

THIN FILMS FOR NOVEL COST-EFFICIENT SOLAR CELL APPLICATION

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CdTe, CdS, ZnO and ZnO:Al thin films were prepared by Close-spaced sublimation (CSS), Chemical Bath Deposition (CBD) and Magnetron sputtering methods, respectively. The films were characterized by X-Ray Diffraction (XRD) and Atomic Force Microscopy (AFM) methods. Electrical properties depending on crystallinities of the obtained films were studied. Substrate configured solar cell devices on the basis of obtained films were fabricated.

Keywords: thin films, magnetron sputtering, crystallinity, conductivity, solar cells

Introduction

In the photovoltaic material family, cadmium telluride is regarded as one of the most promising material for fabrication of high efficiency polycrystalline CdTe/CdS thin film solar cells [1,2] because of its near-optimum band gap of about 1.46 eV and high optical absorption coefficient in visible range. In spite of the large lattice mismatch between cubic CdTe and hexagonal CdS (nearly 9.7%) the CdTe/CdS solar cells are characterized by essentially high efficiencies caused by interdiffusion at the junction interface removing the lattice mismatch [3]. The maximum efficiency of about 16.5% of the laboratory samples of polycrystalline CdTe based thin film solar cells was achieved by using nanostructured CdS:O window layer and the modified device structure [2]. "CdCl₂ heat treatment" is considered as a key step in CdTe/CdS device processing leading to interdiffusion between CdTe and CdS. It is usually carried out either by means of deposition of CdCl₂ layer onto CdTe surface with following annealing in ambient atmosphere or annealing the structure in CdCl₂ vapor. In the former case the optimum CdCl₂ thickness value varies in the wide range depending on the base layer technology [4].

Conventional thin film CdTe solar cells contain a SnO₂-bilayer (conducting layer with thickness of 500nm and non-conducting buffer layer with thickness of 100 nm), a 80-100 nm CdS film, 5-10 μm CdTe film, and HgTe-Cu₂Te

back contact subsequently deposited on a 1mm-thick Corning 7059 glass substrate. This configuration has some shortcomings leading to increase of solar cell cost; utilization of 8-10 μm thickness of CdTe base material to provide the best absorbance, utilization of expensive borosilicate Corning 7059 glasses to prevent of Na diffusion from glass substrate, complicated back-contact process consisting of three steps: CdTe surface etching (so-called NP-etching), application of a specially prepared graphite paste which contains Cu_xTe and HgTe, and final layer of Ag-paste [5].

All of the indicated shortcomings show a limiting ability of the conventional technologies and call for new approaches to the design and optimization of CdTe thin film solar cells.

In this paper the first results on the fabrication of CdTe based thin film solar cells of modified configuration and studies of their photoelectrical properties are given.

Experimental details

Soda lime glass substrates with selenized molybdenum coating were used for CdS/CdTe solar cell fabrication. CdTe film of 2μm thickness was deposited by close-space sublimation (Two Zones Furnace for PVD (CSS) Processing - OTF-1200X-RTP-II, MTI,USA) method onto the substrate. Deposition process was carried out in evacuated chamber with total system pressure of about 16 torr (1 torr oxygen + 15 torr helium) at substrate and source temperatures of 580 °C and 620 °C, respectively.

CdS films of 80-100nm thickness were deposited by chemical bath deposition (CBD) method. Cadmium acetate (CdAc_2 , 99.99%), ammonium acetate (NH_4Ac , 99.99%), thiourea ($(\text{NH}_2)_2\text{CS}$, 99+%) and regular ammonium hydroxide (NH_4OH) DI water solution heated up to 90°C was used for CdS deposition. CdCl_2 treatment was carried out using “dry” method. The CdTe/CdS structure was exposed to CdCl_2 vapor at 400°C for 5-7 min in vacuum chamber in the presence of 100 torr oxygen and 400 torr helium.

ZnO and ZnO:Al thin films were deposited on 1.0 mm thick, 2x2 cm size soda lime glass substrates by magnetron sputtering method (EVOVAC deposition system, Angstrom Engineering Inc., Canada) at $200\text{--}400^\circ\text{C}$ substrate temperatures under oxygen/argon gas mixture with different O/Ar ratio (0-6% O_2). Deposition rate was $1\text{Å}/\text{sec}$.

