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Numerical analysis of a highly efficient CdTe/CdS:O solar cell with BSF

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Abstract: The polycrystalline cadmium telluride is known as one of the leading photovoltaic materials due to its superior optoelectronic properties and possibilities of cost effective fabrication. It has a direct bandgap of 1.45 eV and absorption coefficient over $5x10^5$ /cm. It was investigated the possibility of using double buffer layer and BSF to increase the cell performance by numerical analysis with SCAPS-1D simulator. The CdTe absorption layer was reduced to 1 μm only with ZnTe as BSF layer. The Viability of using double buffer layer of ZnO and Zn_2SnO_4 was examined and it showed maximum conversion efficiency of 26.34% (V_{OC}= 1.07 V, J_{SC}=28.7771 mA/cm^2, FF= 85.04%). The proposed cell structure is (Glass/SnO_2/Zn_2SnO_4/ ZnO/ CdS:O/ CdTe /ZnTe /Ni).The thermal stability was investigated and shown temperature coefficient of -0.268 %/°C which clearly indicate the better stability of the proposed cell.

Keywords: Solar cell, CdTe, CdS:O, ZnO, Zn_2SnO_4, BSF, SCAPS-1D, Efficiency, Stability.

I. INTRODUCTION

The Sun is the main source of all energies. As the sun's energy reaches to the earth surface, two third of the energy are absorbed by lands and sea, rest of the energy gets reflected back. The globe is converting to more environmentally friendly energy sources to meet demand because non-renewable energy resources are becoming scarce and have negative effects. Maximum portion of renewable energy shares come from solar photovoltaics till now. A solar photovoltaic system uses photovoltaic cells to convert solar radiation from the sun into usable electrical energy. Semiconductors are used in this process. This energy conversion technique is known as Solar photovoltaic [1]. One of the most promising materials for an effective and affordable photovoltaic solar cell is cadmium telluride. CdTe thin film solar cells under AM1.5 light have demonstrated high conversion efficiency and long-term stable performance for terrestrial use [2]. Although CdTe-based PV modules are already being produced in large quantities, there is still room for improvement in terms of cell efficiency, material utilization, and PV cell stability. These issues will be discussed and statistically investigated to uncover the CdTe/CdS material system's latent potential for greater cell efficiency [3].

Over the past decade, the cost of thin-film solar cells has dropped significantly relative to non-thin-film solar cells and on a wide scale, they are less expensive owing to material utilization, making them easier to adopt [4]. The Direct Bandgap of the semiconductor material, optical absorption coefficient, lattice and electron matching with other materials, and manufacture of n-type and p-type material are all factors that effects how a solar cell functions [5]. Several low-cost methods, including close-spaced-sublimation (CSS), physical vapour deposition (PBD), chemical bath deposition (CBD), and magnetron sputtering, can be used to deposit the polycrystalline layers of a CdS/CdTe cell [6].

CdTe solar cells have a theoretical efficiency of 29% but only reach a maximum actual efficiency of 17.3% [7][8]. A 6% efficiency was reported by Bonnet et al in 1972. Tyan et al. had attained a 15.8% efficiency. For a CdS/CdTe solar cell, Xuanzhi Wu measured an efficiency of 16.5% in 2001. [9][10]. The best cell efficiency achieved was 16.5% whereas the commercial module is 11% efficient [5].

II. MODELING AND SIMULATION

Numerical analysis has been done in order to compare proposed modified cell performance with the baseline solar cell and check whether the proposed cell is feasible to fabricate in real life implementation. In this case a baseline solar cell was chosen to modify which is shown in figure 1(a). Some of the problem associated with different layer of base cell was investigated first then tried to modify the structure to overcome these limitations. In case of window layer of CdS, it has lower bandgap which means it directs less optical photon to the absorber layer resulting low conversion efficiency. And because of thin CdS layer, diffusion arises from buffer layer to absorption causes deterioration of quantum efficiency of the cell.

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Besides, there exists lattice mismatch among different layers which degrades the performance parameters of solar cell because it forms pinhole which leads to carrier recombination loss.

This is the reason, a high bandgap material is suited best for window layer. So a window layer of CdS:O was inserted to overcome this problem cause it has e higher band gap as compared to cadmium sulfide. So it allows more light to incident on the CdTe absorber layer and prevent emission of carrier from window layer. Besides due to high resistive window layer materials, leakage current through the cell is interrupted.

