



Fabrication and characterization of n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} solar cell

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Hot wall deposited CdSe_xTe_{1-x} where $0 \leq x \leq 1$ thin films for solar cell applications have been prepared from a compound synthesized by direct reaction of high purity Cd, Se and Te elements. Crystal structure and composition of the films were analyzed by X-ray diffraction, scanning electron microscope and EDAX. X-ray diffraction studies carried out on pseudo-binary system revealed that the films are polycrystalline in nature with CdSe_{0.7}Te_{0.3} film exhibiting hexagonal structure and CdSe_{0.15}Te_{0.85} film exhibiting cubic zinc blende structure. The type of conduction was determined by Hall studies. A novel solar cell with structure n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} has been fabricated and the efficiency was found to be 3.13%.

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1. Introduction

The cadmium chalcogenide CdSe_xTe_{1-x} has received much attention as it is used in devices such as solar cells, photoconductors, solar control applications and thin film transistors [1–3 and references therein]. CdSe and CdTe form a solid solution over the entire composition range and the band-gap and lattice parameters can be varied by changing the relative amount of chalcogenides in the compound CdSe_xTe_{1-x}. In the case of CdSe_xTe_{1-x}, the crystal structure and band-gap can be tailored by changing the concentration of Se and Te, so that the visible solar energy can be suitably harnessed for maximum conversion to electrical energy. CdSe_xTe_{1-x} thin films have been prepared in the past by several techniques such as thermal flash evaporation, electrophoresis, electrodeposition, slurry painting, two source evaporation of CdSe and CdTe, three source elemental evaporation, thermal evaporation and hot wall deposition technique [3–7].

Among the different techniques available for preparation of thin films, hot wall deposition has gained importance recently, because, it is a simple and an economically viable technique and is a technique where deposition takes place under conditions very close to thermodynamical equilibrium. Schikora et al. [8] have claimed that hot wall deposited CdTe films on GaAs substrates show superior luminescence properties when compared to molecular beam epitaxy (MBE) and metal oxide chemical vapour deposited (MOCVD) films. Pal et al. [9] have fabricated ZnTe/CdSe solar cells by

the hot wall deposition technique and studied the I-V, C-V characteristics and spectral response. As a continuation of our previous work presented on the synthesis and characterization of CdSe_xTe_{1-x} [10–12], in this paper we present a brief method of preparation of CdSe_{0.7}Te_{0.3} and CdSe_{0.15}Te_{0.85} thin films, their structural properties, fabrication of a n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} thin film solar cell and its characteristics. The importance of choosing these two compositions is due to the fact that CdSe_xTe_{1-x} shows a sharp transition from the properties of CdSe to those typical of CdTe in the composition region $x \approx 0.3$ or $x < 0.2$ it will be p-type and for $x > 0.2$ it will be n-type. By choosing the same group of elements for any device applications, the junction problems can be avoided effectively. Although, research studies are ongoing on this ternary compound by the authors and various other groups, there is no report available on solar cells fabricated using hot wall deposited CdSe_xTe_{1-x}/CdSe_xTe_{1-x} ternary thin films.

2. Experimental technique

Compounds, CdSe_{0.7}Te_{0.3} and CdSe_{0.15}Te_{0.85} have been synthesized by direct reaction of high purity elemental Cd, Se and Te. Stoichiometric amounts of the elements Cd, Se and Te according to the composition are taken in a quartz ampoule, which is evacuated to a vacuum of 10^{-4} mbar and then sealed. The sealed ampoule is heated at a rate of 100 °C per hour up to 1200 K for CdSe_{0.7}Te_{0.3} and 1123 K for CdSe_{0.15}Te_{0.85}. The ampoules are maintained at these temperatures for four hours and then cooled slowly to room temperature to avoid thermal cracks in the alloy and in quartz ampoule. During the course of heating and cooling,

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quartz ampoule is rotated continuously by placing it in a rotating furnace to ensure homogeneity in the molten mixture. Synthesized source materials $\text{CdSe}_{0.7}\text{Te}_{0.3}$ and $\text{CdSe}_{0.15}\text{Te}_{0.85}$ have been used to prepare thin films by the hot wall deposition technique. The detailed deposition technique is already explained in our previous article [13].

