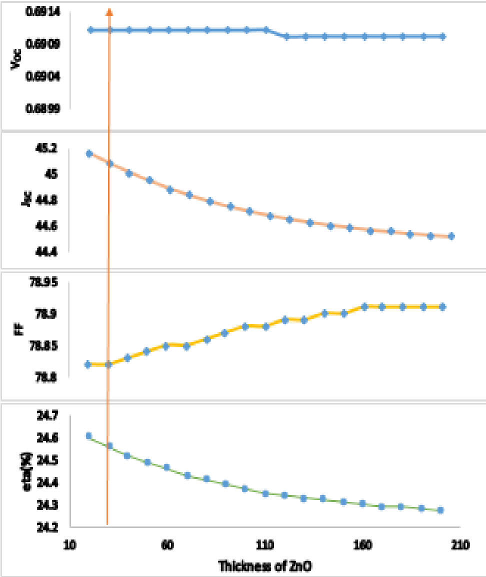

Fig.3. Output of thikness of ZnO layer Change

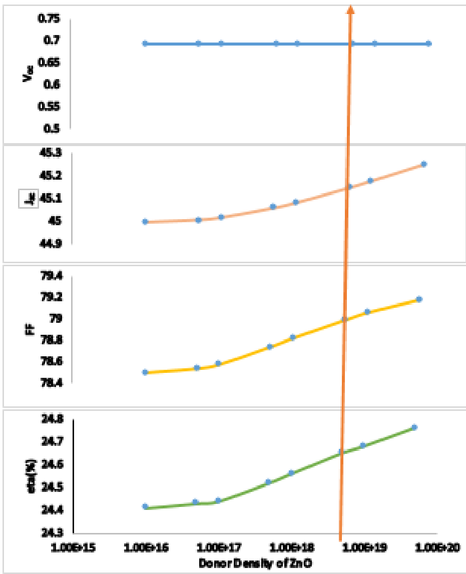

Fig.4. Output of Donor density of ZnO layer Change

Buffer layer, CdS thickness varied from 20nm to 100nm and optimized at 30nm which is shown in Fig.5. After then shallow uniform donor density of CdS varied from 1e16 to 1e19 cm-3 and optimized at 1e17 cm-3 which is shown in fig.6.

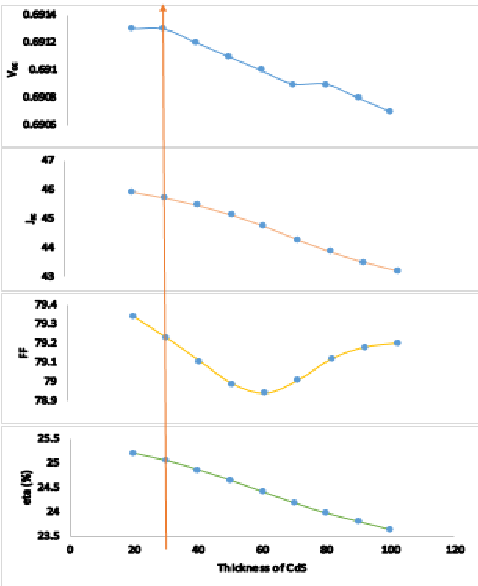

Fig.5. Output of thikness of CdS layer Change

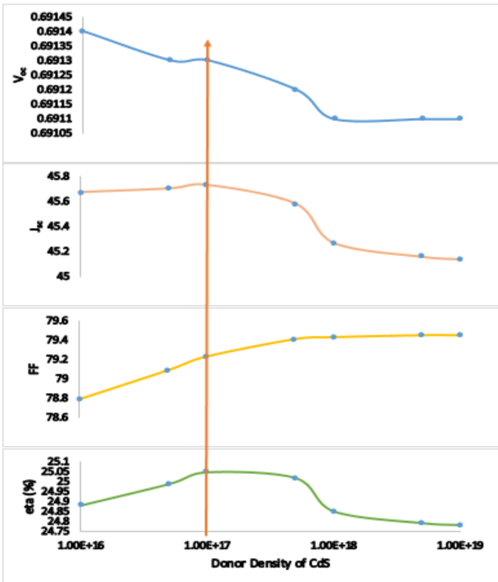

Fig.6. Output of Donor density of CdS layer Change

Acceptor density of CIGS absorber layer is varied from 1e15 to 1e17 cm^{-3} and optimized at 7e16 cm^{-3} which is shown in Fig.7. After then thickness of CIGS solar cell is varied from 1500nm to 3000nm which is shown in Fig.8. The efficiency increases with the increase the thickness of CIGS absorber layer of CIGS solar cell. But after 2500nm efficiency increasing rate is low. So, thickness is optimized at 2500nm.

