

Structural and Electrical Properties of Thin CdTe Films with the Application of CdCl₂ Activation

S.L. Patel^{1, a)}, Himanshu¹⁾, A. Purohit¹⁾, S. Chander²⁾ and M.S. Dhaka¹⁾

¹⁾Department of Physics, Mohanlal Sukhadia University, Udaipur-313001, India

²⁾Department of Chemical Sciences, Indian Institute of Science Education and Research Mohali, Mohali-140306, India

^{a)}Corresponding author: shankar111190@gmail.com

Abstract. This work presents a study on structural and electrical properties of thin CdTe films with the treatment of post-CdCl₂ activation. The thin layers of thickness 550 nm were grown on soda lime glass and ITO coated glass substrates by electron beam vacuum evaporation subsequently CdCl₂ treatment and annealing at different temperature and then subjected to X-ray diffractometer and source-meter to investigate the structural and electrical properties, respectively. The films are found to be in polycrystalline nature with cubic phase at low annealing temperature (≤ 320 °C) and mixture of cubic and hexagonal phases at higher temperature (470 °C). The improvement in crystallinity is also observed with CdCl₂ process while the electrical analysis reveals that the current is varied linearly with the voltage while electrical resistivity is increased with post-CdCl₂ treatment. The obtained outcome of our study demonstrates that the CdCl₂ treated CdTe films processed at 320 °C might be an appropriate candidate as a suitable absorber layer to the thin film solar cells.

Keywords: Thin CdTe layers, e-beam deposition, Structural properties, Electrical properties.

PACS: 88.40. jn, 81.15.-z, 68.55.-a, 73.61. Ga

INTRODUCTION

Nowadays, cadmium telluride (CdTe) thin film solar cells play the main role as alternative to silicon-based solar cells for industry-based photovoltaic (PV) technologies. It is one of the most noticeable candidate from II-VI chalcogenide group of compound semiconductors and commonly used in fabrication of photovoltaic solar cells [1-2]. The thin CdTe film based solar cells have long-term performance and high efficiency because it has appropriate absorber layer properties to the low cost PV cells such as direct band gap (1.45 eV) which is in vicinity to the optimum band gap for high solar energy conversion efficiency and high absorption coefficient ($>10^5$ cm⁻¹) of CdTe films having thickness in order of one micron [3-6]. The post-CdCl₂ heat treatment is a critical processing step to fabricate high-efficiency CdTe-based solar cells as this treatment can partially melt and re-crystallize the CdTe layer as well as interface (with window layer) because chlorine atoms may diffuse from surface to interior of thin CdTe film and reveals reduction in the defects [7]. Several physical and chemical deposition methods could be employed to deposit thin layers of CdTe [8] and in the present work, an electron beam evaporation method is employed because it has some advantages viz. low consumption rate of material and controllable deposition conditions. The main objective of this work is to study the structural and electrical properties of CdCl₂-treated CdTe films in order to understand the nature of films for solar cell application as absorber layer.

EXPERIMENTAL DETAILS

CdTe powder of purity 99.999% was obtained from USA's company Sigma Aldrich and converted into pellets using a hydraulic pelletizer. The e-beam evaporation technique (HHV, Box Coater-300) was used to deposit the films on substrates like soda lime glass and indium tin oxide (ITO) coated glass. The vacuum coating unit was evacuated up to 3×10^{-6} mbar of pressure by using diffusion and rotary pumps. The soda lime glass and ITO substrates were cleaned before the deposition by standard cleaning process and the source material (CdTe pellet) was kept in a crucible. The films with thickness of 550 nm were deposited by evaporating the source material using electron-gun while the thickness was also managed by quartz crystal monitor. The grown films were treated by post-CdCl₂ treatment and air-annealed in a furnace (SONAR) for one hour at different temperature viz. 170°C, 320°C and 470°C followed by removal of excess CdCl₂ from the surface using hot deionized water. The un-treated and post-CdCl₂ treated thin CdTe films were exposed to Rikagu Ultima-IV modeled X-ray diffractometer within the 2 θ -range of 20°-80° to investigate the structural properties. An Agilent source-meter (B2901A) was used to explore the electrical properties of films grown on ITO substrates where the contacts were made by adhesive silver paste (Sigma Aldrich) and measurements were performed in the voltage range from -2 volt to +2 volt as well as the measurements were controlled by a Quick I-V computer software.