Table 1: Layer properties of the cell

Layer propert-ies	**ZnTe**	**p-CdTe**	**n-CdS:O**	**ZnO**	**Zn2 SnO4**	**SnO2**
Thickness (μm)	0.200	1.00	0.05	0.1	0.200	0.2
Bandgap Energy,Eg (eV)	2.5	1.45	2.8	3.0	3.35	3.6
Electron affinity, χ (eV)	3.65	4.28	4.5	4.5	4.5	4.0
Dielectric constant, ε/ε0	14.00	9.4	9.00	9.0	9.00	9.0
Electron mobility, μc (cm2/Vs)	70	320	350	100	320	100
Hole mobility, μh(cm2/Vs)	50	60	50	25	30	25
Conduction band density (cm-3)	7*e17	8*e17	1.8*e19	2.2*e18	2.8*e18	2.2*e18
Valance band de- nsity, Nv (cm-3)	2*e19	1.8*e19	2.2*e18	1.8*e19	1.8*e19	1.8*e19
Donor/Acceptor density, ND/ NA (cm-3)	1*e19	2*e15	1.1*e17	1.1*e19	1.1*e19	1*e17

Again high resistive buffer layer is inserted as a supportive layer of window layer. By supplying larger grains throughout the CBD process, the smoother high-resistive buffer layer further enhances the CdS film morphology [11].

In this work ZnTe was used as Back surface Field layer in order to reduce the barrier height in the back contact resulting the further improvement in power conversion efficiency.

It works like an electron reflector and increase the short circuit current density and hence efficiency. It also plays an important role to establish a stable ohmic contact in the back surface which increase the stability of the cell. In the back contact, Nikel (Ni) was used because it shows better performance with ZnTe BSF layer.

Details of all the parameters utilized in this study, which were chosen based on literature, theory, and experimental data, are included in the table above [12][13].

The front contact layer for the modified baseline structure is made of tin oxide at a 200nm thickness. In order to maximize efficiency, the doping concentration of the CdTe layer was varied while monitoring the effects of the modifications [14].

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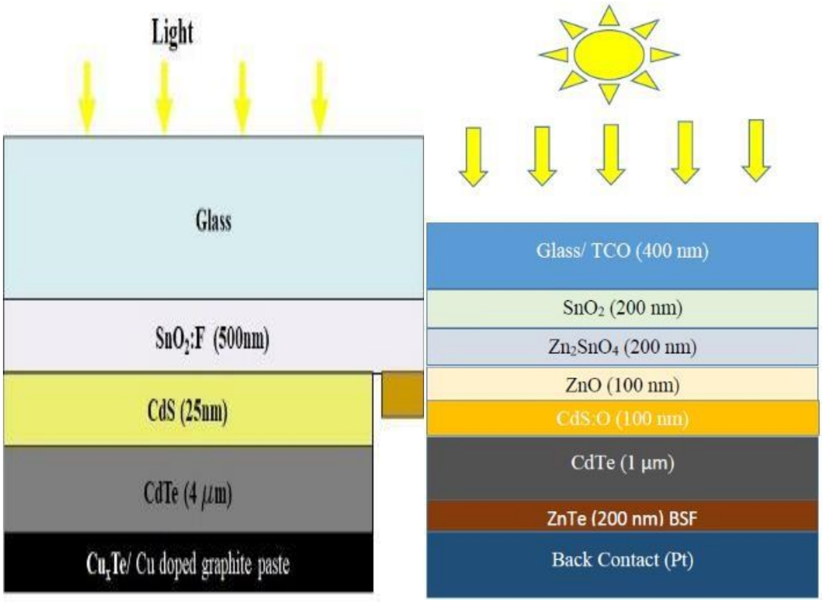


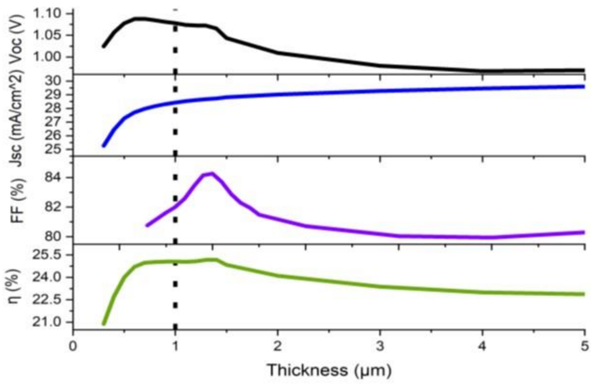
(a) (b)

Fig. 1. Structures of CdTe solar cells: (a) Baseline Structure (b) Proposed Modified Structure.

