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Effect of CdTe Thickness on Various Solar Cell Parameters-a Scaps 1D Study

Saurabh K Sengar

Department of Physics, D S College, Aligarh, 202001

Abstract: ***In the current article, the effect of absorber layer thickness on various solar cell parameters such as open circuit voltage, short circuit current, fill factor and solar cell efficiency has been studied using the Scaps-1D software. It is found that above a certain thickness all the parameters are found to be increased on increasing the absorber layer (CdTe) thickness.***

Keywords: Solar Cell, CdTe, absorber layer, efficiency, Scaps-1D

1. Introduction

To handle the significant global warming issues, world needs renewable, cost- effective, and clean energy sources. Solar energy is one of the environmental friendly and most accessible source of renewable energy. From its inception by Chapin, Fuller, and Pearson of Bell Labs in 1954 in the USA, it is always felt that the power conversion efficiency (PCE) should be improved and the overall production cost of solar photovoltaic (PV) modules should be reduced. In spite of the fact that the PCE of crystalline silicon-based solar cells is the most note-worthy, coming to 26.7% (single-cell) and 24.4% (module) among wafer-based innovations [1][1, 2], thin-film solar cells (TFSCs) innovation has a greater advantage in lessening crude fabric utilization, barring energy-intensive fabricating forms and higher execution soundness at genuine working temperatures. Single junction cuprous sulfide/ cadmium sulfide (Cu2S/CdS) solar cells are the first reported TFSCs and their PCE is about 9.1%, but the long-term execution is weakened due to the diffusion of copper into the CdS lattice and the doping of the CdS layer, due to which further research exercises on Cu2S/CdS based cells were discontinued [2, 3][3, 4].Due to low-cost, material availability, non-toxicity, low processing temperature and cost-effective processing technologies, amorphous silicon (a-Si)-based solar cells among the TFSCs are preferable to the researcher. The PCE of TFSCs based on a-Si can reach up to 13.6% [4][5]. Current investigates based on chalcogenide-based solar powered cells have made awesome commitments to the advancement of low-cost and earth-abundant TF SCs.

Recently, cadmium telluride (CdTe) has drawn considerable attention due to its efficient devices and cost ratio because of its greater flexibility to large scale manufacturing process. Due to its characteristics, CdTe has been respected as the most reasonable fabric for creating high-efficiency thin film solar cells [1][6,7]. Besides, CdTe has direct band gap (~1.45 eV) with absorption coefficient (>105 cm^{-1}) due to which it can absorb more than 90% of incoming photons from solar cell spectrum using only a 1000 nm thick layer [2][3][8, 9]. A transparent conductive oxide (TCO), CdS film, CdTe absorber, and back contact are the typical layers that make up a superstrate CdTe solar cell's conventional structure. In CdTe based thin film solar cells, the thickness of absorber layer is around 4000 nm. As we decrease the thickness of the absorber layer, it results in low crystallinity thin films with pin hole. To avoid the pin holes, thicker absorber layer is used which can lead to shorting from the back contact. Due to its favourable band gap, less absorber layer is needed than other material. Some researchers discovered that it is possible to decrease the absorber layer without much deal in efficiency. If this thickness can be reduced to a minimum value without considerable reduction in efficiency, the amount of material used will be cut, shortening a manufacturing time and its cost as well [4,5] [10, 11]. Decreasing the thickness of CdTe absorber layer would, from the perspective of the industry, not only reduce the material cost and extend the supply of Te, which has a finite reserve, but also dampen the environmental issue associated with disposing of a potentially hazardous material. Based on previous research, an ultrathin solar cell has the challenges of incomplete photo absorption and degradation in efficiency [6][12]. Earlier, carrier lifetime, carrier density, back/front contact, the thickness of layer and doping concentration etc. have been used to scrutinize the performances of the solar cell [7, 8] [13, 14].

In this work, SCAPS-1D has been utilized to examine the performances of the solar cell. Absorber layer (CdTe) thickness has been varied to examine the effects on V_{oc}, J_{sc}, FF and PCE. The key focus in this simulation is to analyse an ultrathin CdTe absorber layer for solar cell applications

