Modified structure for CdTe Based Solar Cells Using CdZnS Buffer Layer

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Abstract: This paper deals with the modified structure of CdTe based solar cells. The oxygenated nanocrystalline cadmium sulfide (CdS:O) window layer is replaced by a large bandgap $Cd_{1-x}Zn_xS$ layer at an optimal x content of 0.6 in order to improve the efficiency of the cell. The absorption edge shifts toward lower wavelength, more photons are absorbed by CdTe layer and the short circuit current density (J_{SC}) is hence improved which in turn improves the efficiency of the cell. Increased efficiency, open circuit voltage (V_{OC}) and J_{SC} of 23.42%, 2.30 V and 30.10 mA/cm^2 were recorded. Numerical simulations were carried out at varying $Cd_{1-x}Zn_xS$ layer thickness to investigate the solar cell behavior. Modified solar cell (Glass/SnO_2/ZTO/$Cd_{1-x}Zn_xS$/$CdTe_{1-x}S_x$/CdTe/ZnTe/Pt) with high efficiency of 23.42% was obtained.

Index Terms **– CdTe Solar Cells, CdZnS Window Layer, Efficiency, Numerical Simulation**

I. INTRODUCTION

Over exploitation of fossil fuels is the main reason of global energy crises. To reduce the use of non-renewable energy resources best solution is to harness the non-vanishing renewable energy resources to fulfill the overshooting demands of energy. Out of five regularly used renewable energy sources (Biomass, water, sun, wind and geothermal), our research is based on solar energy. Best approach for converting solar energy into electrical energy is solar cell. Several types of solar cells based on crystalline Silicon [1], thin-film technology [2,3], organic materials [4,5] and many more are gradually developed in past decades. Out of the oldest technologies, 'Crystalline Silicon (c-Si) PV' are ruling approximately 80 to 90% of world's photovoltaic market with advantages like easy and abundant availability, high stability, durable high-quality cell, outstanding conversion efficiency, non-toxic nature, the possibility of reducing cost, and many more. Thin film technology has emerged during the last decades and has entered into direct competition with traditional multicrystalline silicon technology, which still dominates the market of photovoltaic [6].

Out of all the thin film technologies CdTe based solar cell is the most promising technology in order to achieve better efficiency/cost ratios than the other counterparts. CdTe has a bandgap of ~1.5eV, which is very close to the ideal value for photovoltaic conversion efficiency. It is found to be the most attractive material for thin film solar cells because of its high optical absorption coefficient and high chemical stability. In traditional CdTe solar cells cadmium sulfide (CdS) is used as window layer because of its high transparency, direct band gap transition, high electron affinity and n-type conductivity. There is a lattice mismatch of 10% between CdTe and CdS, still the formed heterojunction maintains an excellent electrical behavior. 28%–30% is the expected theoretical efficiency of CdTe thin-film solar cells, but the achieved efficiencies are still much below than theoretical efficiency providing an attractive area for research. Therefore, there is a large scope for the improvement in CdTe solar cell performance [7].

Performance of CdTe based solar can be improved significantly by introducing an appropriate window layer. By adding zinc (Zn) to substitute Cadmium (Cd) in CdS window layer, bandgap becomes adjustable depending on the Zn:Cd ratio. Bandgap of $Cd_{1-x}Zn_xS$ layer is larger than that of CdS layer, therefore it reduces the window absorption losses and lattice mismatch problems [8]. In this work CdS:O window layer used in the structure proposed in [6] is replaced by 30 nm thick $Cd_{0.4}Zn_{0.6}S$ window layer [8] in order to enhance the CdTe solar cell performance. Incorporation of $Cd_{0.4}Zn_{0.6}S$ window layer increases the blue portion absorption of solar spectrum, which in turn improves the efficiency of CdTe solar cell.

II. MATERIALS AND MODELING

The numerical modeling of the proposed structure is done with the help of Solar Cell Capacitance Simulator in 1 Dimension (SCAPS-1D) developed by burgelman et al [9]. I-V characteristics of proposed structure are investigated and then compared with the conventional structure. SCAPS is a one dimensional solar cell simulation program developed at the department of Electronics and Information Systems (ELIS) of the University of Gent, Belgium. The main functionality of SCAPS is to solve the one-dimensional semiconductor equations [10]. In the bulk of the layers these eauqtions are given by Eq. (1) to Eq. (5) as shown below:

$$J_n = q\mu_n n\varepsilon + qD_n \frac{dn}{dx} = q\mu_n \left(n\varepsilon + \frac{kT}{q}\frac{dn}{dx}\right) = \mu_n n \frac{dE_{Fn}}{dx} \qquad (1)$$