X-Ray diffraction (XRD) analyses of the films were carried out using Bruker D2 Phaser (Germany) diffractometer in θ - 2θ scan mode with Ni-filtered $\text{CuK}\alpha$ radiation ($\lambda=1.54060\text{Å}$) source. The average grain sizes of the polycrystalline films were calculated by the Scherrer equation

$$D = \frac{\alpha\lambda}{\beta \cos \theta} \quad (1)$$

where D is the grain size, α is constant (equal to 0.9), λ is the X-Ray wavelength (1.54060Å), β is full width at half maximum (FWHM) of the diffraction peaks. The crystallinities (crystallization degree) were calculated from XRD patterns of the films using DIFFRAC.EVA.V2.1 PC program.

Topography analysis of the thin films was performed in Smart SPM 1000 AIST NT (Tokyo Instruments, Japan).

Conductivities of the films were measured by standard 4-probe method using HL5500PC Hall system (Nanometrics Inc., USA).

I-V parameters of the devices with an area of about 0.25 cm^2 were measured using Solar cell I-V Testing System IV16 (PV Measurements, Inc.) under $100\text{ mW}/\text{cm}^2$ solar simulator illumination.

All of the measurements were performed at room temperature.

Results and discussion

Resistivity of n-type CdS films prepared by CBD method was found to be $1.2 \times 10^4\ \Omega\text{cm}$. As-grown CdTe films obtained by CSS method showed p-type conductivity with resistivity about $10^7\ \Omega\text{cm}$. “ CdCl_2 -treatment” in 400 torr He and 100 torr O_2 atmosphere at 400°C for 7-10 min. (corresponding to CdCl_2 -treatment of CdTe solar cells) lowered the resistivity down to $6 \times 10^2\ \Omega\text{cm}$.

CdS films showed the hexagonal wurtzite-type structure (space group $P6_3\text{mc}$) whose lattice parameters a and c were determined to be 4121Å and 6716Å , respectively (fig.1a). On the other hand, the obtained CdTe thin films crystallize in the cubic sphalerite type structure (space group $F4_3\text{m}$) with $a=6485\text{Å}$ (fig.1b). Both the CdS and CdTe thin films showed a preferential orientations along the $[002]$ and $[111]$ directions, respectively.

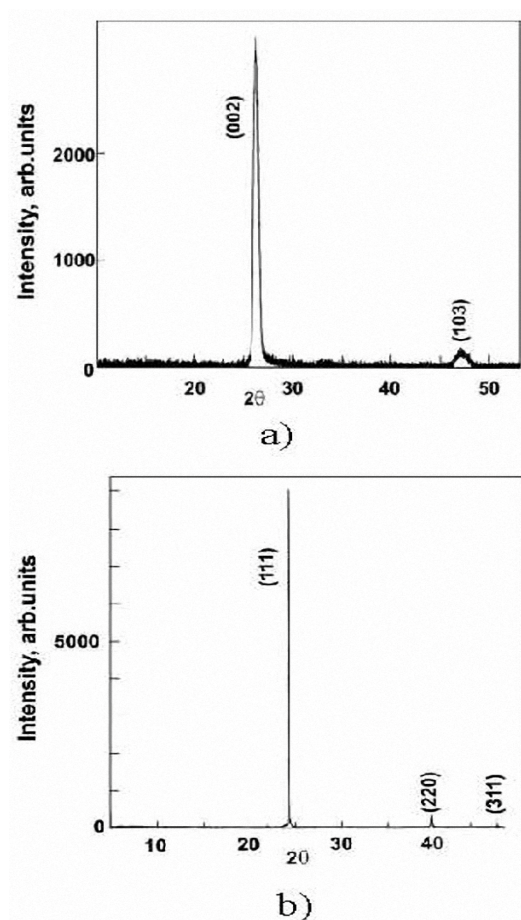


Fig. 1. XRD spectra of CdS (a) and CdTe (b) films

Figure 2 shows the AFM images of CdS (a) and of “as-grown” CdTe (b) films, respectively. As it is seen from the Fig.3a, in CdS film the grains with up to 60 nm size can be observed among the tightly packed grains with smaller sizes. The CdTe film consists of grains 3-5 μm in size and is dense (fig.2b).

It should be noted that no considerable changes in the structural properties and surface morphology of CdTe films were observed after the “dry” CdCl_2 -treatment which is usual for the CdTe films with large grain size obtained by CSS method [6]. Both of CdTe films, “as-grown” and CdCl_2 -treated, have a clearly faceted surface morphology and an average grain size of about 3-4 μm .

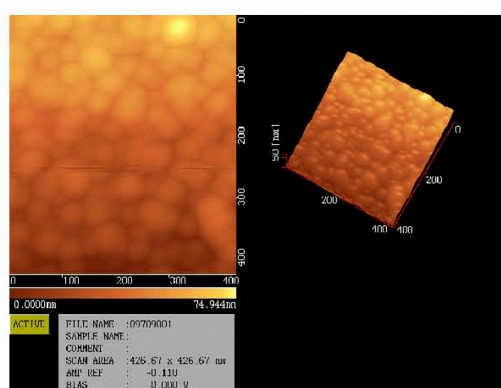
Analysis of XRD patterns show nearly amorphous structure of ZnO and ZnO:Al thin films prepared at substrate temperature of 200°C.

