



Solar Cell Properties of CdS/CdTe Heterojunctions Prepared by using Spray Pyrolysis Technique

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Abstract

The fabrications of CdS/CdTe [n-CS/p-CT] hetero-junction solar cells on thoroughly cleaned soda lime glass (SLG), indium tin oxide (ITO) and commercial F-doped tin oxide (CFTO) substrates by using spray pyrolysis deposition technique only are reported for the first time. The SLG/SF/n-CS/p-CT/Cu [SF: F-doped SnO₂], ITO/n-CS/p-CT/Cu and CFTO/n-CS/p-CT/Cu hetero-junctions are fabricated in present work. The photovoltaic properties obtained for the CdCl₂ treated hetero-junction solar cells are found to be better than that of the solar cells prepared without CdCl₂ treatment. The formation of the p-n junctions and destitute photovoltaic properties for presently fabricated hetero-junctions are the better results as compared to the reported data.

Keywords: CdS, CdTe, Solar cell, Spray pyrolysis, Efficiency.

Introduction

Cadmium Telluride (CdTe) is a leading material for the development of cost effective and reliable photovoltaic devices for terrestrial applications and in ionizing radiation detectors [1]. In the available photovoltaic technologies, cadmium telluride (CdTe) solar cell is the world's second most abundant PV technology after crystalline silicon. The thin film market share of CdTe solar cell in the international market is 43 % [2]. It is a low-cost alternative to traditional silicon based technology and can be manufactured quickly and inexpensively [3]. The two key properties of CdTe material are: (i) it is a direct bandgap (1.45 eV) semiconductor, which is well matched with solar spectrum and (ii) its high optical absorption coefficient for photovoltaic conversion makes it potential candidate for the solar cell device. It is usually sandwiched with CdS to form a p-n junction of solar cell.

The commercially available CdTe modules have efficiencies around 10 % to 13.1 %. Recently in 2014, First solar, USA recorded the 21 % efficiency for CdTe solar cell at laboratory level [4]. It gives lot of hopes and chances to improve the present status of CdTe solar cell photovoltaic technology. There is still



some potential to increase the cell efficiency by increasing crystal quality, improving doping control, and increasing the minority lifetime. The manufacturers are also investigating the possibility of material's reuse and recycling as a way to reduce concerns on toxicity and materials scarcity [5]. There are number of technologies available to manufacture low-cost/inexpensive CdTe thin film solar cells. A thin film of CdTe with thickness of approximately 2 μm will absorb nearly 100 % of the incident solar radiation. Although to-date the highest reported efficiencies for CdTe laboratory devices have been achieved with the close spaced sublimation (CSS) process, several other technologies such as physical vapor deposition (PVD), vapor transport deposition, metal-organic chemical-vapor deposition (CVD), electrodeposition (ED), magnetron sputtering, spray pyrolysis and screen printing have also demonstrated the potential of achieving high performance levels. The theoretical limit of CdTe solar cell is 28 – 30 % [6 - 7]. CdTe solar cells would be achieved efficiency upto 22 % by increasing the open-circuit voltage, which is still smaller as compared to the present similar band-gap crystalline cells [8]. At present, literature survey gives the brief information about fabrication of CdS/CdTe [CS/CT] hetero-junction solar cells by using the different substrates, front & back contacts & method of deposition of junction layers and their photovoltaic performance. The photovoltaic performance of the CdS/CdTe hetero-junctions solar cells, wherein the CdS and CdTe junction layers are deposited by using different deposition techniques is reported in literature with very good solar cell conversion efficiency. However, the photovoltaic performance of the CS/CT hetero-junctions solar cells, wherein the both CdS (CS) and CdTe (CT) junction layers are deposited by using very simple, cheap and ease in operation spray pyrolysis technique [9], which is not reported in literature.

The present work is subjected to the studies on photovoltaic properties of CdS/CdTe heterojunctions fabricated with CdS and CdTe films deposited by using spray pyrolysis technique.