$$J_p = q\mu_p p\varepsilon + qD_p \frac{dp}{dx} = q\mu_p \left(p\varepsilon + \frac{kT}{q}\frac{dp}{dx}\right) = \mu_p p \frac{dE_{Fp}}{dx} \quad (2)$$

$$-\frac{\partial J_n}{\partial x} - U_n + G = \frac{\partial n}{\partial t} \quad (3)$$

$$-\frac{\partial J_p}{\partial x} - U_p + G = \frac{\partial p}{\partial t} \quad (4)$$

$$\frac{\partial}{\partial x}\left(\varepsilon_0 \varepsilon \frac{\partial \Psi}{\partial x}\right) = -q(p - n + N_D - N_A) \quad (5)$$

Conventional CdTe solar cell structure is modified by replacing the CdS:O window layer with larger bandgap $Cd_{0.4}Zn_{0.6}S$ window layer. To provide ohmic contact, Platinum (Pt) with high work function of 5.70 eV is used as a back contact material. In figure 1(a) the conventional solar cell structure with CdS:O window layer is shown whereas in figure 1(b) the modified solar cell structure with $Cd_{0.4}Zn_{0.6}S$ window layer is shown.

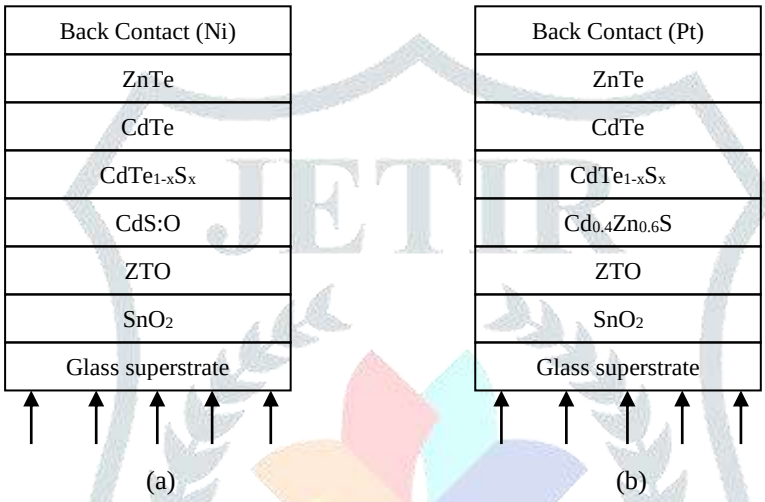

Figure1. (a) Conventional solar cell with CdS:O window layer (b) Proposed solar cell with $Cd_{0.4}Zn_{0.6}S$ Window layer

The selection of material parameters used in this work is done on the basis of some reasonable estimations and by referring the simulation procedures mentioned in [6], [8], [11], [12]. Parameters used in this work are listed in table 1 and table 2.

Table 1. selection of material parameters

Parameters	**ZnTe**	**CdTe**	**$CdTe_{1-x}S_x$**	**$Cd_{0.4}Zn_{0.6}S$**	**ZTO**	**SnO_2**
thickness (μm)	0.1	0.15	0.015	0.03	0.2	0.1
bandgap (eV)	2.26	1.45	1.47	3.07	3.35	3.6
electron affinity (eV)	3.65	4.26	4.26	4.14	4.5	4.55
dielectric permittivity (relative)	14	9.4	9.4	9.3	9	9
CB effective density of states (1/cm3)	7.8E+17	7.9E+17	7.9E+17	2.1E+18	2.1E+18	2.2E+18
VB effective density of states ($1/cm^3$)	1.6E+19	1.8E+19	1.8E+19	1.7E+19	1.5E+19	1.8E+19
electron thermal velocity (cm/s)	1E+7	1E+7	1E+7	1E+7	1E+7	1E+7
hole thermal velocity (cm/s)	1E+7	1E+7	1E+7	1E+7	1E+7	1E+7
electron mobility (cm^2/Vs)	1E+2	3.2E+2	3.2E+2	6.5E+1	5.2E+1	1E+2
hole mobility (cm^2/Vs)	1E+1	4E+1	4E+1	1.5E+1	3E+0	2.5E+1
shallow uniform acceptor	7.5E+19	1E+16	2E+14	1E+15	1E+15	1E+15

density N_A ($1/cm^3$)						
shallow uniform donor density N_D ($1/cm^3$)	1E+15	-	1E+15	1.1E+18	1E+19	1E+17
absorption constant A ($1/cm\ eV^{(½)}$)	1E+5	9.6E+5	1E+5	1E+5	1E+5	1E+5
Defect type	-	Donor	-	-	-	Donor
Capture cross section electrons (cm^2)	-	1E-12	-	-	-	1E-12
capture cross section holes (cm^2)	-	1E-15	-	-	-	1E-15
energetic distribution	-	Gaussian	-	-	-	Gaussian
reference for defect	-	Above Ev	-	-	-	Above Ev
energy level E_t	-					
energy level with respect to Reference (eV)	-	0.600	-	-	-	0.600
N_t total ($1/cm^3$) uniform	-	9.9E+13	-	-	-	1E+15