Crystallinities of ZnO and ZnO:Al thin films prepared under 0-6% O/Ar mixture ratios

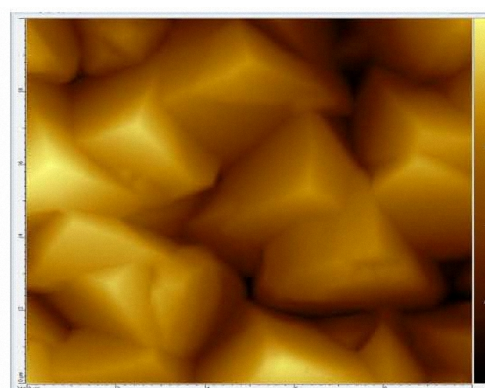
and at 300-400°C substrate temperatures calculated from the XRD patterns using eq.(1) are shown in fig.3. Crystallinities of ZnO films deposited at 300°C and 400°C under 0-6% (O/Ar) mixture ratios are relatively lower than that ZnO:Al films and have a maximum at 2% and 4% ratios, respectively.

Crystallinities of ZnO:Al films deposited at 300°C exhibit relatively low values and have a maximum at 2% O_2 while the films deposited at 400°C have essentially higher crystallinities which decrease with partial pressure of oxygen. Higher crystallinity of ZnO:Al film at 400°C indicate the essential role of Al in nucleation process during film deposition at least at higher temperatures. The enhanced values of grain sizes of ZnO:Al film at 400°C may be evidence of this suggestion.

All of the studied ZnO:Al thin films exhibited n-type electrical conductivities.



a)



b)

Fig 2. AFM images of CdS (a) and CdTe(b) films

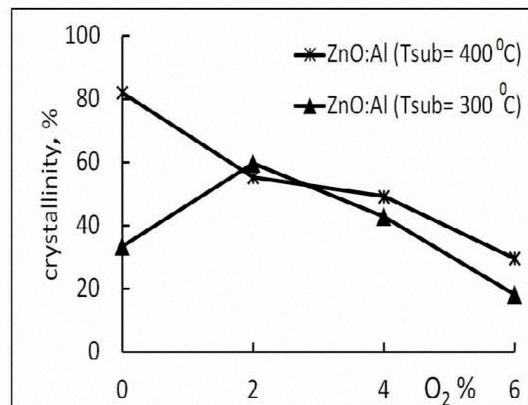
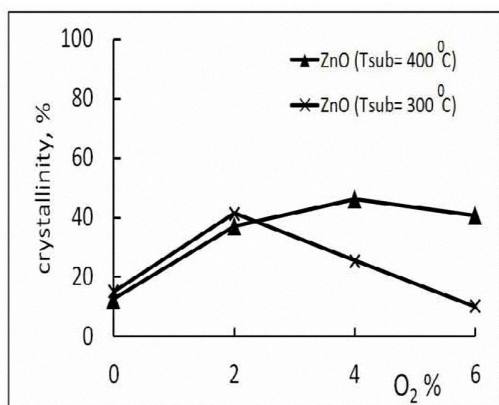


Fig 3. Crystallinities of ZnO and ZnO:Al films

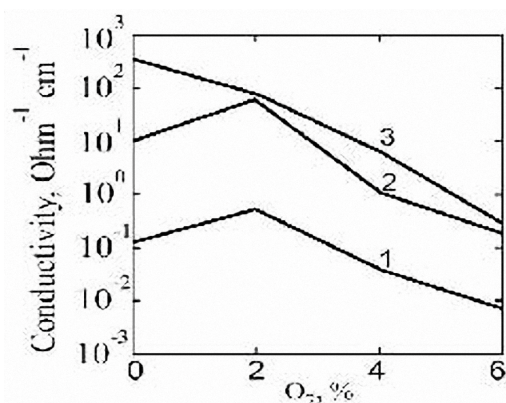


Fig. 4. Conductivities of ZnO:Al films deposited at 1-200°C, 2-300°C, 3- 400°C substrate temperatures

The conductivities of ZnO:Al thin films prepared under 0-6% oxygen/argon mixture ratios and at 200-400°C substrate temperatures are shown in fig.4. The conductivity of the film obtained at 400°C in pure Ar atmosphere is found to be $\sigma \sim 3.5 \times 10^2 \Omega^{-1} \cdot \text{cm}^{-1}$ and decrease with oxygen content in O/Ar mixture. The conductivities of the films deposited at 200°C and 300°C are essentially lower and exhibit maximums at 2% O/Ar ratio.