In the final stage, both ZnO and Zn2SnO4 was inserted as buffer layer were used to see the cell performance. After taking into account all of the above mentioned suggestions, the revised suggested structure is depicted in figure 1(b). Solar cell capacitance simulator was the program used to model the cell and determine the output parameter. The SCAPS application was created to simulate the electrical properties of the thin film hetero-junction solar cell and offers a large number of variable settings.

III. RESULT AND DISCUSSION

This numerical Analysis has been done aiming to realize different properties of the new proposed structure in comparison with the baseline structure. The absorber layer underwent the first alteration in the new construction. To track changes in the performance characteristics, the absorber layer's thickness was changed from 300 nm to 5000 nm. It was seen that with the increase of thickness of CdTe layer, the efficiency increases but considering the material uses, 1000 nm thickness was chosen as the absorber layer thickness. Because after the thickness of 1000 nm, if the thickness increases although the efficiency shows increasing trend but the increasing rate is not satisfactory as compared to the material needed. If thickness is thickening, more photons can be absorbed that is why conversion efficiency increases. Fig.2 shows the performance parameters changes with thickness variation of absorber layer. After this, absorber layer doping concentration was changed to see the performance parameter changes.



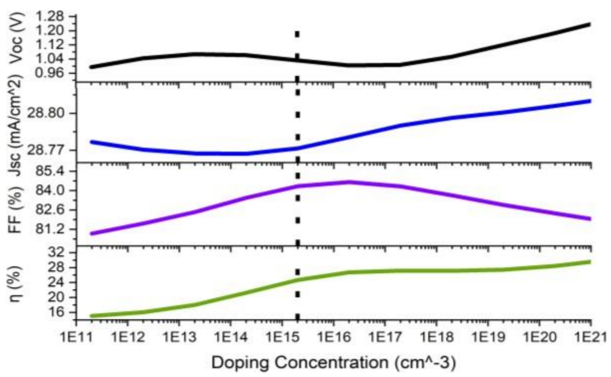


Fig.2. Changes of performance parameters with the variation of thickness of absorber layer.

Fig.3. Change of performance parameters with the change of doping concentration of absorber layer.

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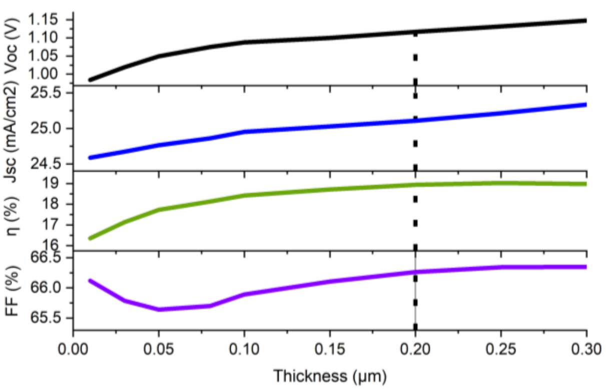
It was observed that with higher the doping concentration of the absorber layer, higher the conversion efficiency. But to consider the cost effectiveness, the doping concentration was fixed at $1x^{15}/cm^3$. After this, a BSF layer of different material of higher bandgap and lower permittivity was inserted at the back contact and observed the effects of these layers. The ohmic contacting issue at the rear contact of CdTe-based solar cells is caused by the material's large electron affinity and subsequently large work function [15]. BSF is the best possible way to overcome this problem to make a stable ohmic contact which eventually improve the performance parameters of the cell. With the insertion of BSF layer, the performance parameter was improved. ZnTe was chosen as BSF layer due to its high bandgap and changed its thickness and doping concentration. It was found that with the increase of thickness, the efficiency also increased and at 200 nm thickness better performance has achieved.