Table 2. Front and back contact parameters

Parameters	Back contact	Front contact
surface recombination velocity of electrons (cm/s)	1.000E+7	1.000E+7
surface recombination velocity of holes (cm/s)	1.000E+7	1.000E+7
Metal work function (eV)	5.7	5.02
Majority Carrier barrier height relative to E_f (eV)	0.2100	0.4700
Majority Carrier barrier height relative to E_v (eV)	0.2500	0.3897

III. RESULTS AND DISCUSSION

To observe the behavior of proposed solar cell after the incorporation of $Cd_{0.4}Zn_{0.6}S$ and Pt as a back contact material, numerical simulation of the structure shown in figure 1(b) was performed using SCAPS-1D. Thereafter comparison of the obtained results with the conventional solar cell was done. The structure that has been simulated is shown in figure 2.

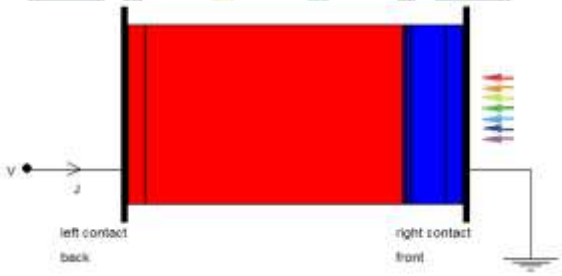

Figure 2. Device Structure used for simulation

I-V characteristics of the proposed structure are shown in figure 3. Efficiency, V_{OC} and J_{SC} was increased from 21.59% to 23.42%, 1.072V to 2.3049V and 25.860 mA/cm^2 to 30.103 mA/cm^2, respectively. Whereas, fill factor was reduced from 77.89% to 33.75% as shown in table 3.

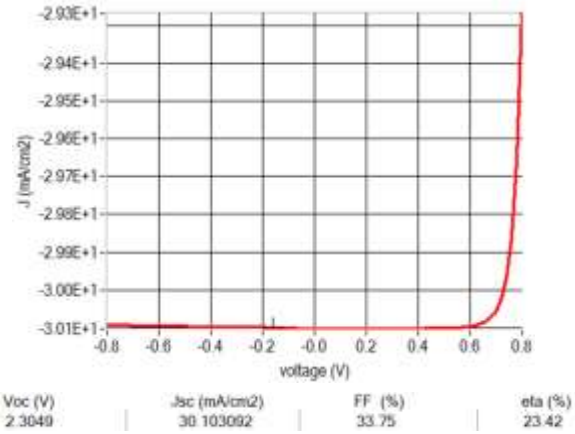

Figure 3. I-V curve for CdTe solar cell with $Cd_{0.4}Zn_{0.6}S$ as a window layer

Table 3. Comparison of conventional and proposed structures

Cell	solar cell with CdS:O window layer (conventional)	solar cell with $Cd_{0.4}Zn_{0.6}S$ window layer (proposed)
Open circuit voltage, Voc (V)	1.072	2.3049
Short circuit current, Jsc (mA/cm^2)	25.860	30.103
Fill Factor, FF (%)	77.89	33.75
Efficiency (%)	21.59	23.42

The comparison results shown in table 3 reflect that addition of $Cd_{0.4}Zn_{0.6}S$ window layer and use of Pt as a back contact material improved the efficiency, Voc and Jsc significantly. Due to the improvement in blue portion absorption of solar spectrum and the ohmic contact provided by Pt, efficiency of the cell was also improved. The variation in CdTe solar cell parameters in accordance with the $Cd_{0.4}Zn_{0.6}S$ window layer thickness is shown in figure 4. As observed in table 4, with increase in the thickness of $Cd_{0.4}Zn_{0.6}S$ layer efficiency of the cell also increases. Simulations were carried out by taking window layer thickness in the range of 10 to 30 nm. Variations in cell parameters can be justified by the equations given below.

