A Novel Ultrathin CdS/CdTe Solar Cell with Conversion Efficiency of 31.2% for Nano-area Application

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Abstract— Due to limited availability and the rising price, the layer thickness reduction of solar cells is an attractive prospect. In this paper, we investigated a thin high efficiency structure of CdTe solar cells for nano-area application. The proposed structure, achieved by rotating 90° in the base line structure, suggests high efficiency due to high current density. The proposed structure showed acceptable efficiency which is quite noteworthy in reducing the amount of material used and associated losses. The result showed a considerable improvement over the 15% efficiency of the reference sample. Under global AM 1.5 conditions, the designed cell had a V_{OC} of 866 mV, a J_{SC} of 74.84 mA/cm^2, and a FF of 48.2%, corresponding to a conversion efficiency of 31.2%.

1. INTRODUCTION

Third generation thin-film solar cells are the most promising field of photovoltaic solar cell research. They are much cheaper to manufacture (due to using simpler deposition processes), and require much less materials, as compared to the conventional single-crystal cells. Polycrystalline CdTe films have high optical absorption coefficient and are normally used in a CdS/CdTe heterojunction configuration. Because of its near ideal band gap of 1.45 eV and high optical absorption coefficient, CdTe has long been a leading material in thin film solar cell fabrication. The most important parameter that affects photon absorption is thickness of the CdTe layer [1, 2]. Reducing the CdTe absorber layer thickness is an attractive prospect due to limited availability and the rising price of Te with regards to very high volume Photovoltaic module manufacture in the future. *Another advantage is that overall material consumption will decrease along with module production costs.* CdS films are suitable as a window layer for CdS/CdTe solar cells. Thinner CdS films produce higher J_{SC} [3, 4]. The maximum theoretical efficiency reported for CdTe solar cells are 28–30% [5, 6]. The record cell efficiency of CdTe solar cells have been increased by only 1.5% during the last 17 years [7–11]. The maximum cell efficiencies of the CdTe solar cells were reported to be between 16% and 16.5% [12–15]. The NRELverified cell efficiency of 20.4% and a module efficiency of 14% were reported by First Solar [16]. Increasing the efficiency of the CdTe thin film solar cells is a current hot research topic. Simulation of CdTe thin film solar cells is an important strategy to test the viability and prediction of the effect of physical changes on the cell performance in the proposed structures. Now, the challenge facing the researchers and technologists is increasing the efficiency of CdS/CdTe solar cell and decreasing the gap between the actual efficiency and the theoretical limit. The goal of this paper is to explore a higher efficiency CdTe solar cell by introducing a new structure.

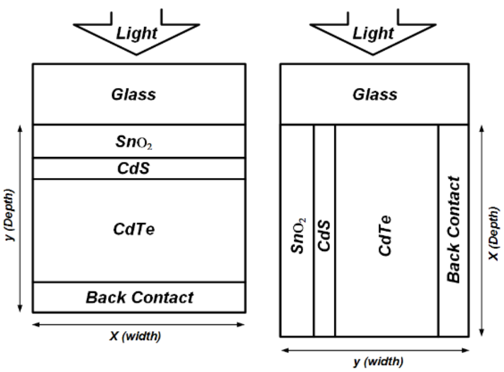
2. ANALYSIS OF CONVENTIONAL AND MODIFIED STRUCTURES

The mechanism of structures could be evaluated by numerical simulations enabling the design of new structures with better efficiency and stability. The starting point of this work was the baseline case as reported in [1]. In brief, the CdTe device model in the base line case consists of a 4 μm-thick CdTe absorber layer, a 100-nm thick CdS window layer, and a 500-nm-thick SnO_2 buffer layer. Most of the important electronic parameters are listed in Table 1. The values have been chosen on the basis of theoretical considerations, experimental data and existing literature.