RESULT AND DISCUSSION

Patterns of X-ray diffractometer for as-grown and post-CdCl₂ treated films are depicted in Figure 1 which show a strong diffraction peak corresponding to reflection (111) for as-grown and post-CdCl₂ treated films treated at 170 °C and 320 °C that reveal films have cubic phase (zinc blende) as indexed by JCPDS file no. 65-8395. Some other peaks like (220) and (311) are also seen for as-grown and films annealed at 170 °C while (331) and (422) for films processed at 320 °C in addition to above-mentioned peaks which reveal the polycrystalline nature of these films. The intensity of prominent peak is significantly increased with post-CdCl₂ heat treatment upto 320°C which may be due to augmentation in crystallinity.

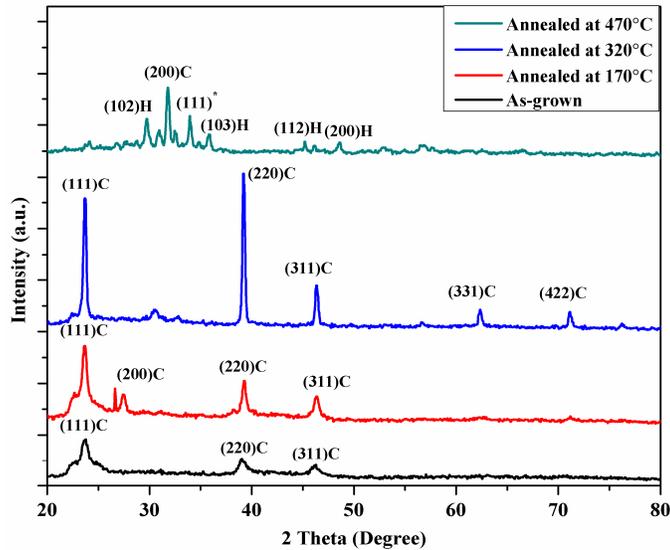


FIGURE 1. Patterns of X-ray diffractometer for as-grown and post-CdCl₂ treated films.

However, post-CdCl₂ treated films annealed at higher temperature (470 °C) showed a mixture of cubic and hexagonal phases which might be attributed to possible recrystallization. In XRD pattern of these films, (200) peak belongs to cubic phase while other peaks like (102), (103) and (102) belong to hexagonal phase as confirmed by JCPDS file no. 80-0089. The remaining peak (111) located at $2\theta = 33.8^\circ$ is found to be associated with cadmium oxide (CdO) which may be due to oxidization at such higher temperature in air-atmosphere (JCPDS file no. 75-0594). The preferred orientation (111) of cubic phase is shifted towards upper side with post-annealing temperature which may be due to decrement in corresponding lattice parameter (from 6.53 Å to 6.48 Å) and improvement in crystallinity. The

lattice parameter lies in the vicinity of standard value 6.48 Å as can be seen in Table 1. The other structural constants like grain size (D), dislocation density (δ), internal strain (ϵ), inter planer spacing (d) and number of crystallites per unit area (N) of pristine (as-grown) and post-CdCl₂ annealed CdTe films were calculated using relations concerned [5] corresponding to diffraction peak (111) of cubic phase and tabulated in Table 1. The average grain size was calculated by Scherrer formula and found to be enlarged from 12.63 nm to 25.85 nm with post-CdCl₂ annealing treatment which may be attributed to enhancement in crystallinity of cubic phase. The inter-planer spacing (d) is found in the range of 3.756-3.768Å and decreased with post-annealing treatment which may be due to corresponding shift in angular position towards upper side.

Table 1. Crystallographic constants of as-grown and post-CdCl₂ annealed thin CdTe films.