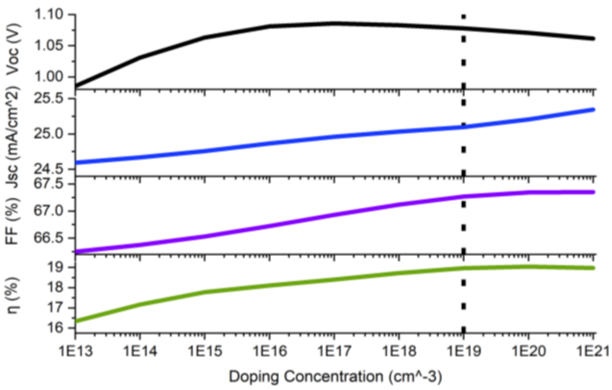
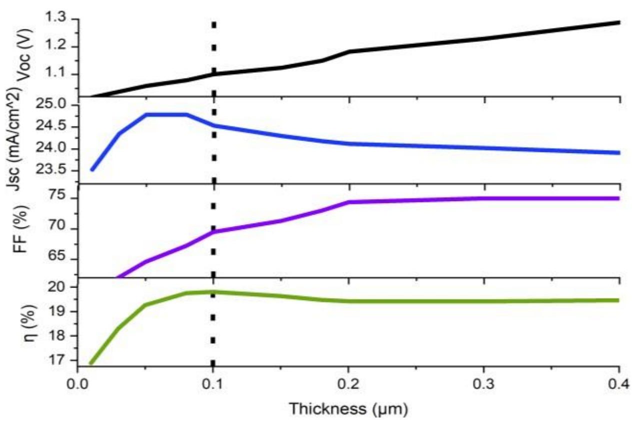


Fig.4. Effect of thickness variation of ZnTe on cell efficiency. Fig.5. Effect of doping concentration variation of ZnTe on cell efficiency.

In the Fig.4 variation of cell performance parameters are shown with respect to thickness of zinc telluride layer. It helps to form a stable ohmic contact at the back contact and reflect electron from the back surface which results in increasing efficiency as minority recombination loss is reduced. In the same way, Doping concentration was varied and took the best performance in consideration. The variation of performance parameters with respect to doping concentration of zinc telluride is shown in Fig.5.

At this stage, two buffer layer was inserted. High resistive material like ZnO and Zn_2SnO_4 were used as buffer layer. Buffer layer works like a supportive layer of window layer. Because of high resistance, buffer layer interrupt leakage current through the cell, so performance parameter improved. Besides little secondary emission occurs here which eventually increase the efficiency. In addition, due to using double buffer layer, the diffusion of tin oxide to CdS layer is restricted strictly. That is why using double buffer layer increase the efficiency of the cell. It was found that 200 nm Zn_2SnO_4 and 100 nm of ZnO has showed best performance parameter. Besides doping concentration of these layers was varied and observed the variation of performance parameter of the solar cell.



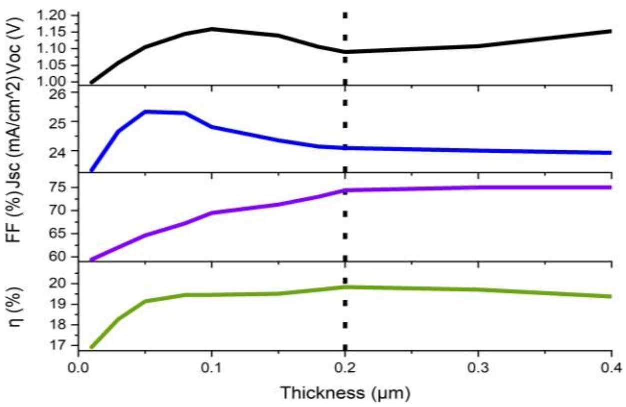


Fig.6. Effect of thickness variation of ZnO on cell efficiency Fig.7. Effect of thickness variation of Zn_2SnO_4 on cell efficiency.

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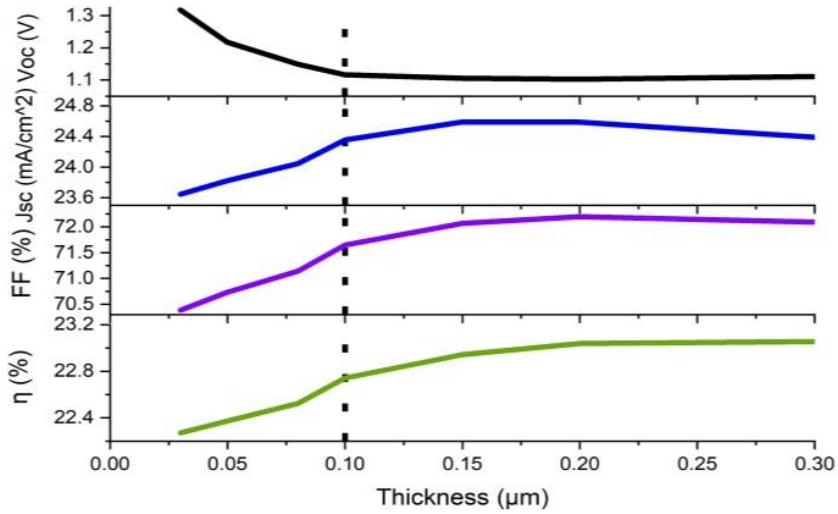
In the Fig.6, the variation of performance parameters with respect to the variation of thickness of ZnO layer is showed. From the figure, it can be seen that efficiency shows an increasing trend below 200 nm and become almost flat after this value.

