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Enhancement in Photovoltaic Characteristics of CdS/CdTe Heterojunction

Araştırma Makalesi / Research Article

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ABSTRACT

The polycrystalline p-type CdTe thin film was deposited to form a solar cell structure with n-type CdS thin film window layer. Material characterization of the deposited thin films were investigated by X-ray diffraction measurements and the preferred orientations were obtained along (111) direction at $2\theta \cong 24°$ and $2\theta \cong 26.5°$ for CdTe and CdS films, respectively. The optical behaviors were investigated according to the transmission spectrum and corresponding direct band gap values were found as 1.51 eV for CdTe and 2.22 eV for CdS thin films. The superstrate CdS/CdTe thin film heterostructure was investigated under the dark and illuminated current-voltage measurements. The heterostructure showed a photovoltaic behavior with the cell efficiency of %1.4. The effects of the etching process on the photovoltaic behavior of CdS/CdTe thin film heterostructure were also discussed and the cell efficiency was enhanced as about %1.6 eV.

Keywords: CdS/CdTe, thin film solar cell, etching.

CdS/CdTe Heteroekleminin Fotovoltaik Karakteristiğindeki Artışı

ÖZ

Güneş hücre yapısı elde etmek için, çoklu kristal p-tipi CdTe ince filmi pencere katmanı olan n-tipi CdS üzerine üretildi. Üretilen filmlerin malzeme özellikleri X-ışını kırınım desenleri ile karakterize edilip, tercihli yönelim sırasıyla CdTe ve CdS için $2\theta \cong 24°$ile $2\theta \cong 26.5^0$'de (111) yönünde elde edilmiştir. Optiksel davranış ve direk geçişli yasak enerji band aralığı değerleri geçirgenlik ölçümleri ile araştırıldı ve yasak enerji bant aralıkları CdTe için 1.51 eV, CdS için ise 2.22 eV bulundu. CdS/CdTe üst tabaka ince film hetero yapısı karanlık ve ışık altında akım-voltaj ölçümleri ile incelendi. Hetero yapı %1.4 verimlilik ile fotovoltavik davranış gösterdi. Aşındırma işleminin CdTe/CdS ince film hetero yapısının fotovoltaik verimliliğine etkisi tartışıldı ve hücre verimliliğinin %1.6 eV a kadar arttığı gözlemlendi.

Anahtar Kelimler: CdS/CdTe, ince film güneş gözesi, aşındırma.

1. INTRODUCTION

In the research field of photovoltaics, CdTe have been the attractive material to enrich the interests together with CuInSe2 and CuInGaSe2 [1]. It is a direct optical band gap semiconducting compound with the value of about 1.5 eV at room temperature and shows high absorption behavior with an absorption coefficient of around 104 cm^{-1} in the visible spectral region. Together with these properties, it is one of the ideal photovoltaic absorber matching with the solar spectrum with a sharp absorption edge in which a few micrometers thin film layer is enough to absorb 90% of the incident photons [2, 3]. The use of CdS as a window layer and thus the CdS/CdTe heterojunction is ongoing of interest as a potential high efficient and low cost photovoltaic cell. In this structure, CdS plays a role of a good n-type wide band gap window with a high optical band gap of about 2.4 eV [4]. The CdS can be obtained by a variety of fabrication techniques such as close spaced sublimation, sol-gel technique, chemical bath deposition (CBD), thermal evaporation, chemical vapor deposition, molecular beam epitaxy, and spray pyrolysis. According to the variation of the deposition process, different optical, structural, electrical, and morphological properties could be achieved [5–10]. Among these methods, RF magnetron sputtering has received much more attention in recent years due to its capacity to deposit CdS thin films. Moreover, it enables to get higher film quality such as better adhesion, larger coverage, high uniformity, controllable thickness at low substrate temperature [11].

In this work, the CdS/CdTe heterojunction solar cell was fabricated in the front-wall configuration. In this type structure, n-CdS thin film window layer was sputtered on

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the fluorine doped tin oxide (FTO) coated soda-lime glass (SLG) substrates, and p-CdTe and Cu-Au ohmic metal contact were subsequently deposited onto this film layer. In addition to the material properties of CdS and CdTe thin film layers were determined. Moreover, the solar response of the fabricated SLG/FTO/CdS /CdTe/ Cu-Au structure was analyzed to see the effect of CdCl2 treatment on the CdTe absorber layer.

