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On the effect of thickness of Te Interlayer on output characteristics of CdTe thin-film solar cell

R Venkatesh[1,2*], N R Banapurmath[1,2], Abhay Palrecha[2] and K Ramesh[3]

[1]Centre for Material Science, K.L.E Technological University, Hubbali-580031, Karnataka, India.
[2]School of Mechanical Engineering, K.L.E. Technological University, Hubbali-580031, Karnataka, India.
[3]Department of Physics, Indian Institute of Science, Bangalore-560012, Karnataka, India.

*E-Mail: rrvenkatesh.t@gmail.com, rrvenkatesh@kletech.ac.in

Abstract : Charge carrier dynamics which governs the output characteristics and performance of solar cells, often depends on the fabrication protocol of these cells. In this study, we have fabricated the FTO/CdS/CdTe/Te/Al thin-film photovoltaic devices using thermal evaporation. We have deposited tellurium as an interlayer between the absorber layer (CdTe) and top-electrode (Al) for a better charge carrier collection. The thickness of this interlayer was varied (10 nm and 30 nm) to observe its effect on the final device output characteristics, and for the same purpose, the fabrication procedure, the thickness of the absorber layer and window layers (CdS) were kept constant of 500 nm and 100 nm respectively. The XRD analysis revealed that the CdS-window layer had a cubic structure while the CdTe existed in both hexagonal and cubic phases. The deposited CdS and CdTe thin-films showed a bandgap of 2.35 eV and 1.5 eV respectively. The device with interlayer thickness of 30 nm device showed a maximum open-circuit voltage (Voc) of 0.40 V and a maximum current of 25 μA whereas for the device with 10 nm thick interlayer shows a Voc of 0.45V and an output current of 6 μA This suggests that introduction of an interlayer enables efficient charge collection and the ability of the charge collection enhances when the thickness of interlayer is increased however, the Voc is marginally different probably due to presence of defects in the 30 nm-thick interlayer cells.

1. INTRODUCTION

The chalcogenides-based semiconductors have shown promising results in the broad field of energy conversion materials and devices. One such material is CdTe which has been vastly exploited as for solar cell applications. This is because of their optical bandgap of 1.5 eV at room temperature which can be tuned, a high absorption coefficient 5x105cm-1 [1,2], a higher efficiency (22.1 % [3] achieved at lab scale with selenium doped CdTe) and economic precursors which favour large-scale production and makes them commercially viable. The CdTe material has all the characteristics of an ideal material which can be used for photovoltaic applications however, many studies conducted on CdTe as potential solar cell materials report variation in their properties due to a different fabrication procedure, differences in charge carrier dynamics, microstructure evolution, effects of annealing on the final device output etc. Besides this, there have been past reports on introduction of an interface layer for an efficient collection of charge carriers and reducing defect concentration between cell layer for better carrier transport. One such material is tellurium (Te) which has been utilized as an interface material for enhancing carrier collection [4]. The selection and utilization of tellurium as an interlayer material is reasonable since it is a p-type semiconducting material with a good alignment of its valence bands to that of CdTe. This reduce the interface defects and increases the conductivity between CdTe and aluminium electrode.

However, an in-depth understanding of the effect of varying the interlayer on the properties and thus, on the output characteristics of CdTe based cells is highly desired. Moreover, it is fundamentally essential to determine a range of thickness which leads to optimized charge carrier collection which enhances final output characteristics of photovoltaic cells. For this purpose, we have fabricated sub-micron sized CdTe solar cells and we have varied the interlayer thickness to observe its effect on the cell(s) performance.