The hot wall deposition technique is a low cost, convenient and scalable technique that can be used to deposit films under conditions very close to thermodynamic equilibrium with minimum loss of material. It is one of the methods that has contributed significantly to the preparation of epitaxial films with bulk-like properties [14]. The main feature of the hot wall system is the heated linear quartz tube, which serves to enclose and direct the vapour from the source to the substrate. The hot wall arrangement used in the present study consisted of a quartz tube of length 65 mm and diameter 10 mm with one end open and the other end closed. Kanthal wire was wound closely along the length of the quartz tube, which acts as wall heater. The quartz tube is charged with the prepared $\text{CdSe}_x\text{Te}_{1-x}$ source material. The substrate is held at a distance of less than 1 mm above the open end of quartz tube acting as a “lid” almost closing the tube. The whole arrangement is placed inside a vacuum chamber in which a pressure of 10^{-5} m bar is achieved prior to the deposition. $\text{CdSe}_{0.7}\text{Te}_{0.3}$ thin films have been deposited onto well cleaned glass substrates with wall temperature around 770 K and $\text{CdSe}_{0.15}\text{Te}_{0.85}$ films have been deposited with wall temperature around 665 K. Due to radiation from the hot wall, the substrate temperature automatically raised to 350 K during the deposition of $\text{CdSe}_{0.7}\text{Te}_{0.3}$ and to 342 K during the deposition of $\text{CdSe}_{0.15}\text{Te}_{0.85}$.

The structure of the deposited films was analyzed using an X-ray diffractometer (JOEL8030, Japan) fitted with monochromatic CuK α radiation. Hall effect measurements was carried out by the Van der Pauw's method at room temperature. The Hall coefficient and the carrier concentration were evaluated using the formulae.

$$\text{Hall Coefficient}(R_H) = (V_H \times t)/(I \times B) \quad (1)$$

Where V_H is the Hall Voltage, t is the thickness of the film, I is the current and B the magnetic Induction.

$$\text{Carrier concentration}(n) = 1/(R_H \times e) \quad (2)$$

Where n is carrier concentration and e is the electronic charge.

A solar cell with n- $\text{CdSe}_{0.7}\text{Te}_{0.3}$ /p- $\text{CdSe}_{0.15}\text{Te}_{0.85}$ structure was formed on a glass substrate by the hot wall deposition technique. Solar cell characterization was carried out by illuminating the cell with a tungsten lamp. The intensity of light was measured using Suryamapi (Suryamapi is a light intensity measuring equipment calibrated in mW/cm^2 , manufactured by CEL, India) and the current and voltage by an optical power meter and a Keithley Electrometer respectively. The fill factor and the efficiency were calculated using the formulae [15].

$$\text{Fill Factor}(FF) = (V_{\max} \times I_{\max})/(V_{oc} \times I_{sc}) \quad (3)$$

$$\text{Efficiency}(\eta) = (V_{\max} \times I_{\max}) \times 100/(P_{in} \times A) \quad (4)$$

P_{in} is incident power, A is area of the cell. $P_{\max} = V_{\max} \times I_{\max}$ was determined by computing the I-V product at various points along the curve and the point where the product is maximum corresponds to the V_{\max} and I_{\max} values. Fill factor gives the squareness of the I-V curve and it indicates the extent of deviation from ideal output. It is well known that the photovoltage versus photocurrent plot is perfectly rectangular in an ideal case. The fill factor also explains how well the junction is formed and, for an ideal cell, the value should lie between 0.6 and 0.8.

