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Tin Sulfide as a potential BSF for CZTS solar cell

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Abstract- Kesterite CZTS is one of the promising solar cell materials for its high efficiency, cost-effectiveness and thermal stability. In this research work, numerical analysis is done by wx-AMPS simulator to investigate the cell performances (Jsc, FF, Voc, efficiency and temperature stability) of ultra-thin CZTS solar cell. Reduction of absorber layer was done and observed that 950 nm absorber layer is enough for acceptable range of cell conversion efficiency in the proposed cell. The possibility of this ultra-thin CdTe absorber layer was investigated, together with 90 nm SnS back surface field (BSF) layer to reduce the barrier height in the valence band and to minimize the recombination losses at the back contact of the CdTe PV cell. From the investigation, it was found that the proposed ultra-thin cell have conversion efficiency of 16.52% (Jsc = 23.32 mA/cm2, FF = 0.794, Voc = .891 V) without BSF and with 90 nm SnS BSF conversion efficiency increased to 19.37% (Jsc = 30.5 mA/cm2, FF = 0.765, Voc = .833 V) with only 0.95 μm of CZTS absorber layer. Moreover, the normalized efficiency of the proposed cell was linearly decreased with the increasing operating temperature at the gradient of -0.22%/°C found in this analysis respectively, which indicated better thermal stability of the proposed CZTS solar cell.

Keywords: CZTS absorber layer, SnS BSF layer, wx-AMPS, Thin film solar cells

1. INTRODUCTION

For the sustainable development in the arena of energy harvesting focus mainly on solar energy which is the most reliable and abundant form of renewable energy that serve as an alternative resource of energy for rapid raising demand of power consumption. Conventional energy sources are diminishing day by day in response of bulk demand of energy and consequently the price of these energy sources are increasing gradually. At present, it is burning question to explore the alternative source of energy having clean, environment friendly, cost effective and sustainability.

Si-based solar cells are treated as first generation solar cells have been dominating in the field of Photo energy harvesting from the sun rays for the last few decades for the property of high conversion efficiency. Prospects of Si solar cells faced challenges due to the high cost of Si refining and risk to fall some of their efficiency at higher temperatures at hot sunny days and also decreases at a certain manner year by year than thin-film solar cells. Polycrystalline second generation thin film solar cells (CdTe, CIGS and CZTS) have been considered as the most promising alternate to Si based solar cells. As a second generation solar cell, extensive research work is going on CdTe and CIGS solar cells and 20% to 22% conversion efficiency have been achieved by the researchers [1][10].But the most thoughtful problem with efficiency CdTe and CIGS solar cell is their rarer material used in the semiconducting compound.

Researchers are very much optimistic and highly confident in implementing the CZTS solar cell because of the abundance of Zinc (Zn) and Tin (Sn) in earth's crust. The availability of Sn and Zn are 45 times and1500 times greater than that of Indium (In) respectively. Moreover Tellurium (Te) availability has reached its limit to harvest from earth's crust. Consequently the price of

Zn and Sn is many many times cheaper than that of In due to its scarcity and refining cost effect [2].Subsequently, investigation has been done on CZTS thin film solar cell to explore the hidden potentiality by adding different additional layer materials as the availability of Zn and Sn led to design cost effective and high efficiency thin film solar cells. The abundance of Zn and Sn motivated to perform research work on CZTS solar cells since the scarcity and high costing problem of In and Ga are replaced by mostly available Zn and Sn respectively. CZTS has high photon absorption coefficient about (10^4 cm^{-1}) and optimal direct band gap energy of 1.4-1.5 eV which are absolutely required in solar cell materials as the best photo-conversion performing solar cell [3][12].The structures of CZTS are stannite and kesterite considering the different locations of Cu and Zn. The kesterite structure showed the property of high stability [4] and the stannite structure exhibits monocrystal found by Olekseyuk et al. [5]. Typically Cu-rich growth method provides a better grain size and better photo-conversion performance also. Tanaka et al. mentioned that the higher ratio of Cu/(Zn+Sn) gives an improved the grain size but Cu-rich condition having low resistivity which caused unfitness for the fabrication of solar cell [6][13].Highest efficiency obtained 17.89% by Mrinmoy et al. in REL CUET using (i-ZnO/n-Bi_2S_3/p-CZTS) structure instead of CdS buffer layer [7].