2. EXPERIMENTAL DETAILS

We have fabricated CdTe-based photovoltaic devices using soda-lime glass as a substrate material and utilizing an in-house thermal evaporator setup. The precursors of the thin-films were kept in a molybdenum (Mo) boat for the purpose of evaporation and the films were deposited at a rate of 0.2 Ås−1, under vacuum ($10-5\ m.bar$). The materials were deposited in the following fashion: first, a fluorine-doped SnO2 (7 Ωcm−2, Sigma Aldrich) conducting oxide was used as the bottom electrode. Following this, a CdS thin film of 100 nm thickness was deposited on the bottom electrode using precursor CdS powder (purity 0f 99.9%, Sigma Aldrich), and the substrate was kept at 100°C during deposition and annealed at 300°C for 60 minutes in order to improve the crystallinity of the CdS thin-film. Next, we deposited a 500 nm thick CdTe thin-film using CdTe powder (purity of 99.98%, Sigma Aldrich) was deposited on CdS thin film and in this specific case, we maintained the substrate temperature to be 250°C. In order to make a heterojunction between the deposited CdS and CdTe thin-films, we have annealed the substrate at 420°C for 15 minutes and slowly cooled down to the room temperature. Later, Tellurium (Te) (purity 99.99%, Sigma Aldrich) was deposited on the CdTe films with two different thicknesses. In the first case, 10 nm while in the second case a 30 nm thick films were deposited. Finally, we have coated aluminium (purity 99.9%, Sigma Aldrich) at 50°C, as a top electrode (thickness: 100 nm, area: 3 mm × 3 mm) by shadow masking on the deposited tellurium film. The structural properties of both CdS and CdTe films were examined using X-Ray diffraction method (Rigaku, Cu Kα radiation 1.54 Å). The optical properties of the deposited were measured using Shimadzu MPC3600 UV-Visible-IR spectrometer in the wavelength range from 400 nm to 1500 nm. The I-V characteristics of the prepared devices were measured using solar simulator at room temperature.

3. RESULTS AND DISCUSSION

3.1. XRD Analysis
We have conducted XRD measurement on the as-deposited thin-films in the 2θ range between 20°−70° which is mentioned in figure 1. The XRD pattern showed reflections corresponding to the different materials that were deposited. The CdTe was observed to exist in two phases: cubic and hexagonal. The cubic phase was confirmed by the position of the most intense peak at 23.8° corresponding to (111) plane (d-spacing: 3.73 Å) and other peaks at 22.67° and 25.36° corresponding to (010) and (011) planes [5]. The existence of hexagonal phase was identified by the presence of most intense peak corresponding to (022) plane (d-spacing: 2.29 Å) was observed at 39.32° along with other peaks corresponding to this phase at 46.48° ((113) plane), 56.87° ((001) plane), and 62.47° ((133) plane) [6]. Besides this, the cubic phase CdS films was identified from the peaks observed at 26.54° and 51.44° corresponding to (111) plane and (113) plane respectively [7]. Also, the peaks of fluorine-doped SnO2 were identified from the X-ray pattern and are marked as FTO.
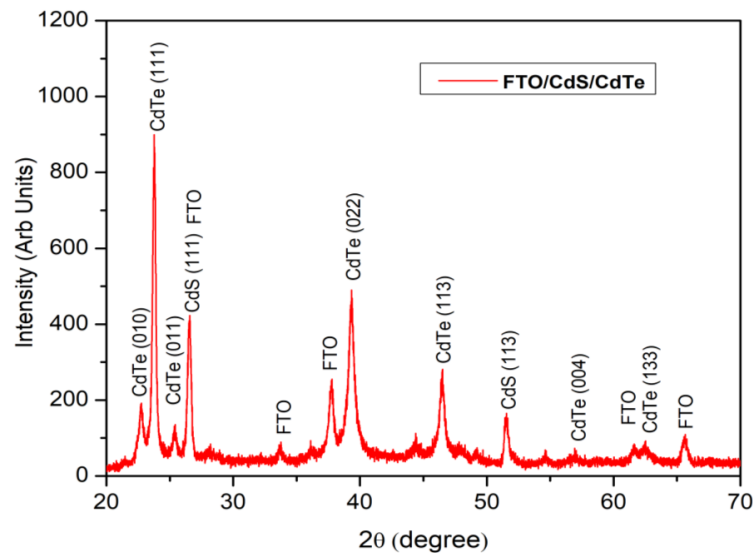
Figure 1. XRD patterns of FTO/CdS/CdTe film