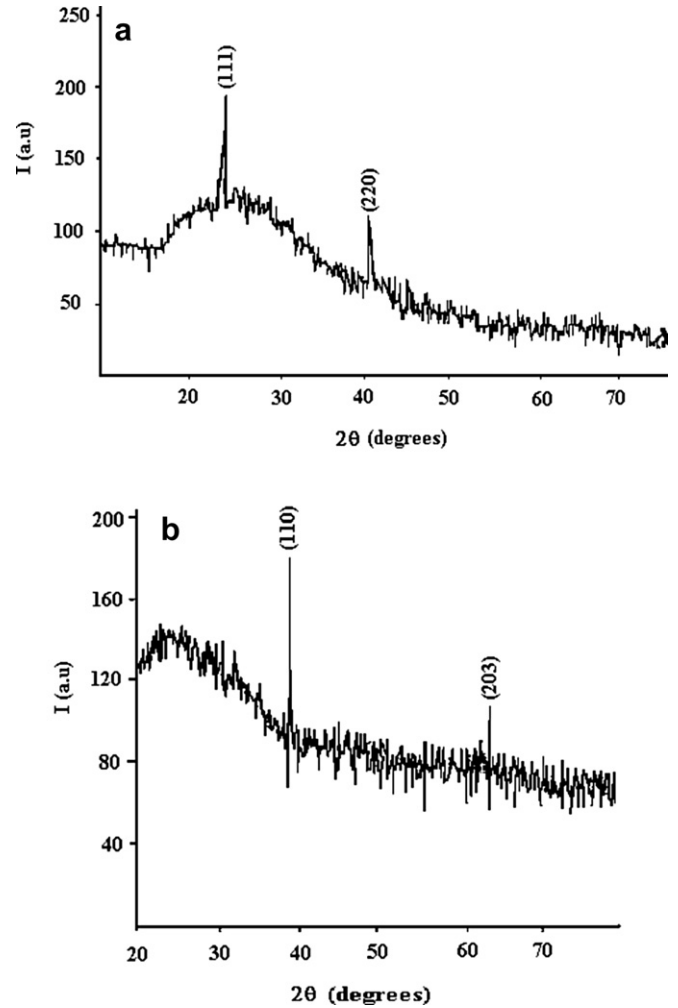


Fig. 1. a) X-ray diffraction pattern of $\text{CdSe}_{0.15}\text{Te}_{0.85}$ thin film of thickness 1455 Å and b) X-ray diffraction pattern of $\text{CdSe}_{0.7}\text{Te}_{0.3}$ thin film of thickness 1210 Å.

3. Results and discussion

The X-ray diffraction pattern of $\text{CdSe}_{0.15}\text{Te}_{0.85}$ and $\text{CdSe}_{0.7}\text{Te}_{0.3}$ films shown in Fig. 1 consists of sharp peaks, which indicates that the films are polycrystalline in nature. The $\text{CdSe}_{0.15}\text{Te}_{0.85}$ film is found to exhibit a cubic zinc blende structure with preferred orientation of grains along (111) and (220) directions, but the $\text{CdSe}_{0.7}\text{Te}_{0.3}$ film is seen to crystallize in a hexagonal structure with a preferred orientation along (110) direction. The lattice parameter value ‘a’ of $\text{CdSe}_{0.15}\text{Te}_{0.85}$ film is found to be 6.38 Å, which is in close agreement with ASTM (American Society for Testing and Measurements) data (41-1324 and 41-1325). The lattice parameter values ‘a’ and ‘c’ of the $\text{CdSe}_{0.7}\text{Te}_{0.3}$ thin film are 4.30 Å and 7.08 Å respectively, which are in good agreement with the ASTM data. The grain size, dislocation density and strain of $\text{CdSe}_{0.15}\text{Te}_{0.85}$ and $\text{CdSe}_{0.7}\text{Te}_{0.3}$ thin films have been calculated and are shown in Table 1. The methodology of calculation is fully explained in our previous articles [3,13]. The evaluated values of strain and dislocation density are within the

Table 1
Microstructural parameters.

Composition	Thickness (Å)	Grain size (Å)	Dislocation density (lines/m^2)	Strain
$\text{CdSe}_{0.15}\text{Te}_{0.85}$	1455	105	9.07×10^{15}	12.8×10^{-3}
$\text{CdSe}_{0.7}\text{Te}_{0.3}$	1210	302	1.09×10^{15}	0.967×10^{-3}