In this research work, numerical analysis was done to explore the possibility of ultra-thin CZTS solar cell with FTO as transparent conducting oxide(TCO) and SnS as back surface field(BSF) as potential cell structure using wx-AMPS to improve the different parameters of cell performance. During the research, effect of BSF, variation of the thickness of BSF layer, variation of doping concentration, effect of capture cross section, Quantum efficiency and thermal stability are investigated for efficient CZTS solar cell.

2. MODELING AND SIMULATION

In this research work, the purpose of numerical modeling and simulation were done using wx-AMPS to investigate the possibility of ultra-thin CZTS absorber layer for low cost solar cells. By incorporating a 100 nm TCO layer as a front contact (FTO), a 30nm window layer (i-ZnO), a 40 nm buffer layer (CdS) and a 90nm BSF layer of tin sulfide (SnS) to be added in 950 nm CZTS solar cell. Fig.1: shows the schematic diagram of the proposed CZTS solar cell structure used in this work.

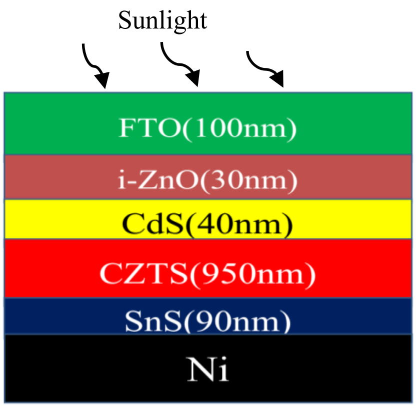

Fig.1: The proposed structure of CZTS solar cell

Ni has been used as a back contact material in this proposed CZTS solar cell structure.

Table 1: Parameters used for the simulation of CZTS solar cell

	FTO	i-ZnO	CZTS	SnS
Layer thickness (nm)	100	30	950	90
ε	10	9	10	12.5
E_g	4.20	3.27	1.5	1.25
χ	4.50	4.6	4.5	4.2
N_c	1.2×10^{20}	2.2×10^{18}	2.2×10^{18}	1.0×10^{19}
N_v	7.0×10^{20}	1.88×10^{19}	1.8×1019	4.3×10^{19}
μ_n	20	100	20	100
μ_p	100	25	100	25
N_D	1.0×10^{16}	1.0×10^{5}	0	0
N_A	0	0	1.0×10^{14}	2.0×10^{19}

Table 1 shows the materials parameters used to design CZTS solar cells which were selected based on experimental data, literature values, theory, or in some cases reasonable estimations

3. RESULT AND DISCUSSION

3.1 Effect of the presence of Tin sulfide (SnS) BSF layer

Back surface field BSF usually used for minimizing recombination losses of electron within the absorber layer and back contact. Use of BSF layer affects conversion efficiency of the CZTS solar cell.

Table 2: Output parameter of CZTS cell with and without BSF layer

Parameter	With BSF	Without BSF
Voc(V)	0.833	0.891
Jsc(mA/cm^2)	30.35	23.32
FF%	76.55	79.48
Efficiency%	19.37	16.52

Around 2% efficiency increased in case of using Tin sulfide (SnS) BSF layer.

3.2 Effect of absorber layer Thickness with BSF layer

In order to preserve the absorber layer material in case of designing highly efficient solar cells it is mandatory to investigate into the performance of solar cell with the