2. Device structure and simulation methodology

In this study, SCAPS-1D simulation software has been used to model the heterojunction thin film solar cells' device properties. At the Electronics and Information Systems (EIS) Department at the University of Gent in Belgium, the "Solar Cell Capacitance Simulator One Dimensional" (SCAPS-1D) application was developed to model solar cells. The continuity equation and Poisson's equation are given for the free electrons and holes in the conduction and valence bands [13][15,16]. The electron and hole continuity equations are as follows

$$-\frac{1}{q}\frac{dj_n}{dx} = [G - R]$$
$$-\frac{1}{q}\frac{dj_p}{dx} = [G - R]$$

where G and R are the generation rates and recombination rates, respectively. J_n and J_p are the current densities for electrons and holes, respectively. The Poisson formula is as follows:

$$\frac{d^2}{dx^2}\psi(x) = -\frac{q}{\epsilon_0\epsilon_r}\left[p(x) - n(x) + N_D - N_A + \rho_p - \rho_n\right]$$

where q is the electrical charge, ε_r is the relative, ε_r is the vacuum permittivity, ψ is the electrostatic potential, p and n are the concentrations of holes and electrons, respectively, NA and ND are the charge impurities of the acceptor and donor types, respectively, and ρp and ρn are the distributions of holes and electrons, respectively. SCAPS-1D solves the above equations while considering boundary conditions using the steady-state response of the fundamental semiconductor equations in one dimension. CdTe based thin film solar cell structure is shown schematically in Figure 1(a). The reference parameters of the CdTe, CdS and ZnO layers which have been used to execute numerical calculations are listed in Table 1.

Table 1: Material parameters used in SCAPS-1D simulator

Parameter	ZnO	CdS	CdTe
Thickness (nm)	30	50	500-2500
Bandgap (eV)	3.3	2.4	1.5
Electron affinity (eV)	3.9	4.1	3.9
Dielectric permittivity	10	10	9.4
Conduction band DOS (cm^{-3})	$2.2x10^{18}$	$2.2x10^{18}$	$8.1x10^{17}$
Valence band DOS (cm^{-3})	$1.8x10^{19}$	$1.9x10^{19}$	$1.8x10^{19}$
Electron thermal velocity (cm/s)	107	107	107
Hole thermal velocity (cm/s)	107	107	107
Electron mobility (cm^2/Vs)	100	100	320
Hole mobility (cm^2/Vs)	25	25	40
Donor density N_D (cm^{-3})	1017	1018	0
Acceptor density N_A (cm^{-3})	0	0	1016

3. Results and Discussion

The absorber layer should be tuned to the optimal thickness to absorb the maximum photons and produce electron-hole pairs. To study the correlation between the CdTe absorber layer thickness and the different solar cell parameters V_{oc}, J_{sc}, Fill factor and Power conversion efficiency, the thickness of the CdTe absorber layer is varied from 0.3μm -to 2.4μm, while keeping the all other parameters fixed as represented in Table 1. A typical I-V Curve of the present solar cell structure for the CdTe thickness of 2.4μm is shown in Figure 1(b). The variation of Voc and Jsc on increasing the CdTe absorber layer thickness is shown in Figure 2. It can be seen that as the thickness of the CdTe absorber layer varies from 0.3 to 2.4 μm. The Voc rises from 0.97 V to 1.00 V. This increasing trend of Voc on increasing the CdTe thickness can be explained on the basis of increased absorption of light on increasing the thickness of absorption layer. It is evident from Fig. 2b that the Jsc grows rapidly in the early stages and climbs slowly after 1 μm, finally reaching a maximum value of 27.79 mA/cm^2 at 2.4μm.

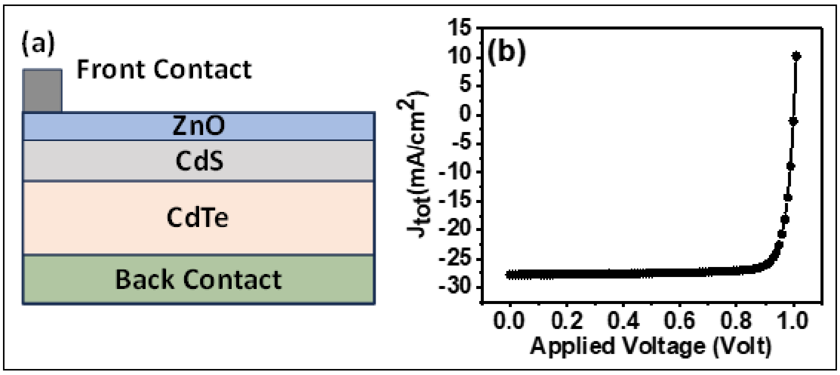

Figure 1: (a) schematic diagram and (b) I-V characteristic curve of the (metal/CdTe/CdS/ ZnO/metal) solar cell