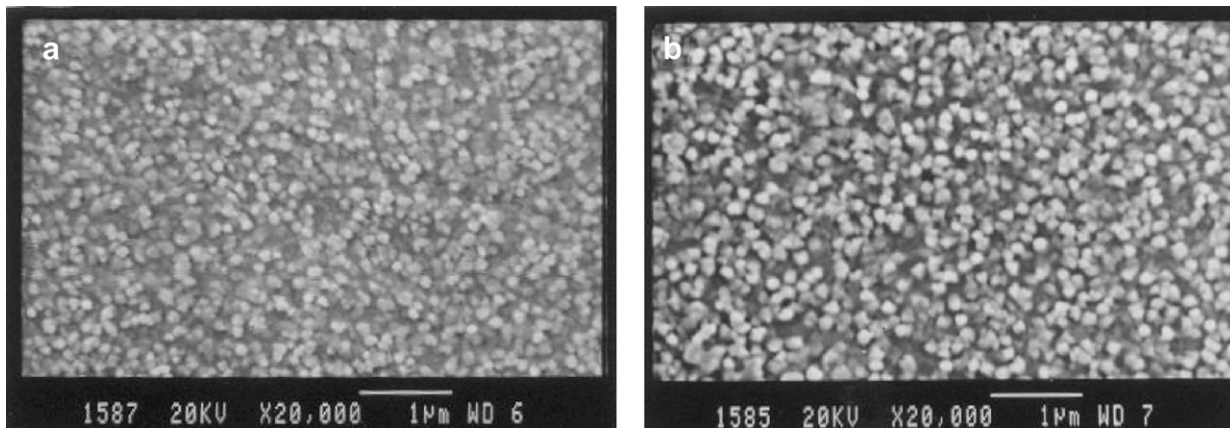


Fig. 2. a) SEM micrograph of CdSe_{0.15}Te_{0.85} film of thickness 1455 Å and b) SEM micrograph of CdSe_{0.7}Te_{0.3} film of thickness 1210 Å.

tolerable limits noted for other semiconductor materials by our research group.

Composition of the deposited films has been determined by energy dispersive X-ray analysis. EDAX analysis of a CdSe_{0.15}Te_{0.85} film gives the composition Cd-50.25 atomic%, Se-6.85 atomic% and Te-42.90 atomic%. The CdSe_{0.7}Te_{0.3} film is found to have the composition of Cd-51.10 atomic%, Se-35.56 atomic% and Te-13.34 atomic%. Generally II-VI group compounds undergo complete dissociation during evaporation and the films are grown by allowing the constituent vapours to react with each other at the substrate at elevated temperatures. In the hot wall deposition technique the dissociation can be avoided by suitably adjusting the wall and source temperatures. Because 'Se' is the element of lowest melting point of the three, the resulting film will always be 'Se' deficient. The vapour pressures of Cd and Se at sublimation temperature of the compound are almost the same but the Te vapour pressure is quite different from both Cd and Se [3]. The vapour pressures are related as follows: $V_p(\text{Se}) > V_p(\text{Cd}) > V_p(\text{Te})$ at a particular temperature where V_p stands for vapour pressure. Hence at the beginning of the evaporation, the 'Se' vapour pressure will be more than that of 'Cd' and 'Te'. So a film, deficient in selenium will be produced. The sticking coefficient of the elements is also a factor in the formation of stoichiometric films. The sticking coefficients are in the order $S_{\text{Te}} > S_{\text{Cd}} > S_{\text{Se}}$ where S is the sticking coefficient. So, in order to avoid the escape of 'Se', the substrate was kept as close as possible to the open end of quartz tube.

SEM micrographs of CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} films shown in Fig. 2 (a & b), reveal that the films are polycrystalline in nature. From the SEM micrographs it is observed that the film surface is homogeneous and the particle size is around 100 Å and 300 Å for the CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} films, respectively. This is in agreement with the grain size evaluated from the X-ray analysis. The Hall measurements revealed that the films with composition-CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} are p-type and n-type, respectively. The p-nature of CdSe_{0.15}Te_{0.85} films may be attributed to the presence of Te acceptor impurities and the n-nature of CdSe_{0.7}Te_{0.3} films to the Cd donor impurities [see ref 3 and references therein]. The carrier concentration and Hall mobility of CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} films have been evaluated from the Hall effect studies and are given in Table 2.

Table 2
HaU parameters.