Materials and Methods

For the fabrication of hetero-junction CS/CT solar cells, soda lime glass (SLG), indium tin oxide (ITO) and commercial fluorine (F)-doped tin oxide (CFTO) substrates were used. The SLG substrates were washed by using the procedure: (a) washing with laboline detergent followed by rinsing with double distilled water (DDW), (b) heating in concentrated chromic acid (0.5 M) for 1 hr followed keeping in it for 12 hr, (c) rinsing & cleaning ultrasonically in DDW for 20 min., (d) ultrasonic cleaning in AR grade acetone for 10 min. and finally (e) drying under IR lamp. The ITO/CFTO substrates were washed by using the procedure: (a) washing with laboline detergent followed by rinsing with DDW, (b) drying at 80 $^{\circ}\text{C}$ for 15 min., (c) ultrasonic cleaning in ethanol for 10 min. & then in AR grade acetone for 10 min. and finally (d) cleaning by using 2-isopropanol followed drying under IR lamp.

The hetero-junction CS/CT solar cells having version: SLG/SF/n-CS/p-CT/Cu were fabricated by using the procedure as given below. Fig. 1 gives the schematic diagram for hetero-junction CS/CT solar cell



having version: SLG/SF/n-CS/p-CT/Cu. The process parameters used for the fabrication of above-mentioned solar cells are summarized in Table - I.

- i) The conducting F-doped SnO_2 (SF) thin film was deposited on thoroughly cleaned SLG substrates (Fig. 1) by using the home-built spray pyrolysis system with the process parameters as mentioned in Table - I. The conducting SF thin layer acts as a front contact for solar cell (Fig. 1).
- ii) The semiconducting n-CdS (n-CS) thin film as a window layer of solar cell was deposited on SF film (Fig. 1) by using the home-built spray pyrolysis system with the process parameters as mentioned in Table - I.
- iii) The semiconducting p-CdTe (p-CT) film as absorber layer of the solar cell was deposited on CS film (Fig. 1) by using the home-built spray pyrolysis system with the process parameters as mentioned in Table - I.
- iv) The whole structure SLG/SF/n-CS/p-CT was etched by using NP (Nitric-Phosphoric acid) solution at RT for 5 - 7 sec. The ratio of nitric acid, HNO_3 (65 %): phosphorus acid, H_3PO_4 (85 %): water was 1:70:29.
- v) After etching, the whole cell structure SLG/SF/n-CS/p-CT was annealed at 300°C in air atmosphere for 20 min.
- vi) The metallic Cu thin layer was deposited on the p-CT film (Fig. 1) by using thermal evaporation technique at 10^{-6} mbar vacuum with process parameters as mentioned in Table - I. This acts as a back contact for solar cell.

The hetero-junction CS/CT solar cells having version: ITO/n-CS/p-CT/Cu and CFTO/n-CS/p-CT/Cu were fabricated by using the procedure as given below. Fig. 2 gives the schematic diagram for hetero-junction CS/CT solar cell having version: ITO/n-CS/p-CT/Cu or CFTO/n-CS/p-CT/Cu. The process parameters used for the fabrication of above-mentioned solar cells are summarized Table - II.

- i) The semiconducting n-CS thin film as a window layer of solar cell was deposited (Fig. 2) on thoroughly cleaned ITO/CFTO substrate by using the home-built spray pyrolysis system with the process parameters as mentioned in Table - II. The conducting SF thin layer acts as a front contact for solar cell (Fig. 2).
- ii) The semiconducting p-CT film as an absorber layer of the solar cell was deposited on n-CS film (Fig. 2) by using the home-built spray pyrolysis system with the process parameters as mentioned in Table - II.
- iii) The whole structure ITO/n-CS/p-CT or CFTO/n-CS/p-CT was etched by using NP (Nitric-Phosphoric acid) solution at RT for 5 - 7 sec. The ratio of nitric acid, HNO_3 (65 %): phosphorus acid, H_3PO_4 (85 %): water was 1:70:29.

- iv) After etching, the whole cell structures ITO/n-CS/p-CT or CFTO/n-CS/p-CT were annealed at 300 °C in air atmosphere for 20 min.
- v) The metallic Cu thin films were deposited on p-CT film (Fig. 2) by using thermal evaporation technique at 10^{-6} mbar vacuum with process parameters as mentioned in Table - II. This acts as a back contact for solar cell.