After all these, thickness of window was varied and observed that the narrower the layer, the higher the efficiency of the cell.



But considering the fabrication cost of such thin layer 50 nm CdS:O layer was chosen. CdS:O shows better performance compared to CdS because it has higher bandgap than cadmium sulfide which means it has higher optical throughput. This is why oxygenated cadmium sulfide was chosen as window layer in the proposed cell.

At last thermal stability of the final modified proposed cell was checked varying temperature from 290 K to 373K.

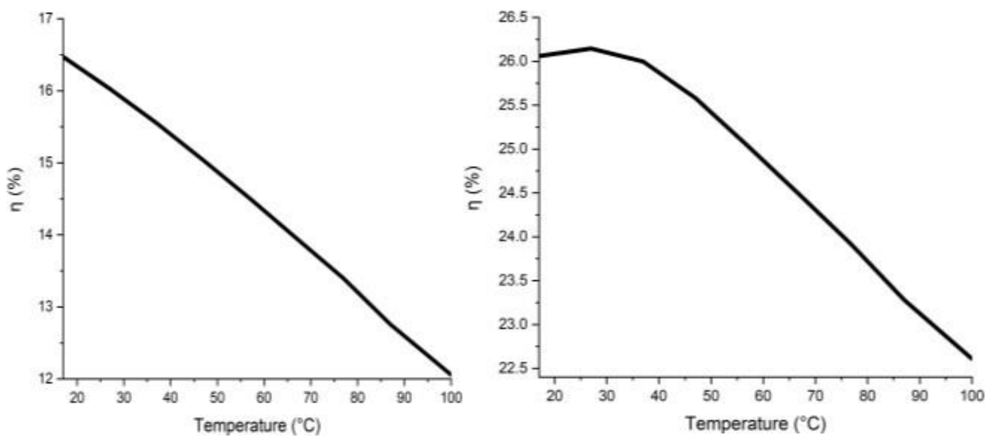


Fig.9. Effect of temperature variation on cell efficiency. (a) Base cell (b) Proposed cell

In the Fig.9, it is shown that with the increase, efficiency of the cell decrease as the temperature coefficient is negative.

IV. CONCLUSION

Among solar cells, CdTe-based cells are particularly more promising candidate due to its superior optoelectronic properties and low cost of fabrication technology. The CdS layer was replaced with oxygenated Cadmium Sulfide (CdS:O) and effect of this layer was observed. CdS:O layer shows better performance because it has higher bandgap as compared to CdS which means higher optical throughput. Comparing with related works, it was found that the proposed cell has better performance than the others.

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The proposed cell structure is (Glass/SnO_2/Zn_2SnO_4/ZnO/CdS:O/CdTe/ZnTe/Ni) and efficiency of the cell is 26.34% (V_{OC}= 1.07 V, J_{SC}=28.7771 mA/cm^2, FF=85.04%).The cell structure (Glass/TCO(400nm)/ SnO_2(100nm)/ CdS(100nm)/ CdTe(6000nm)/Au) has efficiency (V_{OC}= 0.95 V, J_{SC}=29.09 mA/cm^2, FF= 83.47%) [16] which clearly shows the proposed cell performance is higher. At the same time, the proposed cell requires less absorber material as compared to this cell structure as it used 6 μm whereas proposed cell absorber layer thickness reduced to 1 μm which will reduce time, money, energy and fabrication cost. Another cell structure (Glass(0.5 μm)/SnO_2(100nm)/ Zn_2SnO_4 (100 nm)/ CdS (80 nm)/ CdTe (1 μm)/SnTe (100 nm)/In) has efficiency 22.61%(V_{OC}=1.06 V, J_{SC}= 24.27 mA/cm^2, FF= 87.61%). Again the proposed cell shows high performance comparing to this cell structure[17].

Besides the proposed cell is more stable because of its lower temperature coefficient of -0.268%/°C. Despite of having more layers, if the cell is manufactured with single line technology, it will reduce fabrication cost and the cell will be economical. In the future, cell performance can be further enhanced by increasing doping concentration and fabrication of different layer with more advanced technology.

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