2. EXPERIMENTAL STUDY

A schematic superstrate configuration of the fabricated heterostructure is shown in Fig.1. In the deposition process, n-type CdS thin film layer was deposited by radio-frequency (RF) magnetron sputtering of single CdS target with a substrate temperature of 200°C onto a transparent conducting oxide (TCO)-coated soda-lime glass. In this study, FTO was used as a TCO material which exhibits high transparency in the visible region and also high electrical conductivity. The junction was produced by single target RF magnetron sputtering of CdTe film layer on the CdS with the substrate temperature of 150°C. Inficon XTM/2 deposition monitor including a gold-coated quartz crystal inside the vacuum chamber was used to follow and control in situ deposition rates. The actual reading in thickness of the films was done by a Dektak 6M profilometer. As a final step, Cu-Au ohmic back contact was deposited on top of CdTe layer, with thermal evaporation of Au and e-beam evaporation of Cu on the film surface. The film depositions and contact geometry were designed to get a 4×4 cm^2 active surface area for the solar cell measurements.

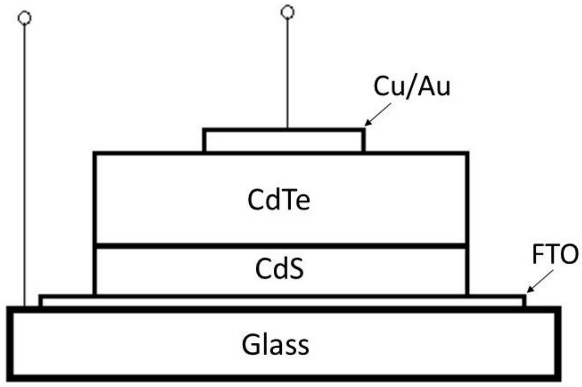

Figure 1. Schematic diagram of FTO/CdS/CdTe heterostructure

The material characterization of the deposited film layers was performed in terms of structural and optical analysis. The X-ray diffraction (XRD) line profiles were investigated by using a Rigaku Miniflex XRD system equipped with CuKα radiation (λ=1.54 Å). In addition, the atomic concentration of the constituents in film samples was determined by Quanta 400 FEG model scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) analyzer system. For optical characterization, transmission spectra of the films were measured using Perkin-Elmer LAMBDA 45 UV/Vis spectrophotometer in the wavelength interval from 320 to 1100 nm at room temperature. The final heterostructure was investigated by current-voltage (I-V) measurements under dark and illuminated conditions in which the spectrum was calibrated to the AM1.5 global normalized to 100 mW/cm^2. In the evaluation of device processing, wet etching $CdCl_2$ treatment was carried out on the complete the full device structure and the resulted I-V characteristics were analyzed under the aim of producing high-quality CdTe layers with large grains and few defects [12].

3. RESULTS AND DISCUSSION

The atomic ratios of the elements in the CdS and CdTe thin films were investigated by EDS measurements, and they were found to be nearly stoichiometric within the experimental error limit of the precision of EDS analysis.

In addition to monitoring the thickness of the films in deposition processes via thickness monitor, the final values were determined by using a stylus profilometer and they were observed as about 80 nm and 3 μm, for CdS and CdTe layers, respectively.

XRD spectrum of the films was studied to investigate the phase formation of the structures. According to the XRD results, both of the CdTe and CdS films revealed single phase and polycrystalline nature (Fig.2 and Fig.3). As given in Fig.2, the high intensity reflection in CdTe film structure was obtained at the major peak 2θ ≅ 24° indicating the preferred orientation of CdTe films along (111) direction and giving stable zinc-blende crystalline structure [13, 14]. For the CdS layer, the XRD profile was also matched with the ICDD database and literature [15, 16] and the existence of highly preferred orientation peak at 2θ ≅ 26.5° along (111) orientation direction that confirms a wurtzite structure [17] as illustrated in Fig.3.