3.2. Optical studies

The room temperature UV-Visible-IR spectra of the CdS film and the CdTe film deposited on the FTO and the FTO/CdS coated substrate respectively, were measured in the wavelength range (400 nm−1500 nm) as shown in figure 2.
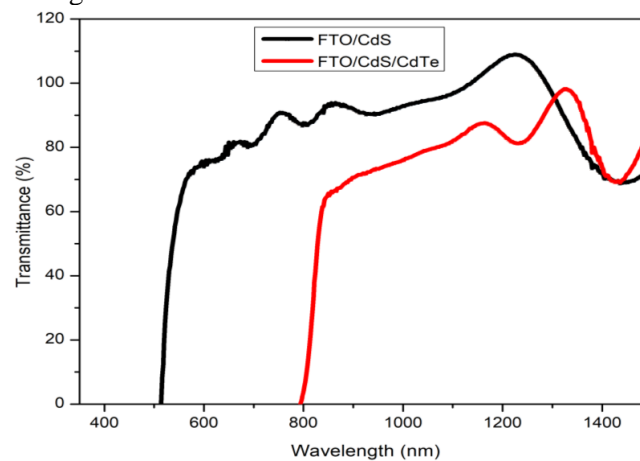

Figure 2. Transmittance spectra in the wavelength range 400-1800 nm of the fabricated devices

From the transmission spectrum of CdS-coated FTO, we observe a transmission intensity greater than 70% between a wavelength range from 1200 nm to 515 nm and later, a reduction in the intensity. However, the transmission spectrum of CdTe coated FTO/CdS film shows a decrease in the intensity to 65% with a cut-off wavelength 794 nm. A reduction of 10-20% in the transmission intensity on comparing both the spectrums strongly suggests a complete absorption of visible and UV radiations only after the deposition of CdTe thin-film which could be observed after the spectrum ends at 794 nm.

The optical band gap (Eg) of both the CdS and CdTe thin films was estimated using Tauc plot using the following relation [8]

$$\alpha h\nu = (h\nu - Eg)n \qquad\qquad 1$$

where A is constant, $h\nu$ is the energy of the illuminating light, $\boldsymbol{\alpha}$ is the absorption coefficient and $\boldsymbol{n}$ is taken for 1/2, 2, 3, and 3/2 for direct, indirect, forbidden indirect and direct forbidden bandgap respectively. The optical band gap of the CdS and CdTe films were determined by plotting a graph

between $(\alpha h\nu)2$ as a function of $h\nu$[9]. Here, CdS and CdTe as they both are shown direct band-semiconductors. We found a distinct linear regime for $h\nu>2.25\ eV$, and on extrapolating this linear region to the x-axis led us to deduce the energy gap. The energy gap (Eg) of CdS and CdTe was determined to be 2.35 eV[10] and 1.5 eV[11] respectively as shown in figure 3.
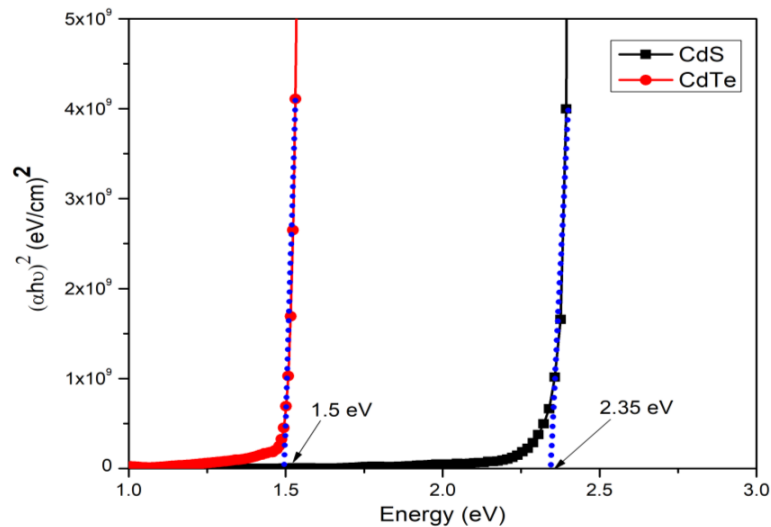

Figure 3. Plot of (αhν) vs photon energy (hν) 2 for the evaluation of energy band gap of CdS and CdTe thin films