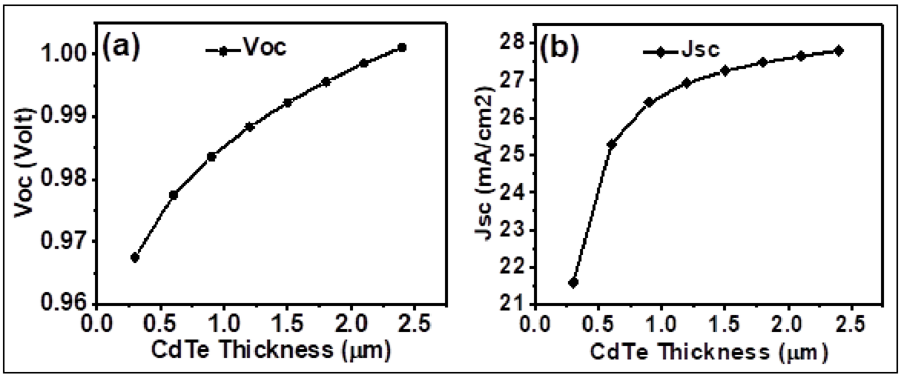

Figure 2: (a) Variation of Voc and (b) Jsc on varying the CdTe absorber layer thickness in (metal/CdTe/ CdS/ ZnO/metal) solar cell

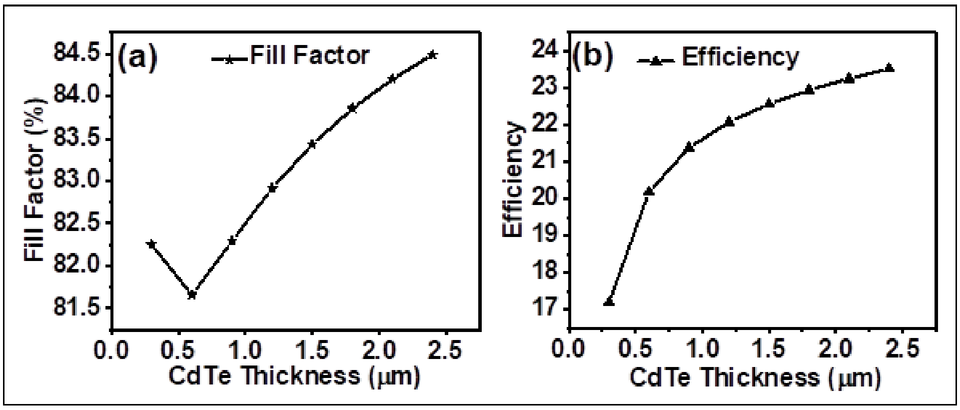

Figure 3: (a) Variation of Fill Factor and (b) Power Conversion Efficiency on varying the CdTe absorber layer thickness in (metal/CdTe/ CdS/ ZnO/metal) solar cell

The variation of fill factor (FF) and the power conversion efficiency (PCE) on increasing the CdTe layer thickness is shown in Figure3. As shown in Figure 3 (a), Initially the value of fill factor (FF) decreases from 82.25 % to 81.65 % to om increasing the CdTe Thickness from 0.3 μm to 0.6 μm. On further increasing the CdTe thickness, FF increases and attains a value of 84.48 % at 2.4 μm. The increased serial resistance and inside power loss on increasing the thickness of the absorber layer may be responsible for the increased value of FF on increasing the CdTe thickness. As shown in Figure 3 (b), the value of efficiency increases from 17.2 % to 22.29 % om increasing the CdTe Thickness from 0.3 μm to 1.8μm. On further increasing the thickness, the efficiency does not increase much and is saturated. the saturated behaviour of efficiency can be explained on the basis of light absorption and carrier transport. If the absorber thickness (lower than the ideal value) is less than the carrier diffusion length, light absorption becomes a more significant component for device performance. As a result, we do not need to take carrier transport into account at this time. However, carrier transport becomes important when the CdTe thickness is larger than the ideal thickness. It is on account of the fact that when the absorption layer reaches enough thickness, the light absorption is saturated. When the thickness of the absorption layer is greater than the carrier transport length, the carrier cannot favourably reach the corresponding electrode owing to its short carrier lifetime (9.9 ns) [17]. Therefore, the additional portion of the photo-generated carriers from thick absorber has no effect on raising the device efficiency.

4. Conclusion

It is found that above a certain thickness all the parameters are found to be increased on increasing the absorber layer (CdTe) thickness. The increased values of the discussed parameters can be explained on the basis of increased absorption of light on increasing the thickness of absorption layer.

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