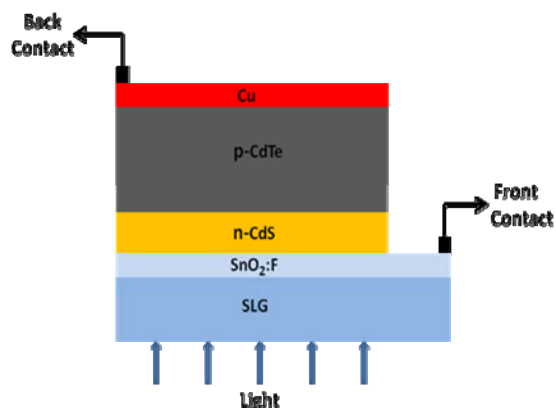


Fig. 1 Schematic diagram for hetero-junction CS/CT solar cell having version: SLG/SF/n-CS/p-CT/Cu

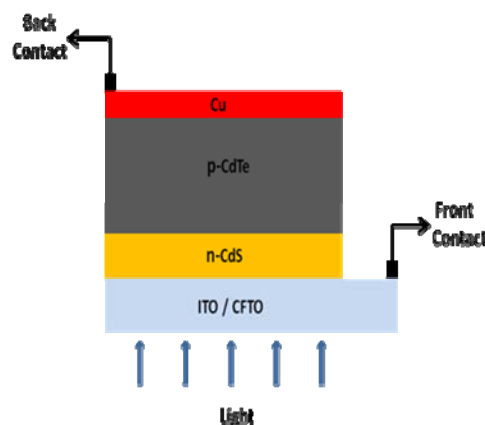


Fig. 2 Schematic diagram for hetero-junction CS/CT solar cell having version: ITO/n-CS/p-CT/Cu or CFTO/n-CS/p-CT/Cu.

Table – 1 Process parameters for the fabrication of solar cell having version: SLG/SF/n-CS/p-CT/Cu

Sr. No.	Name of layer	Substrate temperature (°C)	Amount of solution sprayed (ml)	Deposition time (min.)	Atmospheric/ vacuum conditions	Approximate thickness of layer
1.	SF	425	20	10	Air	100 ± 5 nm
2.	n-CS	400	20	10	Grade-I nitrogen	200 ± 5 nm
3.	p-CT	350	50	20	Grade-I nitrogen	4 - 5 μ m
4.	Cu	--	--	2	10^{-6} mbar vacuum	50 ± 5 nm

Table – 2 Process parameters for the fabrication of solar cell having versions: ITO/n-CS/p-CT/Cu or CFTO/n-CS/p-CT/Cu.

Sr. No.	Name of layer	Substrate temperature (°C)	Amount of solution sprayed (ml)	Deposition time (min.)	Atmospheric/ vacuum conditions	Approximate thickness of layer
1.	n-CS	400	20	10	Grade-I nitrogen	200 ± 5 nm
2.	p-CT	350	50	20	Grade-I nitrogen	4 - 5 μ m
3.	Cu	--	--	2	10^{-6} mbar vacuum	50 ± 5 nm

These solar cells were CdCl₂-treated after CdTe deposition in order to improve the quality of CdTe, and heat-treated for Cu diffusion. These treatments are important to upgrade device performance [12]. It is well known that heat treatment with CdCl₂ is a major step in preparing high-quality CdTe/CdS solar cells [13 - 16]. CdCl₂ treatment has become a standard and critical process in the fabrication of high-efficiency CdTe-based photovoltaic devices, regardless of the method used for depositing the CdTe layer. That is a chemical reaction between CdTe and CdS activated by CdCl₂ can occur and this is the driving force for the bulk and grain-boundary inter-diffusion of CdTe and CdS [17-19]. The Table – III gives the list of different CS/CT hetero-junction solar cells for which the photovoltaic properties were recorded. The solar cell properties of all the as-fabricated cells were recorded by using the solar simulator system (Newport Corporation's Oriel® Sol2A® Class ABA).

Table – 3 Photovoltaic properties of CdTe solar cells

Name of CS/CT hetero-junction solar cell	Version of hetero-junction
A	SLG/SF/n-CS/p-CT/Cu
B	CdCl ₂ treated SLG/SF/n-CS/p-CT/Cu
C	CFTO/n-CS/p-CT/Cu
D	CdCl ₂ treated CFTO/n-CS/p-CT/Cu
E	ITO/n-CS/p-CT/Cu

Results and Discussion

The results obtained for photovoltaic properties of different CS/CT hetero-junction solar cells by using the solar simulator system (Newport Corporation's Oriel® Sol2A® Class ABA) and home-built solar cell characteristics system are given below. The photovoltaic properties for different A, B, C, D and E hetero-junction solar cells are obtained from their respective J_{SC} - V curves as shown Fig. 3. Table - IV gives the photovoltaic properties for different A, B, C, D and E hetero-junction solar cells.