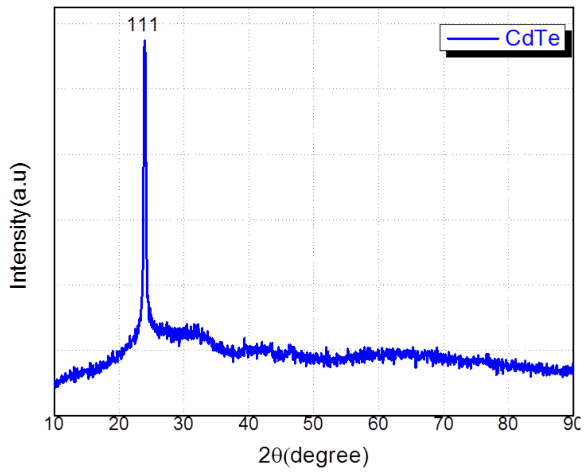

Figure 2. XRD profile of the CdTe thin film layer

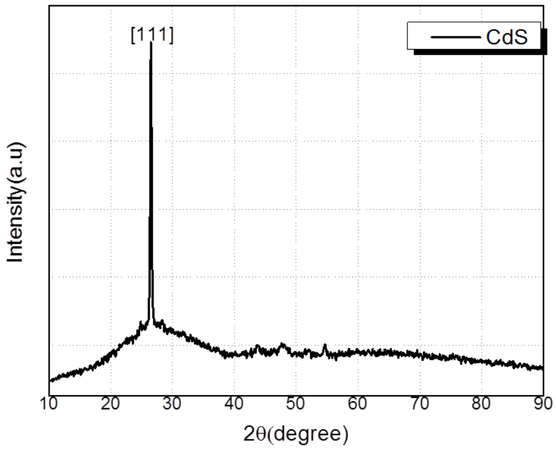

Figure 3. XRD profile of the CdS thin film layer

Average dimension of the crystallites in the CdTe and CdS thin films were evaluated by using Scherrer formula [18],

$$d = \frac{k\lambda}{\beta\cos\theta} \tag{1}$$

where k is the Scherrer constant and it was estimated as 0.94 with cubic symmetry [19], λ is the wavelength of X-rays, β is defined as the diffraction peak width at full width at half maximum (FWHM), and θ is the angle between the incident and diffracted rays. The results of this calculation depends on the peak broadening however, strain or composition variations in the structure are not included to this approximation, therefore the grain size values can be underestimated [20]. From the XRD results of the films and by using Eq.1, these values were found as about 5.4 and 5.6 nm for CdS and CdTe films, respectively. In addition to the particle size analysis, the mechanical behavior of the polycrystalline thin films were investigated from the distribution of the crystallite orientations [21].

$$\varepsilon = \left(\frac{\lambda}{d\cos\theta} - \beta\right)\frac{1}{\tan\theta}. \tag{2}$$

From the XRD results of the films and by using Eq.2, the strain values, ε, were found as 5.68 and 5.02 (x10^{-2}) for the CdTe and CdS samples, respectively.

Room temperature optical transmission spectra in the wavelength interval of 320-1100 were shown in Fig.4 and Fig.5 for CdS and CdTe film layers, respectively. From Fig.3, CdS film exhibits high transparency with about 85% transmissivity in the wavelength region of interest and in Fig.5, transmission values of CdTe film were observed at top value of around 50% transmissivity. The absorption coefficient (α) of the samples was found by using the transmission data by using the following relation;

$$\alpha(\lambda) = \frac{1}{d}\ln\left(\frac{I_0}{I}\right) \tag{3}$$

where $T(\lambda)$ is the normalized transmittance, t is the thickness of the thin films and I is the intensity of transmitted light and I_0 is the incident light perpendicular to the surface of sample. These values were obtained from the experiment aI_0/Is corresponds to the light intensity transmitted only from the film layer.. According to the optical transmission spectra of the films, the absorption coefficient values were calculated as about 2.6 and 0.9 (x10^4) cm^{-1} for CdS and CdTe layer, respectively. Fig. 4 (inset) and Fig.5 (inset) depict the relation between absorption coefficient and photon energy for the thin films in the high absorption region. According to the Tauc plots [22], the optical band gap values were determined by considering the direct optical transition in the structures, and for CdS and CdTe films, they were obtained as 2.22 and 1.51 eV, respectively.