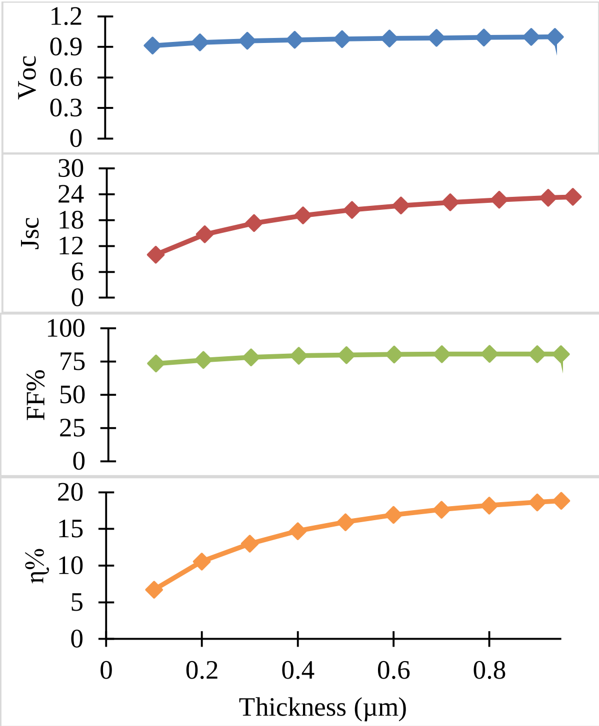

Fig.2: Effect of CZTS thickness variation for the proposed cell

variation of absorber layer thickness. Numerical analysis has been done to evaluate the performance of CZTS solar cell structure (FTO/i-ZnO/CdS/CZTS/SnS). The simulation results for thickness variation of absorber layer from 0.1 μm to 1 μm are shown in Fig. 2 below.

Fig.2: shows performance of CZTS solar cell with differentcell performance parameters for the variation of absorber layer with additional p-type BSF layer back to CZTS layer.The cell performance parameter V_{oc} is increased almost linearly with the increase of absorber layer thickness and J_{sc} shows increasing trend but approximately saturated after 900nm thickness of absorber layer. The magnitude of FF is not noticeably increased with the increase of absorber layer thickness. The highest conversion efficiency 19.37% (FF = 0.765, V_{oc} = 0.83 V and J_{sc} = 30.35 mA/cm^2) was achieved for only 950 nm thickness of absorber layer in the proposed CZTS solar cell. These results of cell performance are according to the related published work [2]. The conversion efficiency is improved about 2% for the decrease of absorber layer thickness from 3 μm to .95 μm. This research work indicated that the preservation of CZTS absorber layer material was possible around 70% without compromising cell efficiency rather than increasing in conversion of 2 % efficiency.

3.3 Effect of Doping concentration of absorber layer

The performance of solar cells depends on the amount of doping concentration. In this study, the doping concentration of p- type absorber layer is varied from 1×10^{13} to 1×10^{17} cm-3 to evaluate the performance of

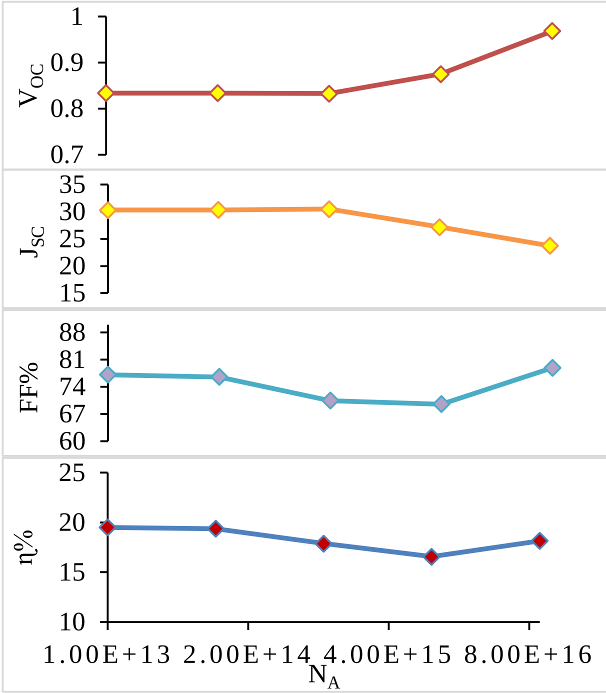

Fig.3: Effect of the CZTS doping concentration on cell performance

CZTS solar cell with CdS buffer layer and additional (SnS) BSF layer. Fig.3: depicts the performance of hetero-junction CZTS solar cell under different level of practically attainable doping concentration. The cell basic parameter current density is almost constant in response to certain value and then on the decreasing trend according to the variation of absorber layer doping concentration whereas the open circuit voltage cell parameter is increasing trend. The FF is in decreasing trend after a certain level of doping concentration and raised suddenly. The performance of cell conversion efficiency is increased to 19.37% at highest doping concentration (1.0×1014 cm^{-3}) of CZTS absorber layer.