Table – 4 Photovoltaic properties of different hetero-junction solar cell

Name of CS/CT hetero-junction	Voc (mV)	Jsc (mA/cm ²)	Pmax (mW)	Fill factor (%)	Efficiency (%)	R at Voc	R at Isc
A	274	0.0427	0.001456	49.59	0.0058	8352	258539
B	304	0.0335	0.001947	73.31	0.0078	5129	223240
C	286	0.0763	0.002814	51.52	0.0113	1883	261792
D	318	0.0651	0.004302	83.03	0.0172	1025	65214
E	312	0.0261	0.001299	63.69	0.0051	9780	174136

The nature of J_{sc} - V curves presented in Fig. 3 indicates the formation of junctions in different solar cell as mentioned in Table - III. The overall photovoltaic properties obtained for different A, B, C, D and E hetero-junction solar cells are found to be destitute. The photovoltaic properties obtained for the $CdCl_2$ treated CS/CT hetero-junction solar cells are found to be better than that of the solar cells prepared without $CdCl_2$ treatment. The formation of junctions and destitute photovoltaic properties obtained for the solar cells prepared in present work by using only spray pyrolysis technique are found to be better results as compared to the corresponding data presented in the literature.

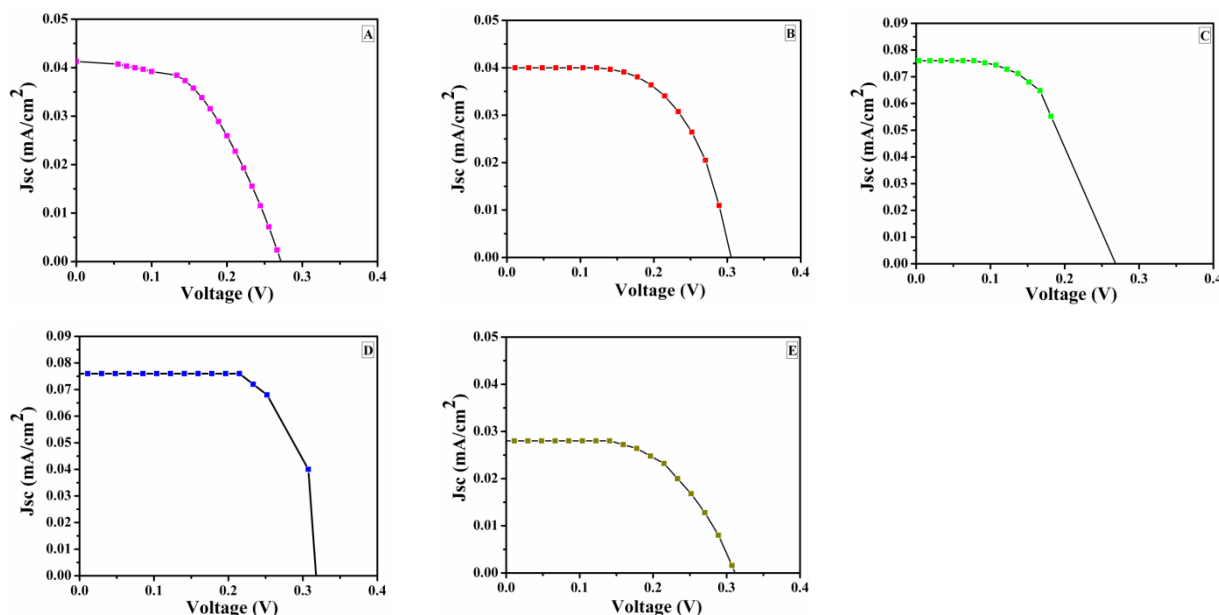


Fig. 3 The variation of current density (J_{sc}) mA/cm² with voltage (V) volt for hetero-junctions A, B, C, D and E

Conclusions

Following conclusions could be drawn from data obtained related to the photovoltaic properties obtained for different CS/CT hetero-junction solar cells prepared by using the only spray pyrolysis technique.

- The spray pyrolysis is cheap and easy to operate technique for the preparation of CS/CT hetero-junction solar cells.
- The photovoltaic properties obtained for the $CdCl_2$ treated CS/CT hetero-junction solar cells are found to be better than that of the solar cells prepared without $CdCl_2$ treatment.
- The formation p-n junctions and destitute photovoltaic properties obtained for the solar cells prepared in present work by using only spray pyrolysis technique are better results as compared to the corresponding data presented in the literature.

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