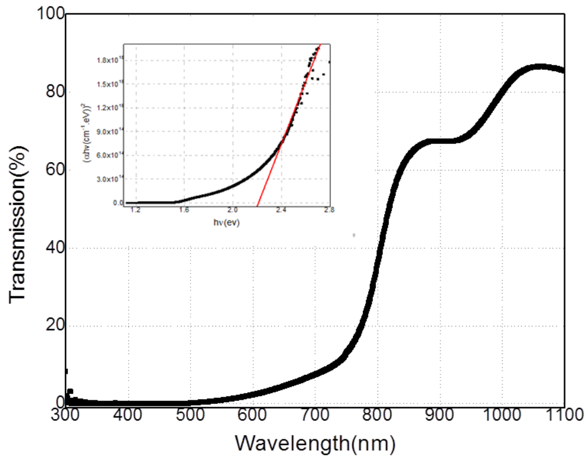

Figure 4. Transmission spectrum and corresponding Tauc plot (inset) of CdS

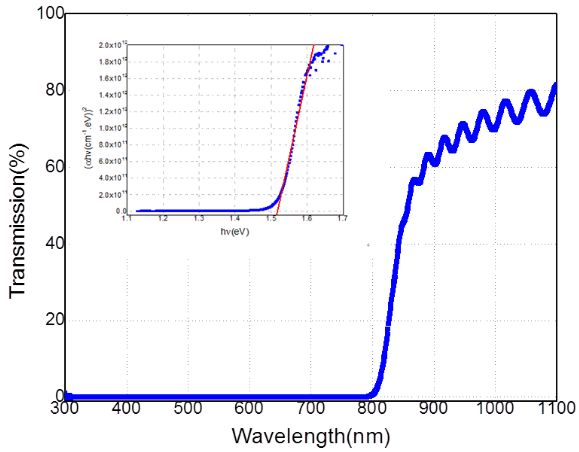

Figure 5. Transmission spectrum and corresponding Tauc plot (inset) of CdTe

On the completed heterostructure, electrical characteristics were measured by applying standard solar cell techniques as I-V measurements under dark and illuminated conditions. It was also investigated before and after wet $CdCl_2$ treatments on the CdTe layer surface.

Under these conditions, the basic layer structure with and without etching processes, solar cell parameters were determined as shown in Fig.6. The cell performance was found from the forward I-V region as V_{OC} = 0.35 mV, J_{SC} = 1.12mA/cm^2 with FF = 0.35, and the cell efficiency was calculated as 1.4%. After etching process, the parameters of V_{OC} and J_{SC} are achieved to 0.50mV and 0.65mA/cm^2, respectively. As a result, the solar efficiency was obtained as 1.6% with FF = 0.47. This observed improvement in the performance of the cell can be the indication as the $CdCl_2$ treatment effect that can modify the defect structure in CdTe resulting in better overall transport properties [23].

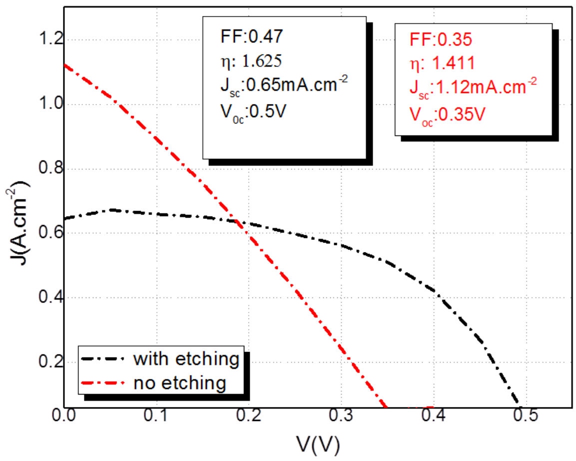

Figure 6 J–V response of the SLG/FTO/CdS/CdTe/Cu-Au structure

4. CONCLUSION

In this study, high quality CdS and CdTe thin film layers were deposited by RF magnetron sputtering technique from single target. The front contact surface was formed by using FTO coated SLG, and then back contact of this superstrate structure was established by depositing Cu-Au onto the CdTe layer. Material characterization of the deposited film layers were studied in terms of structural and optical measurements, and both films were found in polycrystalline nature and having direct band gap characteristics with 2.4 and 1.5 eV, for CdS and CdTe, respectively. Additionally, the SLG/FTO/CdS/CdTe/Cu-Au heterostructure device was characterized for photovoltaic applications and the effects of the wet $CdCl_2$ etching treatment on the device performance were investigated. It is seen that there is an increase in the value of V_{oc} from 0.35 mV to 0.50 mV while the value of J_{sc} decreased from 1.12mA/cm^2 to 0.65mA/cm^2. On the other hand, FF value enhanced with the etching process. As a result, the obtained 1.4 % cell efficiency was improved with wet $CdCl_2$ etching treatment as about 1.6 %. It is deduced that the impact of the $CdCl_2$ step improved photovoltaic behaviors of the fabricated heterostructure.

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