Sample	2θ(°)	(hkl)	d(Å)	a(Å)	a(Å)	D (nm)	$\epsilon \times 10^{-3}$	$\delta \times 10^{14} \text{m}^{-2}$	$N \times 10^{18} \text{m}^{-2}$
			Obs.	Obs.	Std.				
As-grown	23.57	111	3.768	6.52	6.48	12.63	6.27	14.02	43.54
	38.98	220	2.310	6.53	-	-	6.14	8.50	43.08
170 °C	23.61	111	3.763	6.52	-	19.04	2.76	9.29	28.89
	39.26	220	2.292	6.49	-	-	2.07	4.90	25.01
320 °C	23.65	111	3.756	6.51	-	25.85	1.50	6.83	21.28
	39.28	220	2.290	6.48	-	-	1.06	3.49	17.87
470 °C	31.78	200	2.813	5.67	-	-	-	-	-

The other structural constants viz. internal strain, dislocation density and number of crystallites per unit area corresponding to (111) peak of cubic phase are found within the range $(1.50-6.27) \times 10^{-3}$, $(6.83-14.02) \times 10^{14} \text{m}^{-2}$ and $(21.28-43.54) \times 10^{18} \text{m}^{-2}$ respectively and detected to decrease with heat treatment which might be possibly due to increase in grain size and improvement in crystallinity of the films. The transverse characteristics of current-voltage ($I-V$) for as grown and post CdCl₂ annealed CdTe thin films are presented in Figure 2.

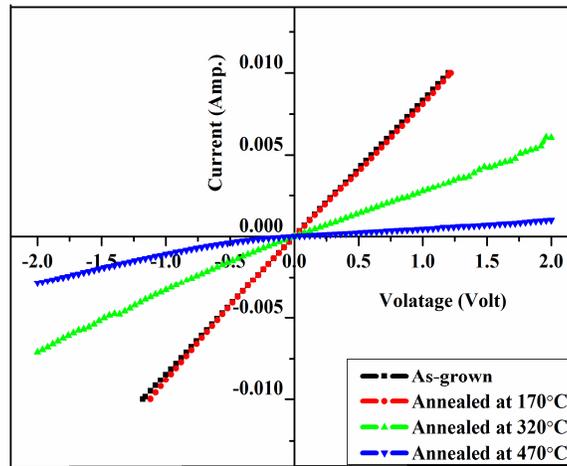


FIGURE 2. The $I-V$ characteristics of as-grown and post-CdCl₂ annealed CdTe thin films.

The variation in current with voltage is observed to be linear and current is also found to decrease slightly with heat treatment of post-CdCl₂ treatment. The $I-V$ characteristics for as-grown and annealed film at 170 °C almost overlap each other revealed that lower annealing temperature is not so effective. The value of electrical resistivity is found to increase with temperature of air annealing while decrement in electrical conductivity is observed which might be attributed to furnace contamination. A similar current-voltage behavior is also reported in earlier studies [9-11] for CdTe thin films with the application of post-annealing (in air atmospheric annealing) and CdCl₂ treatments.

CONCLUSIONS

In this paper, the structural and electrical properties of e-beam evaporated CdTe thin films is reported with post-CdCl₂ treatment. The polycrystalline nature with cubic phase of these films is found at lower annealing temperature ($\leq 320^\circ\text{C}$) while a mixture of cubic and hexagonal phases is observed at 470°C . The crystallinity was improved with post-CdCl₂ annealing and highest grain-growth is attained for 320°C annealed films. The electrical studies reveal that the current-voltage behavior was found to be linear while electrical resistivity increased with post-CdCl₂ activation. The results demonstrated that the CdCl₂-treated films processed at 320°C might be well-suitable to the CdTe-based solar cells as an absorber layer.

ACKNOWLEDGEMENTS

The authors sincerely extend their gratitude to DST-SERB for financial assistance through extramural research project scheme (F.No. EMR/2017/003330). The authors would also like to acknowledge Malaviya National Institute of Technology, Jaipur for providing experimental facilities.

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