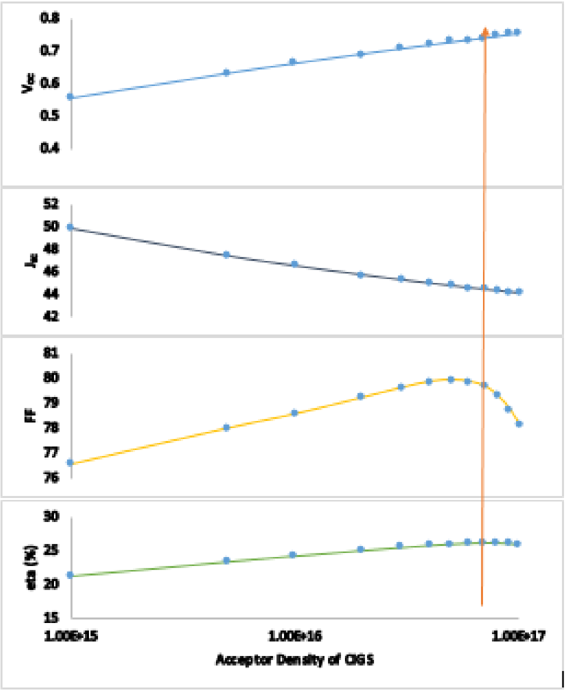

Fig.7. Output of Acceptor density of CIGS layer Change

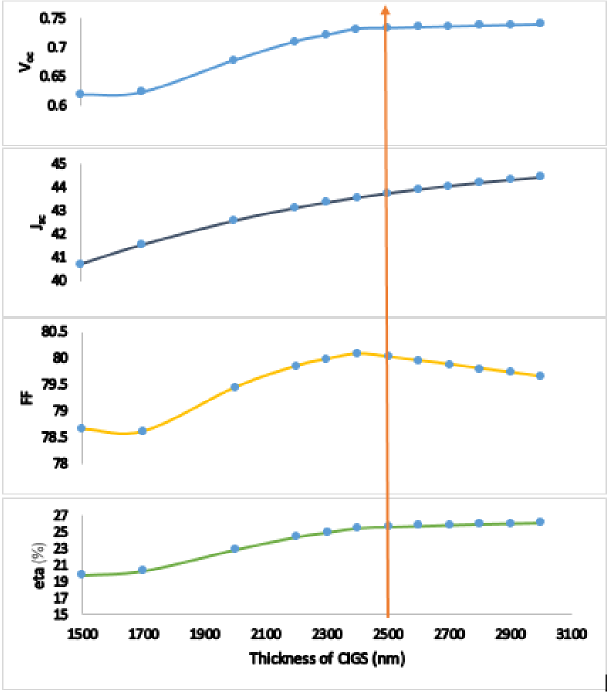

Fig.8. Output of thikness of CIGS layer Change

The final optimized cell show the 25.69 % efficiency with open circuit voltage, 0.734V, short circuit current 43.74293 mA/cm^2 and fill factor, 80.02%.

C. Ultra-thin cell and SnS BSF layer:

To reduce the material use for minimizing production cost CIGS thickness is changed towards ultra-thin film which thickness is less than 1000nm. For this Thickness of CIGS absorber layer is varied from 100nm to 700nm which is shown in Fig.9. After considering performance absorber layer thickness taken is 300nm where efficiency is 8.81%.