The decrease of conductivity with oxygen content of the ZnO:Al film deposited at 400°C can be attributed to formation of Zn vacancies in case of oxygen excess which, as it is well known, are acceptor-type defects in ZnO compound [7-9].

We prepared a series of glass/selenized Mo/CdTe/CdS/ZnO/ZnO:Al device structures for solar cell application. The modified device structure is schematically shown in fig.5.

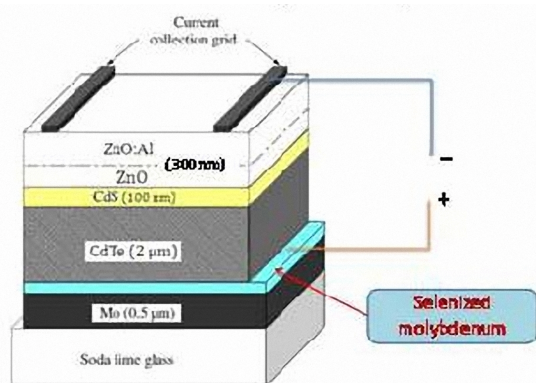


Fig.5. Schematic representation glass/selenized Mo/CdTe/CdS/ZnO/ZnO:Al device

The device structures were prepared on $1 \times 2 \text{ cm}^2$ square substrates which were cut into individual 0.2 cm^2 square pieces and I-V characteristics of the obtained cells were measured. The highest efficiency was obtained with the parameters: $V_{oc}=0.69\text{V}$, $J_{sc}=21.5 \text{ mA/cm}^2$, fill factor $FF=56.1\%$, a total area conversion efficiency of 8.4 %.

It should be noted that the highest efficiency was observed in the cell prepared from the central part of substrate. At the same time, the devices fabricated using the pieces cut from edge part of the substrate exhibited lower efficiencies. The most obvious reason for this is a high density of pinholes emerging on the substrate edges where the CdTe film quality is essentially lower compared to central part.

As it is seen, in spite of simplified technology, the efficiencies of the obtained cells are much less than that of the cells prepared by conventional method. Obviously, further optimization of constituent elements properties and device performance is necessary.

Conclusions

CdTe based solar cells of modified configuration ("substrate" configuration) were fabricated using selenized molybdenum as an ohmic contact to CdTe thin films. The obtained cells are characterized by the parameters: $V_{oc}=0.69\text{V}$, $J_{sc}=21.5 \text{ mA/cm}^2$, fill factor $FF=56.1\%$, a total area conversion efficiency of 8.4%. This configuration makes it possible to utilize of 1-2 μm thickness of CdTe base material, inexpensive soda lime glass and simplified contact processing in comparison with the conventional technology. Further optimization of device performance is needed to increase the cell efficiency.

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YENİ UCUZ GÜNƏŞ ELEMENTLƏRİ ÜÇÜN NAZİK TƏBƏQƏLƏR

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CdTe, CdS, ZnO və ZnO:Al nazik təbəqələri uyğun olaraq yaxın məsafədən sublimasiya (CSS), kimyəvi vanna üsulu (CBD) və maqnetron tozlandırma üsulu ilə hazırlanmışdır. Təbəqələr rentgen difraktometriya (XRD) və atom qüvvə mikroskopiyası (AFM) üsulları ilə tədqiq olunmuşdur. Alınmış təbəqələrin kristallaşma dərəcəsi asılı olaraq elektrik xassələri öyrənilmişdir. Alınmış təbəqələr əsasında “substrate” konfigurasiyalı günəş elementləri yaradılmışdır.

Açar sözlər: nazik təbəqələr, maqnetron tozlandırma, kristallaşma, keçiricilik, günəş elementləri

ТОНКИЕ ПЛЕНКИ ДЛЯ НОВЫХ ЭКОНОМИЧНЫХ СОЛНЕЧНЫХ БАТАРЕЙ

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Получены тонкие плёнки CdTe, CdS, ZnO и ZnO:Al методами сублимации с ближнего расстояния (XRD), соляной ванны (CBD) и магнетронного распыления, соответственно. Тонкие плёнки исследованы методами рентгенодифракционного анализа (XRD) и атомно-силовой микроскопии (AFM). Изучена зависимость электрических свойств от степени кристалличности в этих плёнках. На основе полученных плёнок изготовлены солнечные элементы “substrate” конфигурации.

Ключевые слова: тонкие плёнки, магнетронное распыление, кристалличность, проводимость, солнечные элементы