$$Voc = \frac{mK_BT}{q} \ln\left(\frac{J_{ph}}{J_o} + 1\right) \quad (6)$$

$$J_{SC} = J(V) + J_0\left(e^{\frac{qV}{mTK_B}} - 1\right) \quad (7)$$

$$FF = \frac{P_{max}}{V_{oc/sc}} = \frac{V_{mp}\, J_{mp}}{V_{oc} J_{sc}} \quad (8)$$

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{sc} V_{oc}\, FF}{P_{in}} \quad (9)$$

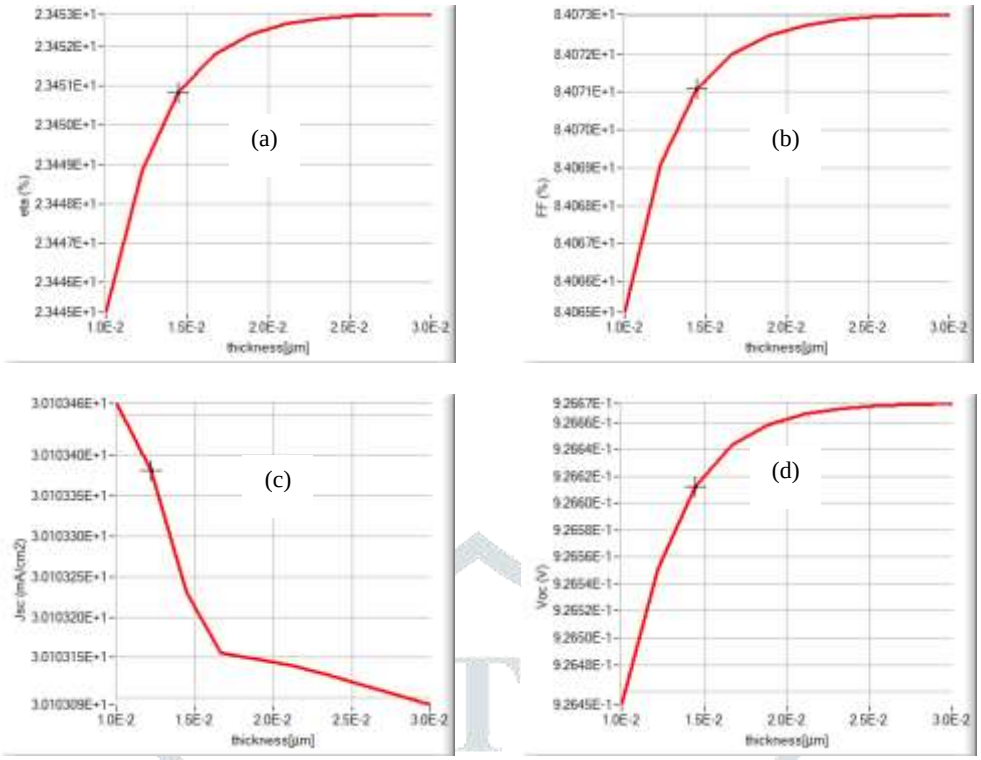

Figure 4. Variation of cell parameters in accordance with $Cd_{0.4}Zn_{0.6}S$ window layer

Table 4. Summary of the simulated results at varying thickness of $Cd_{0.4}Zn_{0.6}S$ layer.

Thickness (µm)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	η (%)
0.010	2.2947	30.103464	33.89	23.41
0.015	2.3025	30.103180	33.78	23.41
0.020	2.3044	30.103143	33.75	23.41
0.025	2.3048	30.103120	33.75	23.42
0.030	2.3049	30.103092	33.75	23.42

It can be observed from table 4 that V_{OC} increases from 2.2947 V to 2.3049 V with increasing thickness of $Cd_{0.4}Zn_{0.6}S$ layer. Whereas J_{SC} and FF decreases from 30.103464 to 30.103092 mA/cm^2 and 33.89 to 33.75% with increasing thickness. Efficiency increases from 23.41 to 23.42 % when thickness increases from 0.020 to 0.025 µm and remains constant till 0.030 µm.

IV. Conclusion

CdTe solar cell structure with 30 nm thick $Cd_{0.4}Zn_{0.6}S$ window layer was designed. Numerical simulations were carried out by the variation of window layer thickness. It is shown that $Cd_{0.4}Zn_{0.6}S$/CdTe solar cell with Pt as a back contact material has significant improvement in efficiency. Effects of modifying the solar cell structure were investigated effectively with the help of numerical simulations. The research of the $Cd_{1-x}Zn_xS$ layer optimization provides constructive guidelines for the future design and fabrication of CdTe solar cells.

V. Acknowledgment

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