The back barrier in CdTe layer was low (0.3 eV). It is assumed that 5% of the incident light was reflected at the front contact. The electron lifetime of 0.5 ns was used in the CdTe absorber layer of the baseline case. Using the mentioned parameters, the baseline solar cell parameters were $V_{OC} = 0.865\,\mathrm{V}$, $J_{SC} = 25\,\mathrm{mA/cm^2}$, $FF = 73\%$, and $\eta = 157\%$. At the next step, this structure was modified by rotating 90° of the structure without dimension variation. Figure 1 illustrates the CdTe baseline case structure and the modified structures investigated in this study.

Table 1: Best cell parameters.

Layer Properties			
	CdS	**SnO_2**	**CdTe**
Layer Width $\boldsymbol{D}$ [nm]	100	500	4000
Dielectric Constant ε/ε	10	9	9.4
Electron Mobility $\boldsymbol{\mu_e}$ [cm^2/Vs]	100	100	32
Hole Mobility $\boldsymbol{\mu_h}$ [cm^2/Vs]	25	25	4
Electron/Hole Density $\boldsymbol{n}$, $\boldsymbol{p}$ [cm^{-3}]	n: 10^{17}	n: 10^{18}	p: 2×10^{14}
Band Gap Energy $\boldsymbol{E_g}$ [eV]	2.4	3.6	1.5
Effective Density of States $\boldsymbol{N_C}$ [cm^{-3}]	2.2×10^{18}	2.2×10^{18}	8×10^{17}
Effective Density of States $\boldsymbol{N_V}$ [cm^{-3}]	1.8×10^{19}	1.8×10^{19}	1.8×10^{18}
Defect States			
	CdS	**CdS**	**CdTe**
Acceptor/Donor Defect Density $\boldsymbol{N_{DG}}$, $\boldsymbol{N_{AG}}$ [cm^{-3}]	A: 10^{17}	A: 10^{15}	D: 2×10^{14}
Defect Peak Energy $\boldsymbol{E_A}$, $\boldsymbol{E_D}$ [eV]	midgap	midgap	midgap
Distribution Width $\boldsymbol{W_G}$ [eV]	0.1	0.1	0.1
Capture Cross Section $\boldsymbol{\sigma_e}$ [cm^2]	10^{-17}	10^{-15}	10^{-12}
Capture Cross Section $\boldsymbol{\sigma_h}$ [cm^2]	10^{-12}	10^{-12}	10^{-15}



Structure (a) Structure (b)

Figure 1: Structures of the CdTe solar cells: (a) baseline case structure and (b) modified cell structure for higher efficiency.

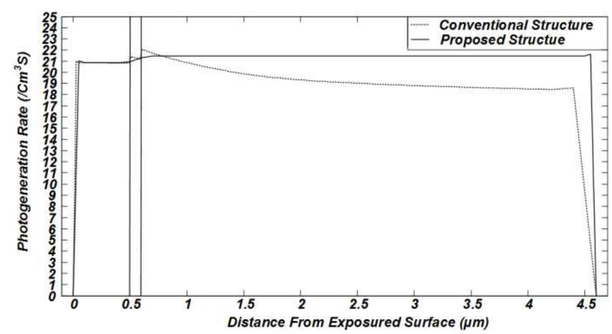


Figure 2: Photogeneration rate for the conventional and proposed structure.

The proposed structure has many advantages such as high photogeneration and low recombination rate. The J_{SC} of the cell can be improved by reducing the carrier recombination losses at the back contact or increasing the photogeneration rate in the absorber layer. Because the light inters to layers independently, the photogeneration rate is high in each layer. Figure 2 shows the comparison the photogeneration rate between conventional and proposed structure.

In addition, using less semiconductor material by thin cells is one of the main goals of today's solar cell research. Also, the thinning will reduce the recombination loss as well as lower production time and the energy need to produce solar cells. Consequently, all of these factors will decrease the production cost. Hence, it is possible to reduce the dimension of proposed structure considerably and achieve better base line results, simultaneously. Figure 3 shows the current-voltage and power-voltage curves for comparison with the base line case.

As it is shown in Figure 3, the conversion efficiency can be increased to 31.2% mostly due to improvement of J_{SC} compared to the base line case. Although FF is smaller than base line case because of the high difference between J_{SC} and maximum current of the cell the important parameters of the solar cell are much more than base line case. Figure 4 and Figure 5 show the characteristics of the proposed cell by decreasing the cell depth.