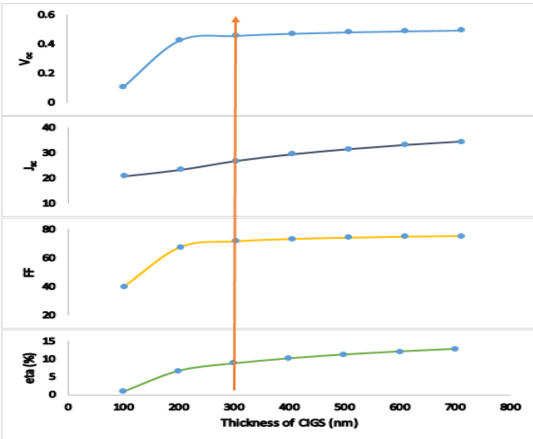

Fig.9. Output of thickness of CIGS layer Change to ultra-thin cell

Table. 2. Properties of SnS[11][12]

Thickness(nm)	20-100
Electron affinity(eV)	4.2
Bandgap(eV)	1.2
Dielectric Permitivity (relative)	13
CB Effective density of states(cm^{-3})	2.2×10^{18}
VB effective desnsity of states (cm^{-3})	1.8×10^{19}
Electron Mobility (cm^2/Vs)	15
Hole Mobility (cm^2/Vs)	100
Shallow uniform donor density (cm^{-3})	0
Shallow uniform donor density(cm^{-3})	1×10^{16}

The efficiency of ultra- thin film solar cell is very poor. A BSF layer can increase the efficiency. In this paper SnS layer is used as BSF layer. The properties of SnS layer shown in Table 2 [11][12]. After inserting the BSF layer i.e. SnS layer, thickness of BSF layer is varied. Fig.10 show the variation of thickness of SnS layer. SnS layer thickness is optimized at 40 nm.

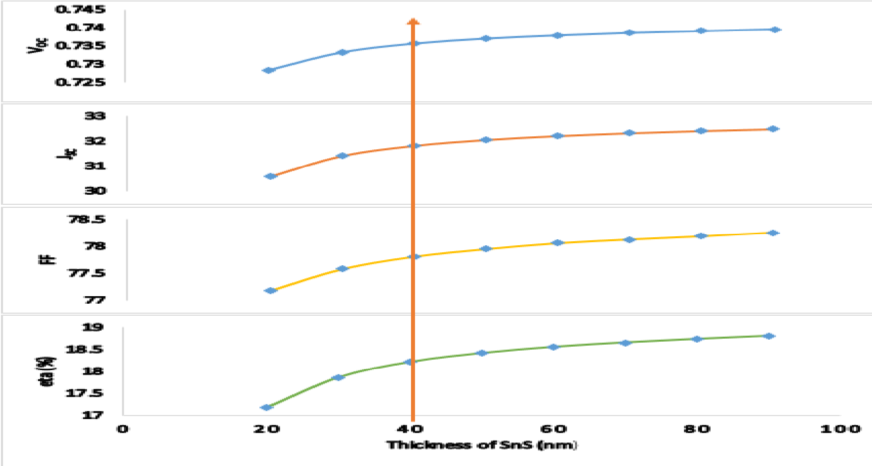

Fig.10. Output of ultra-thin CIGS cell with SnS BSF layer thickness change

III. Results

The proposed ultra-thin film CIGS solar cell with SnS solar cell is shown in Fig.11 and properties of its shown in Table 3. The proposed cell absorber layer thickness is 300nm and SnS BSF layer thickness is 40nm. The proposed cell show 18.22% efficiency whereas without BSF layer CIGS cell with 300 nm absorber layer show only 8.81% efficiency. Band diagram of the proposed cell is shown in Fig.12.