Composition	Conductivity type	Carrier concentration cm ⁻³	Hall mobility cm ² V ⁻¹ s ⁻¹
CdSe _{0.15} Te _{0.85}	p	10 ¹⁵	6
CdSe _{0.7} Te _{0.3}	n	10 ¹⁶	12

A Solar cell was fabricated with the structure as depicted in Fig. 3. Plain, optically-flat glass substrates were well cleaned and, using electron beam evaporation technique, a very thin layer of ≈ 0.8 microns of molybdenum was deposited. The absorber layer p-CdSe_{0.15}Te_{0.85} was deposited over the molybdenum and its thickness was 145.5 nm. Then the window layer n-CdSe_{0.7}Te_{0.3} with a thickness of 121 nm was deposited over the absorber layer. The bottom contact was to the molybdenum and the contact made to the top n-layer using silver paste as shown in Fig. 3.

The power output characteristic of the fabricated solar cell with n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} structure and an area 27.1 mm² is shown in Fig. 4. The efficiency and fill factors were found to be 3.13% and 0.59 respectively. The low efficiency may be due to the low shunt resistance (940Ω), which may be caused by leakage of current across the semiconductor surface. The micro-crystallites in a polycrystalline films are in general normal to the film plane: their presence and orientation of the crystallite boundaries may be responsible for current leakage. After the deposition of each layer, the films are taken out of the vacuum chamber to load the other source material. There is every possibility for the formation of an insulating layer between any two layers. This may be another reason for the reduced efficiency of the fabricated cell. Also, surface treatment over the p-layer, routinely done for CdTe solar cells and which plays a crucial role in improving the efficiency was not carried out. Efforts are ongoing to optimize the wall temperature and substrate temperature in order to grow films with larger grain size, which should increase cell efficiency. Also deposition of both layers in one pump down operation is being attempted so that there is no exposure to atmosphere.

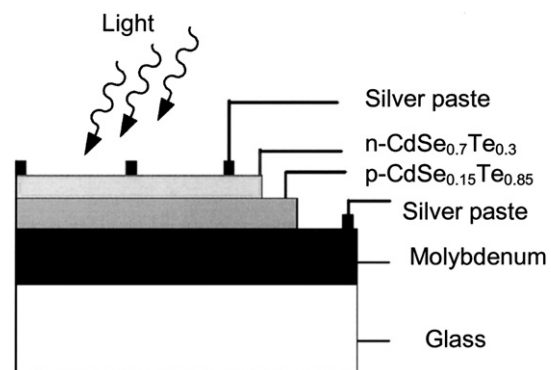


Fig. 3. Sketch of the fabricated solar cell depicting the contact layers, window layer and the absorber layer.

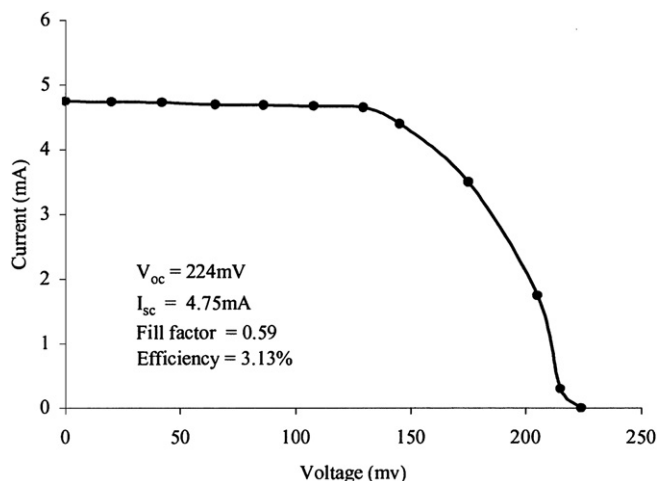


Fig. 4. Power output characteristics of n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} solar cell.

4. Conclusion

CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} compounds were synthesized from their individual elements. The synthesized CdSe_{0.15}Te_{0.85} and CdSe_{0.7}Te_{0.3} compounds were taken as the source material to prepare films by the hot wall deposition technique and their structure, composition and type of conduction was determined by X-ray diffraction, ED AX and Hall studies, respectively. A solar cell with n-CdSe_{0.7}Te_{0.3}/p-CdSe_{0.15}Te_{0.85} structure was fabricated and its efficiency was found to be 3.13%. The low efficiency was attributed to the presence of grain boundaries and inadequate surface treatments.

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