It is clear from Figure 4, the J_{SC} decreases and V_{OC} increases by increasing the depth. Therefore, cell has a lower FF. Figure 6 shows the cell efficiency and FF of the proposed structure as a function of depth.

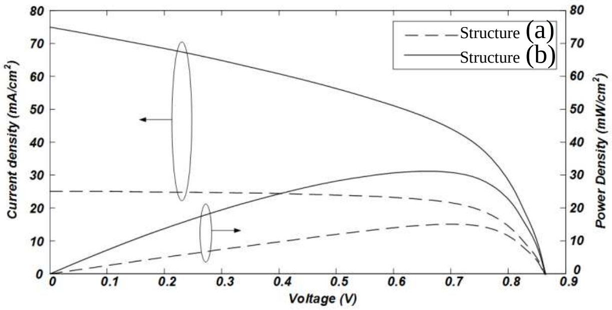


Figure 3: characteristics of the (a) baseline case structure and (b) modified cell structure for higher efficiency.

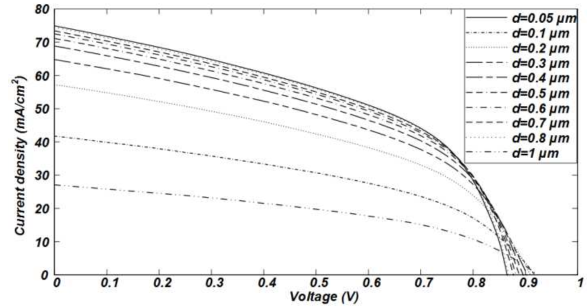


Figure 4: Light J-V curves of the cell with the lower depth (d).

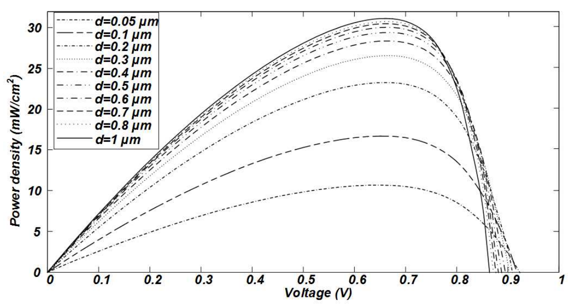


Figure 5: Power curves of the cell with the lower depth (d).

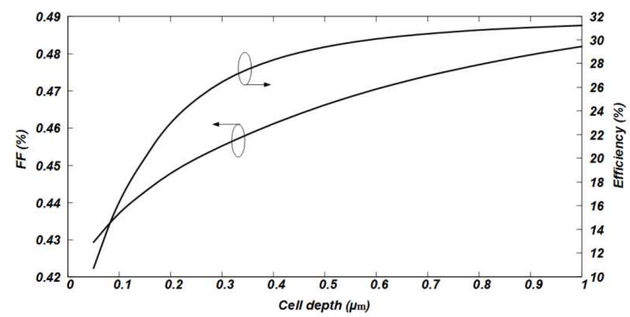


Figure 6: Efficiency and FF of the cell as a function of the cell depth.

Because of reducing the depth corresponding to a thinner cell, photogeneration rate decreases. As a result, the efficiency of the cell is decreased. It can be seen from Figure 5 by decreasing the depth up to 0.1, the cell efficiency is still better than base line case.

3. CONCLUSION

In this study, a base line structure is considered and a new structure is proposed which is achieved by rotating 90° in the base line structure. The result showed a considerable improvement over the 15% efficiency of the reference sample. The proposed structure showed acceptable efficiency which is quite noteworthy in reducing the amount of material used and associated losses. It was shown that 0.1 μm of CdTe absorber layer was sufficient to produce conversion efficiency over 15%. Under global AM 1.5 conditions, the designed cell had a V_{OC} of 866 mV, a J_{SC} of 74.84 mA/cm^2, and a FF of 48.2%, corresponding to a conversion efficiency of 31.2%.

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