3.4 Quantum efficiency

The With BSF layer CZTS solar sell showed higher Quantum efficiency than without BSF layer. Here it's confirmed that higher quantum efficiency extended to a wider band of light within visible and invisible range of light around 400nm to 1000nm wavelength QE becomes constant.

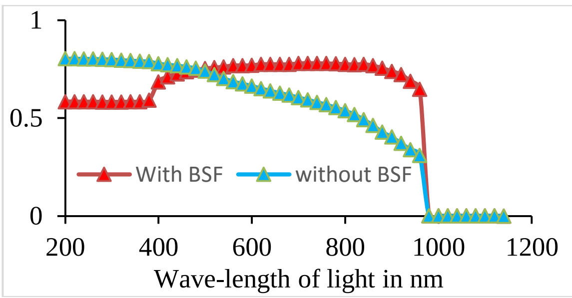

Fig.4: Comparison of Quantum efficiency with BSF and Without BSF layer

3.5 Capture cross section

In this study, the performance of CZTS solar cells are investigated based on the variation of hole capture cross section with the constant magnitude of electron capture cross section Which has been shown in the Fig.5:. Efficiency and output parameter changed with capture P

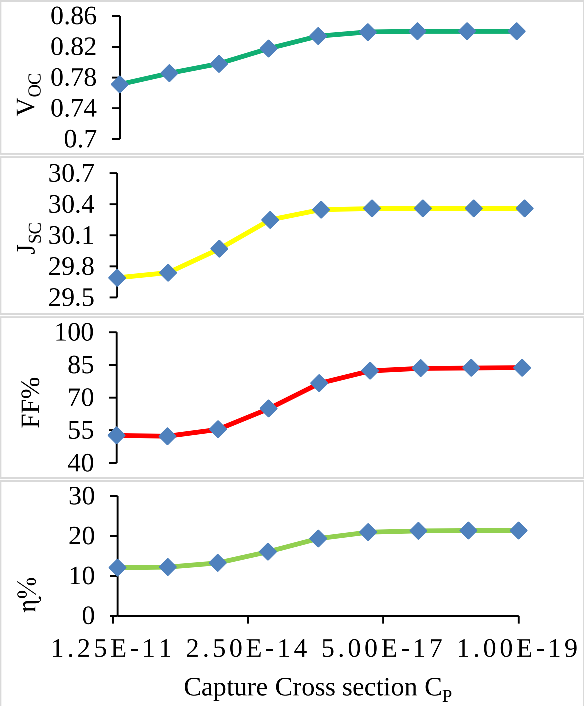

Fig.5: Effect of capture cross section of hole on cell performance

Fig.5: shows the performance of different cell parameters of CZTS solar cell after the variation of hole capture cross section. The conversion efficiency is almost constant with the increase of the order of capture cross section up to 1×10^{-19} cm^2. The performance of CZTS solar cell is constant in response of hole capture cross section after 1×10^{-15} cm^2.

3.6 Effect of Temperature

The performance of solar cells is affected by the operating temperature and it is considered as important issue to test the designed solar cell for better thermal stability. To investigate the cell thermal stability, it is mandatory to examine the performance of designed CZTS solar cell with higher operating temperature. For this purpose, the proposed cell has been examined with higher operating temperature ranging from 0°C to 100°C which has been shown in Fig. 5. The cell conversion efficiency showed decreasing trend with the increase in operating temperature as expected. Open circuit current and current density decreased rapidly as operating temperature increased to a certain limit. The highest efficiency reached about 19.37% at the temperature of 25°C or 298K.