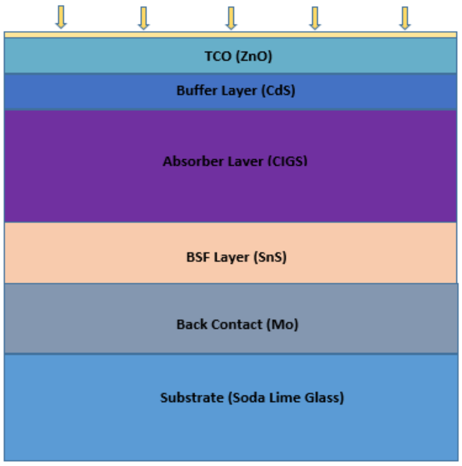

Fig. 11. Proposed cell

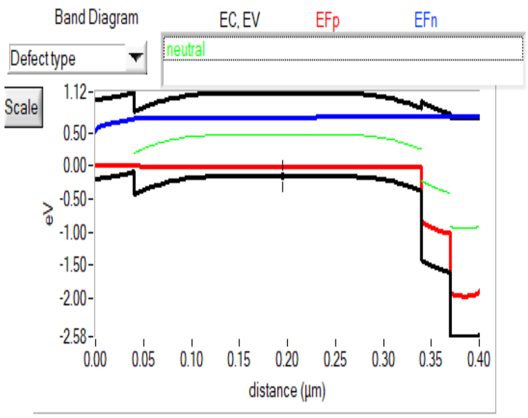

Fig. 12. Band diagram of Proposed cell

Table. 3. Properties of Proposed ultra-thin cell with SnS BSF layer

Parameters and Units	ZnO	CdS	CIGS	SnS
Thickness(nm)	30	30	300	40
Electron Affinity(eV)	4.5	4.4	4.5	4.2
BandGap(eV)	3.3	2.4	1.25	1.2
Dielectric Permittivity(relative)	9	10	13.6	13
CB Effective Density of States(cm^{-3})	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}
VB Effective Density of States(cm^{-3})	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}
Electron Mobility (cm^2/Vs)	100	100	100	15
Hole Mobility(cm^2/Vs)	25	25	25	100
Shallow uniform donor density N_D(cm^{-3})	5×10^{18}	1×10^{17}	0	0
Shallow uniform acceptor density N_D(cm^{-3})	0	0	7×10^{16}	1×10^{16}

The quantum efficiency of the proposed ultra-thin CIGS solar cell with SnS BSF layer and the quantum efficiency of optimized CIGS solar cell are shown in Fig.13. In lower wavelength quantum efficiency of proposed cell and optimized cell are almost equal. But for higher wavelength proposed cell quantum efficiency is low due to thin absorber layer. Efficiency vs. temperature show in Fig.14. From this figure it is easily conclude that efficiency remain unchanged with temperature.

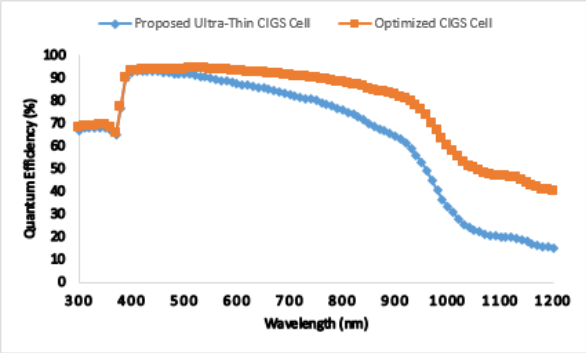

Fig.13. Quantum Efficiency of Proposed cell and Optimized cell

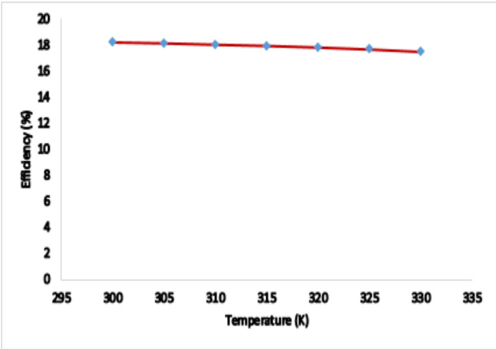

Fig. 14. Temperature vs. efficiency curve of proposed cell

IV. Conclusion

CIGS solar cell are well known thin film solar cell. To reduce the material cost, absorber layer thickness is reduced to ultra-thin level. SnS layer inserting as BSF layer increase the efficiency after reducing the thickness. The 300nm CIGS absorber layer along with 40 nm SnS layer show efficiency of 18.22% with 0.73 V open circuit voltage, 31.83 mA/cm^2 short circuit current and 77.81% fill factor. The change of efficiency of the cell is small i.e. remain constant with the temperature. In future this cell can be implement to reduce material without reducing the efficiency.

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