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Determination Structural Properties of In-Doped CdTe/CdS Thin Films Solar Cells

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ABSTRACT

Many methods have been used to produce thin film solar cells. Many of these methods are technically complex and expensive. In the present study, a thermal evaporation method with fewer usage parameters was used to produce thin film solar cells. In addition, the impacts of annealing on the structure of solar cells were investigated. The surface morphology of solar cells and the approximate content of each element were carried out with a QUANTA (FEG-250) model scanning electron microscopy and Energy Dispersive X-Ray Spectroscopy (SEM/EDS). The X-ray diffraction (XRD) measurements were performed using a BRUKER XRD system (D8 Advance) X-ray diffractometer. In the SEM analyzes, it was determined that the reduced in the roughness of the film surfaces was and clumping occurred as a result of annealing. But if the crystallite size is at submicron level, this negative situation can be overlooked. An increase in Cd was observed with EDS analysis. XRD diffraction has shown that the peaks in the (111), (200) and (211) planes increase the intensity of these peaks in the annealing result. As a result, it was determined that annealing affects positively the structural characteristics of In-doped CdTe/CdS solar cells.

ÖZ

Anahtar Kelimeler:
Isısal buharlaştırma,
İnce film güneş pili,
In katkılı CdTe,
Yapısal özellikler.

İnce film güneş pilleri üretiminde birçok yöntem kullanılmıştır. Bu yöntemlerin çoğu teknik olarak karmaşık ve pahalıdır. Bu çalışmada ince film güneş pillerini üretmek için daha az kullanım parametresi içeren ısısal buharlaştırma yöntemi kullanılmıştır. Ayrıca tavlamanın güneş pillerinin yapısı üzerindeki etkileri araştırılmıştır. Güneş pillerinin yüzey morfolojisi ve her bir elementin yaklaşık içeriği bir QUANTA (FEG-250) model tarama elektron mikroskobu ve enerji dağılımlı X-ışını spektroskobu (SEM/EDS) ile gerçekleştirilmiştir. X-ışını kırınımı (XRD) ölçümleri bir BRUKER XRD sistemi (D8 Advance) X-ışını difraktometresi kullanılarak gerçekleştirildi. SEM analizlerinde tavlama sonucunda film yüzeylerindeki pürüzlüğün azaldığı topaklanmaların oluştuğu tespit edilmiştir. Fakat tanecik boyutunun micron altı seviyesinde olması bu olumsuz durumun göz ardı edilebileceğini göstermektedir. EDS analizleri ile Cd oranında bir artış gözlemlenmiştir. XRD saçılmaları ile (111), (200), (211) düzlemlerinde pikler gözlemlenirken tavlama sonucunda bu piklerin şiddetlerini arttığını göstermiştir. Sonuç olarak tavlama işleminin In-katkılı CdTe/CdS güneş pillerinin yapısal özellikleri üzerinde olumlu yönde etki ettiği belirlenmiştir.

1. Introduction

In recent years, compounds II-VI have been intensively studied for practices in the semiconductor devices, electronic, optoelectronic, and photovoltaic industries [1-4]. Consist of II-VI compounds; CdTe has a solar energy ideal band gap of 1.45 eV. This range is very suitable for solar cells production [5-9]. CdTe crystal structure is usually cubic or hexagonal [10-12].

Yılmaz et al. (2017) in studies, as-grown CdTe films have high Cd spaces and due to which limits its use in solar cell applications result p-type conduction. They reported that it would be possible to fill Cd spaces by adding indium atoms to the structure, thus resulting in n-type conduction [13].

CdS films are n-type semiconducting materials with a band gap of 2.42-2.5 eV [14-17]. Along with semiconductors such as CdTe (1.5 eV), which has a narrower bandwidth than itself, in the heterojunction thin film solar cells is preferred as window material that collects and transmits the incoming rays [18-20].

There are many studies on CdTe and In-doped CdTe structures. The structural and electrical properties of these structures are available in the literature [21-25]. A study of In-doped CdTe/CdS solar cell produced by thermal evaporation has not yet been reported in the literature. For this reason, the primary goal of this work is to determine the structural properties of the In-doped CdTe/CdS solar cell produced by thermal evaporation and the effect of annealing to the structural characteristic of this solar cell.