3.3. J-V characteristics

The J-V curves of two CdTe-photovoltaic devices were measured using solar simulator (keithley source meter 2400) under AM 1.5 illumination (1KWm-2, 25°C) are shown in figure 4. Each device had a tellurium interlayer with a thickness of 10 nm and 30 nm respectively. For both the devices, the collected current was lower in magnitude due to a thick CdTe layer which led to poor light absorption. However, we observe some differences in both the trend and the magnitude of the J-V characteristics of both photovoltaic devices fabricated with different interlayer thickness. The J-V characteristics of the device with an interlayer thickness of 10 nm shows an almost straight line compared to 30 nm-interlayer devices. Moreover, the Jsc of the device with an interlayer thickness of 30 nm showed a relative increase of 25 μA compared to the device with a less thick interlayer (~6 μA).
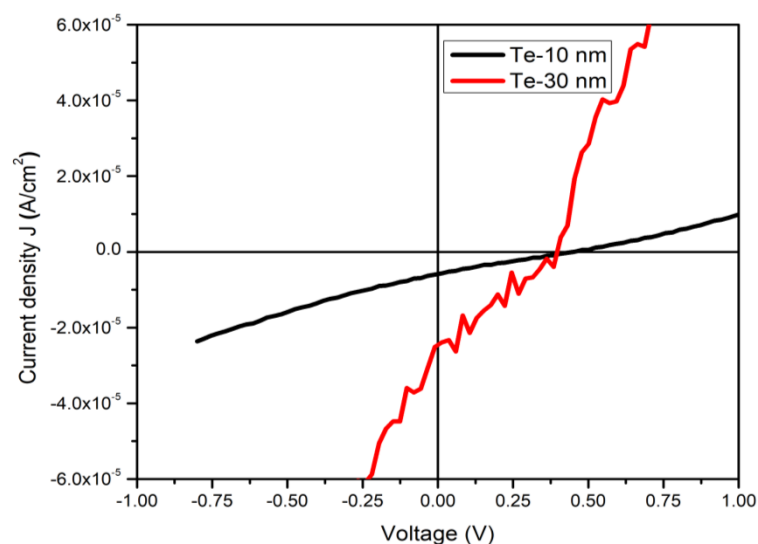

Figure 4. J-V characteristics of FTO/CdS/CdTe/Te/Al device

This is because of both a high series resistance of the 10 nm-interlayer device and a relatively higher recombination rate of the charge carriers whereas a thicker interlayer enhances the overall charge collection of the device. Nevertheless, the open-circuit voltage of both the devices is almost identical i.e 0.45 V and 0.40 V for the devices with 10 nm and 30 nm interlayer thickness. This is plausibly due to presence of charged acceptor defects in the CdTe thin-film of the device with thick interlayer as previously reported [12].

4. CONCLUSION

We have fabricated two FTO/CdS/CdTe/Te/Al solar cells utilizing a thermal evaporator, each with an overall thickness of each device was $<1\mu m$. An interlayer of tellurium was introduced between CdTe and top aluminium (Al) electrode to reduce the potential resistance. In order to enhance electrical conductivity and optimize the output of these cells, we vary the interlayer thickness. The cell with a 10 nm-thick interlayer gave an output current density and voltage of ~6 μA and $0.45V$ whereas on increasing the interlayer thickness, the output current density enhanced by four-times (25 μA) however, the open circuit voltage was almost same (0.4 V). Thus, it affirms that introduction of an interlayer enables to further improve the output characteristics of the solar cell devices however, for the complete optimization processes, we need to play with one parameter at a time. and 30 nm thin layer of Te was introduced between CdTe and top electrode to reduces the potential resistance between CdTe and Al electrode in 2 different iterations. The maximum open circuit voltage of 0.45 V extracted for 10 nm Te film coated device which gives less current extraction of 6 μA. For the device 30 nm Te coated shows Voc of 0.4 V only with Jsc of 25 μA. The efficiency of the devices shows less than 1% efficiency, these devices performance could be further improved by CdCl2 treatment, improving the thickness of CdTe and reduces the thickness of CdS film.

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