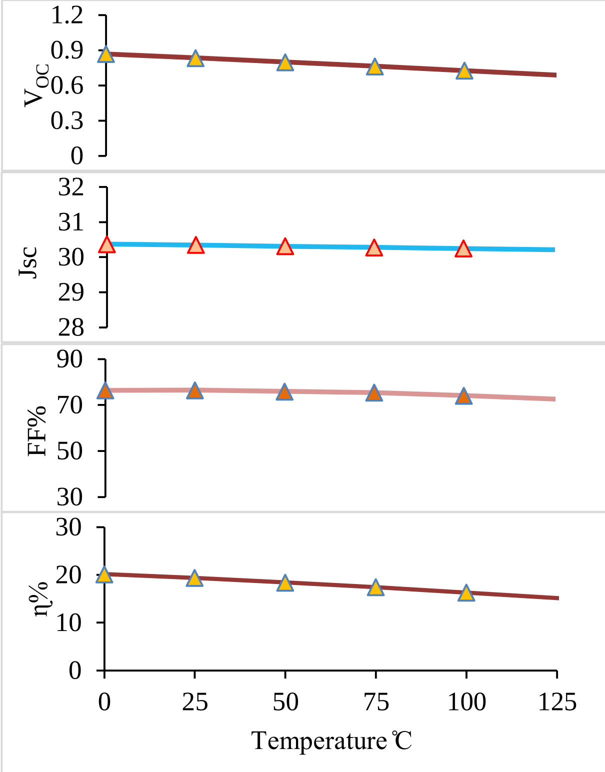

Fig.6: Effect of temperature on cell performances

The normalized efficiency of solar cell is decreased with the increase of operating temperature. It is evident from Fig.6: that the normalized efficiency of the proposed CZTS cell has linearly decreased with the increase of operating temperature at a temperature coefficient (TC) of -0.22%/°C.

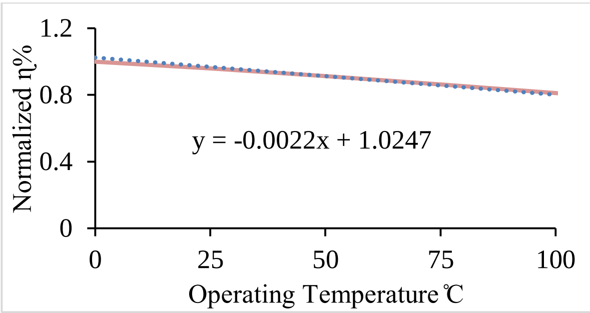

Fig. 7: Effect of operating temperature on normalized efficiency

Fig. 7: Shows that TC follows the equation (y = -0.0022x + 1.0247). This TC indicates better stability of the cells at higher operating temperature. Whereas temperature co-efficient was about -0.42%/°C for CZTS cell structure without BSF layer.

4. CONCLUSION

The prospect of CZTS solar cell with back contact buffer layer and newly emerged front contact FTO was investigated to design very low cost, highly efficient and stable ultrathin CZTS solar cell structure. The highest efficiency was achieved 19.37% (FF =0.765, V_{oc} = 0.83 V and J_{sc} = 30.35 mA/cm^2) for 100 nm FTO front contact layer, 30 nm i-ZnO as protective layer, 40 nm CdS as buffer layer, only 950 nm CZTS absorber layer with 90 nm SnS BSF material. Series and shunt resistance also changed (shunt and series resistance 3604 ohm/cm^2 and 0.1207 Ohm/cm^2) because of using better front contact (FTO). The thermal stability curve of the proposed cell indicated better stability at higher operating temperature with temperature gradient of -0.22%/℃.

5. ACKOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
$\varepsilon/\varepsilon_0$	Permittivity	
E_g	Band gap	(eV)
N_c	Density of states in the valence band	(1/cm^3)
N_V	Density of states in the valence band	(1/cm^3)
μp	hole mobility	(cm2/Vs)
μn	electron mobility	(cm2/Vs)
N_D	donor concentration	(1/cm^3)
N_A	Acceptor concentration	(1/cm^3)
χ	Affinity	(eV)
η	Efficiency	%