2. Material and Method

2.1. Sintered of Polycrystalline Materials

For CdTe prepared by weighing at stoichiometric ratios, 8 grams of Cd corresponding to 9.08 grams Te was added. For doping 1% In, 0.17 grams of In added material reached 17.25 grams weight. The materials were placed in chemically cleaned quartz tubes. The mouths of the tubes were closed. The sintering process was started by placing the tubes in a horizontal tube furnace. The oven was heated gradually. When the oven temperature reached 1150 ºC after 48 hours, it was left for 24 hours [13]. The tube in the oven was shaken at regular intervals to form a homogenous mixture. After the crystal formation was achieved, the cooling was also carried out gradually (10-15 ˚C/h). The obtained polycrystalline material was pulverized again.

2.2. Deposition of In-doped CdTe Thin Films

The powdered polycrystals were bound to the holder of the thermal evaporation system in tungsten crucibles. The chemically and ultrasonically cleaned Indium Tin Oxide (ITO) coated substrate was placed in a circle. Once the compression of the vacuum chamber arrives $5x10^{-5}$ Torr, the flow was gradually started to flow through the pot. When the current passing through the cruiser reached 50 Ampere, the material started to flush. The current was initiated by opening the cutter at the value of 71 Ampere. The evaporation rate of the material was about 9-13 Å/s. When the thickness of 0.7 μm (7 kÅ) was reached after about 10 minutes, the cutter was closed and storage was terminated.

2.3. Annealing of In-doped CdTe Thin Films

In-doped CdTe substrate produced by thermal evaporation was located in a Protherm trademark annealing-furnace warmed to 400 ˚C [26]. Along the annealing, nitrogen gas was continuously injected through the furnace to prevent oxidation on the film. The oven temperature was kept at 400 ºC and annealing was performed for 1 hour. Then the oven was turned off. The oven was cooled to room temperature naturally in nitrogen gas, and then the samples were removed.

2.4. Deposition of CdS Thin Films

After the generation of the glass/ITO/In-doped CdTe structure, the annealed and non-annealed specimens were positioned in the holder in the system to deposition the CdS polycrystalline at window layer. Afterwards the chamber was shut down by placing 99.999% pure CdS powder in the tungsten crucible. Vacuum chamber internal pressure was brought to $5x10^{-5}$ Torr. Then 30 ampere current was started to flow on the pot. As the current value was gradually increased, the potential of the pot was observed when the amperage reached 70 A passing through the pot. When the current value reached 100 A, the cutter was opened and the storage process started. Substrate temperature 0 ˚C and evaporation rate of material was kept at 10-11 Å/s during the process. When the coating thickness from the thickness monitor was read as 0.7 μm (7 kÅ), the cutter was closed and the storage process was terminated.

2.5. Deposition of Top Contact

After the solar cell structure has been formed, the annealed and non-annealed samples are placed in the holder of the thermal evaporation system to receive contact. The upper contacts were removed from indium by thermal evaporation in the Van der Pauw geometry.

2.6. Characterization

The surface morphology of solar cells and the approximate content of each element were carried out with a QUANTA (FEG-250) model scanning electron microscopy and Energy Dispersive X-Ray Spectroscopy (SEM/EDS). The X-ray diffraction (XRD) measurements were carried out using a BRUKER XRD system (D8 Advance) X-ray diffractometer.

3. Results and Discussion

The samples were prepared by thermal evaporation at a thickness of about 1.4 µm. ITO coated glass is used as the substrate. For the In-doped CdTe/CdS thin film solar cells, the non-annealed was named S1and the 400 ºC annealed at 1 hour was named S1_400.

3.1. Structural Analysis

XRD scattering results of thin film solar cells are shown in Figure 1. In the S1 and S1_400 samples, peaks were observed at approximately 2θ=23.9º, 26.6º and 33.0º. The positions of the designated peaks are the same and it is observed that the severity is increased due to the annealing. Due to annealing, the peak positions have not changed. But their density has increased. This situation can be interpreted as the reduction of structural defects and the structure of thin films are polycrystalline rather than amorphous. The diffraction lines produced by the 2θ=23,9º, 2θ=26,6º and 2θ=33,0º peaks correspond to the (111), (200) and (211) [1], [27].

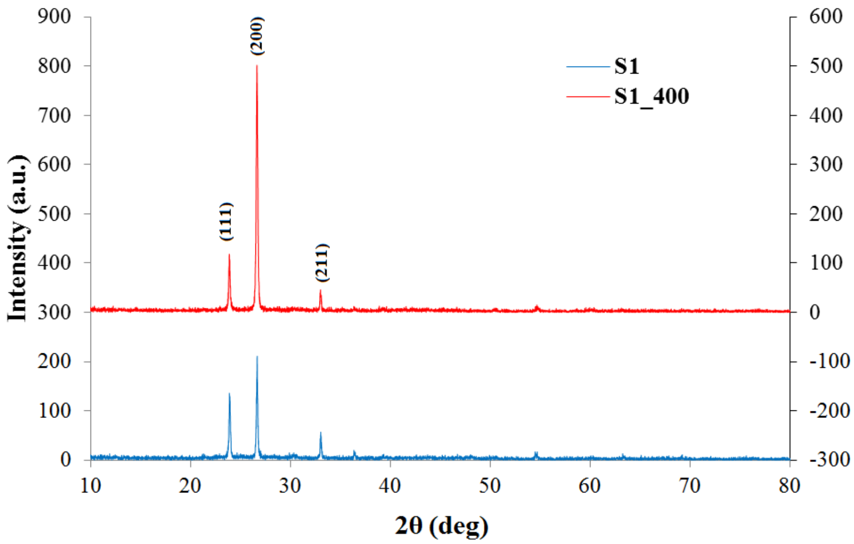

Figure 1. The X-ray diffraction patterns of S1 and S1_400

The Inter-planar distance (d) and the lattice constant (a) with the help of the XRD profile can be calculated according to the following equation known as Bragg law.

$$d = \frac{\lambda}{2sin\theta} \quad (1)$$

Here, X-ray wavelength used λ, lattice spacing d, Bragg's angle θ. The plane-spacing equation can be calculated with the following equation.

$$\frac{1}{d^2} = \frac{(h^2+k^2+l^2)}{a^2} \tag{2}$$

Miller indices of the planes are expressed as (h k l).

Scherrer formula is used to calculate the crystallite sizes of thin films with XRD data.

$$D = \frac{k\lambda}{\beta Cos\,\theta} \tag{3}$$

Here; expressed in terms of crystal size D, wavelength of the X-ray source used λ, the half-maximum width of the diffraction peak in radians β, Bragg diffraction angle of the XRD peak θ and a constant related to the film whose crystallite size is calculated k [28].

Using equations (1) and (2), the distance between planes (d) and lattice constant (a) in thin film solar cells were calculated. The crystallite size was calculated using equation (3). These values calculated for S1 and S1_400 samples are delivered in Table 1. With the effect of annealing, it was determined that the crystallite size increased, that is, the films passed from the amorphous structure to the polycrystalline structure. The crystallite size comparisons given in Table 1 and obtained from the SEM images in Figure 2 together with the XRD scattering crystallite size calculations show compatibility. Calculations of inter-planar distance (d), lattice constant (a) [29] are similar to the ones they have done.

Table 1. Calculations for S1 and S1_400 samples

	S1				**S1_400**			
hkl	2θ (deg)	*d* (Å)	*a* (Å)	*D* (nm)	2θ (deg)	*d* (Å)	*a* (Å)	*D* (nm)
(111)	23,95	3,711	6,427	31,41	23,93	3,715	6,435	49,89
(200)	26,68	3,337	6,674	34,11	26,65	3,340	6,681	42,63
(211)	33,05	2,707	6,631	29,84	33,09	2,703	6,623	36,06

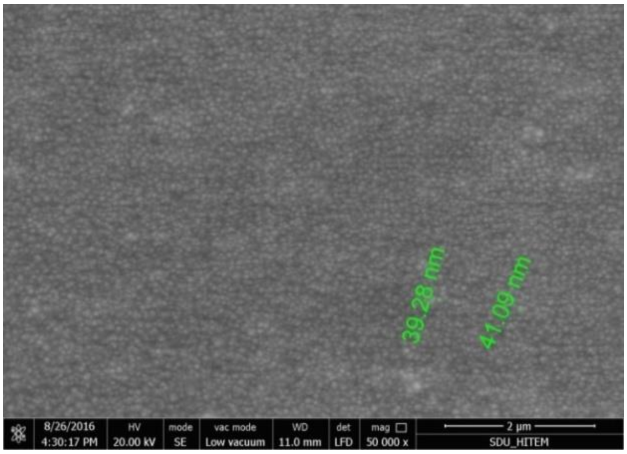

Figure 2. The crystallite size obtained in SEM images

3.2. Compositional and surface topographical analysis

Thin film solar cells are produced using ITO coated glass as substrate, In-doped CdTe as the lower film material and CdS (powder) materials as the upper film material. These solar cells were production by thermal evaporation. In Figure 3, energy dispersive X-ray spectroscopy (EDS) plots are given in Figure 4 and Figure 5 for SEM images of annealed and non-annealed solar cells with the aim of determining the surface morphology of the materials. When Figure 3 is examined, it is seen that the surface roughness of the annealed film decreases and clumping occurs. The crystallite size of films is generally known to depend on film thickness, surface temperature and annealing temperature. The resulting crystallite size is lower microns in size. Chander and Dhaka (2016) have achieved similar results in their work [18]. In Figure 4 and Figure 5, while the increase in the annealing result Cd was observed in the lower films deposited by the thermal evaporation method, a decrease in the ratio of in and Te was detected.

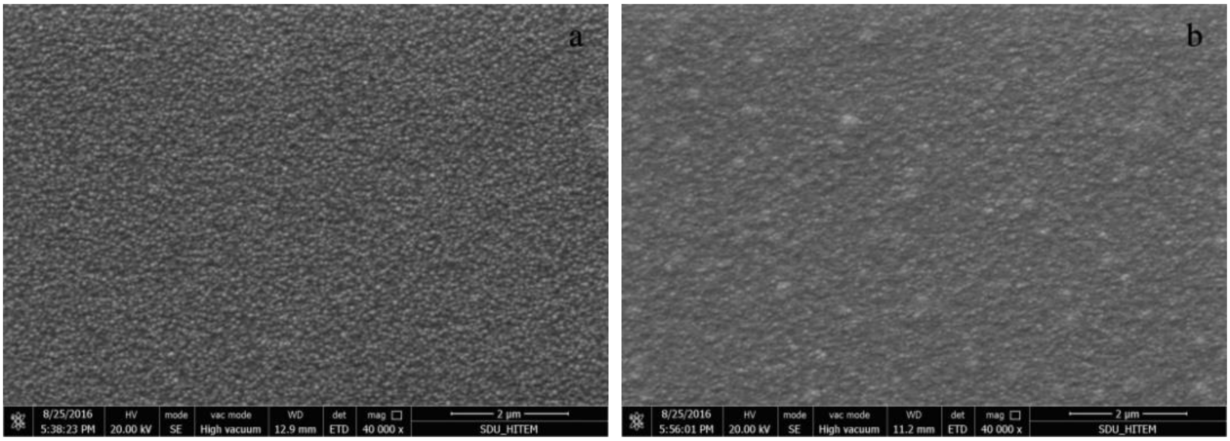

Figure 3. The SEM images of (a) S1 and (b) S1_400

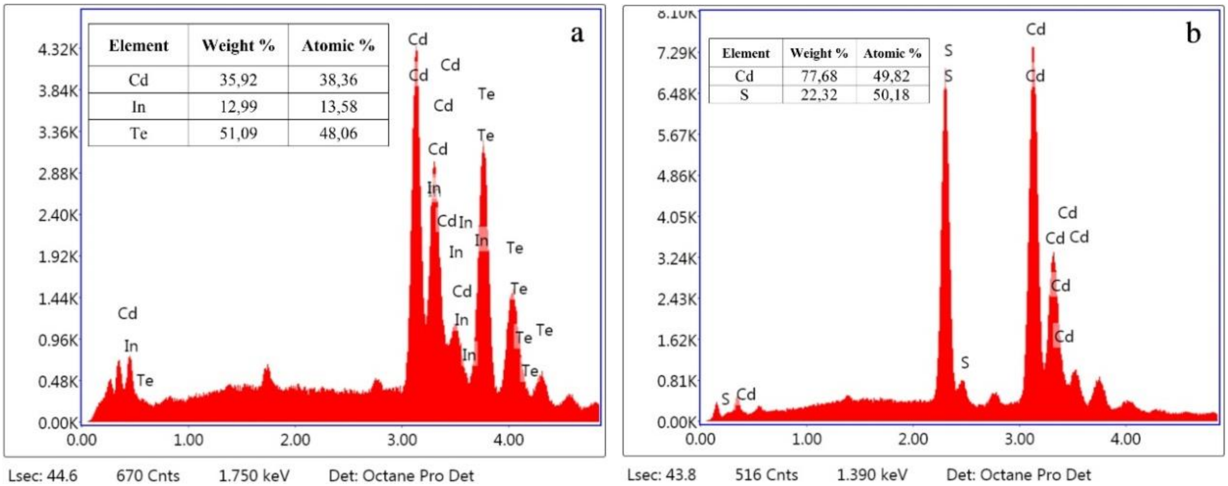

Figure 4. The typical energy dispersive spectrum (EDS) of S1 (a) In-Doped CdTe layer (b) CdS layer

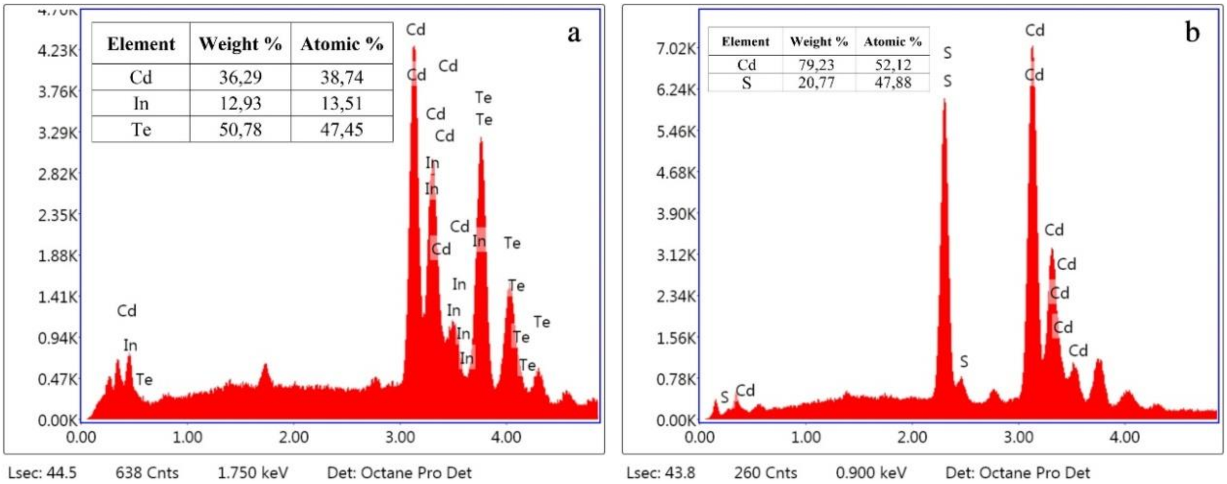

Figure 5. The typical energy dispersive spectrum (EDS) of S1_400 (a) In-Doped CdTe layer (b) CdS layer

4. Conclusion

The effect of annealing on the structural properties of In-doped CdTe/CdS thin film solar cells produced using the thermal evaporation method is investigated. $2\theta=23.9^{o}$, $2\theta=26.6^{o}$ and $2\theta=33.0^{o}$ peaks were observed after XRD scattering and the diffraction lines produced by these peaks corresponded to the (111), (200) and (211) structures respectively. As a result of annealing, these peak positions have not changed but their intensity has increased. This situation is interpreted as a decrease in structural defects. The crystallite size (D), the Inter-planar distance (d) and the lattice constant (a) calculations are similar to those in the literature. As a result of SEM analysis, annealing resulted in lumps in the film structure. From the calculated calculations and SEM images, it is seen that the crystallite size is below micron level. EDS analysis showed an increase in annealing result Cd, a decrease in In and Te ratio. As a result, it has been determined that annealing to the structural properties of In-doped CdTe/CdS solar cells produced by thermal evaporation effects positively.

Competing Interest / Conflict of Interest

"The authors declare that they have no conflict of interests"

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