THIN-FILM CADMIUM TELLURIDE SOLAR CELLS

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Abstract. This work investigates the photovoltaic properties of CdS/CdTe thin-film solar cells. CdS and CdTe were deposited by the close-space-sublimation method on glass plates with an area of 2x2 cm^2 covered with a SnO_2 layer. Solar cells with different CdS thicknesses were manufactured and the influence of CdS thickness upon the quantum efficiency of the structures was explored. Decreasing the window layer thickness resulted in the increase of the response in the wavelength range from 400 to 500 nm.

INTRODUCTION

The first CdTe based solar cells were made on CdTe/Cu_2Te but instabilities caused by Cu diffusion led to the development of CdTe/CdS heterojunction structures. The main drawback of this composition was the insufficient p-doping level and as a consequence, a rectifying back contact [1]. The deposition techniques used for obtaining above 10 % efficiencies on small cells are electrodeposition, close-space sublimation, chemical spraying and atomic layer epitaxy. CdTe has been considered as one of the most promising solar cell material because of its 1.45 eV direct band gap [2]. As a consequence of the direct energy gap the absorption edge is very steep and thus 90 % of the incident solar light will be absorbed in a few micrometers of the material. It has been estimated that thin films can reach the cost limit of 0.6 €/Wp at a capacity of 60 MWp per year, whereas crystalline silicon modules can achieve this cost level only at capacities well above 500 MWp per year [3,4].

The largest single loss in Moldova State University fabricated CdTe solar cells by close space sublimation [5] is excessive absorption of short-wavelength photons in the CdS window layer. The obvious strategy of this work was to make this layer thinner. In this paper, we present the results of the investigation of CdTe cells with a well-controlled series of CdS thicknesses, holding all other parameters constant, and comparing the resulting quantum efficiency curves.

OPTICAL AND ELECTRICAL PROPERTIES OF CDS AND CDTE THIN FILMS

Thin film CdS/CdTe hetero-junction solar cells were fabricated on glass plates with an area of 2x2 cm^2 covered with a SnO_2 layer with the conductivity of 10^3 $\Omega^{-1}cm^{-1}$. SnO_2 served as the transparent front contact to CdS. Both CdS and CdTe layers were grown sequentially without intermediate processing by the Close-Space-Sublimation (CSS) method.

It was established that when CdS layers are grown, the influence of the temperature of the support upon the crystalline structure of the layers is not so prominent as it is in the case of CdTe layers. The most important features of thin layers used as optical window, which must be known, are their transmittance and conductivity. That is why the spectral dependencies were researched in the wavelength range from 400 to 750 nm at room temperature. All samples were prepared in identical technological conditions at the support temperature (310 ± 5)^{o}C, and at the evaporator's temperature (570 ± 5)^{o}C. The energetic resolution of the measurements does not exceed 2 meV. In fig. 1 we present the transmittance spectra at usual incidence of the light on the surface of CdS layers depending on the time of deposition. As one can see, the transmittance spectra possess a structure characteristic to interference phenomena. The layers CdS/SnO_2/glass have the utmost value of transmittance, for which the deposition time is 1 min. The utmost value of transmittance in the spectrum's visible region is (85- 90) % for CdS with deposition time 1 min. It can be observed as well that, alongside with the increase of CdS layer deposition time, the minimum and maximum interference values become more prominent, deeper, narrower and lesser in number, and this fact speaks about the unreasonableness of big thickness of CdS layers for solar cells. It can be easily noticed that the wavelengths which correspond to maximum and minimum values depend on the layers' thickness. Knowing the position of two neighboring maximum or minimum values from the transparency spectra, the thickness of CdS layers was determined using the relation

$$d = \frac{1}{2n}\frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1} \qquad (1),$$

The thickness of CdS thin films changes from 0.56 μm (deposition time 1 min) to 1.88 μm (deposition time 5 min). The dependence of conductivity on the temperature reverse $\log\sigma = f(10^3/T)$ (fig.2) for CdS layer with the deposition time equal to 1 min within the temperature range (16-100)°C contains one linear slope. The conductivity varies with temperature as

$$\sigma \approx \sigma_0 \exp(\frac{\Delta E_a}{2kT}) \qquad (2)$$

In this linear region the activation energy is found to be 0.13 eV.

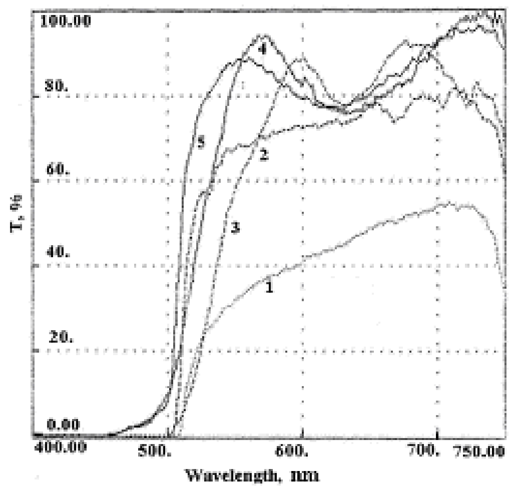

Fig.1. Transparency of the CdS thin films, deposition time, min: 1 - 5; 2 - 4; 3 - 3; 4 - 1; 5 - 2.

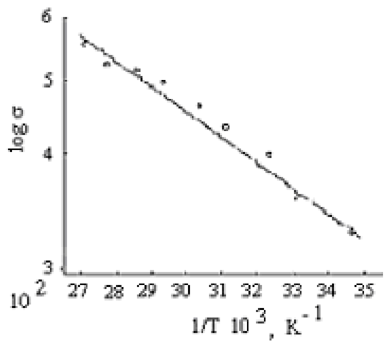

Fig.2. The dependence $\log \sigma = f(10^3/T)$ for CdS layer with deposition time 1 min.

The temperature dependence of the CdTe substrate lateral resistance was studied (see Table 2).

Table 2. *Lateral resistance of the CdTe thin films*

T_s,°C	250	260	270	290	295	310
R, Ω	$2.5\ 10^{10}$	$7.8\ 10^{9}$	$1.2\ 10^{8}$	$2.8\ 10^{8}$	10^{8}	$7.2\ 10^{8}$

The low resistance was obtained when the substrate temperature was T_s = (270-310) ºC. The deposition time was approximately 4 min, and the thickness of the layers ~ 6 μm. These deposition conditions were then used for growth of CdTe layers in the standard glass-based cells following the deposition of CdS/SnO_2. After the CdTe layer was deposited, the structures were held in $CdCl_2:H_2O$. We found that if the CdTe film thickness is less than 3 μm, pinholes occur leading to higher leakage current and drop in fill factor and open circuit voltage. Hence, an optimum thickness in the range of 3-5 μm is essential to obtain better solar cell performance. Also we found that for thinner CdTe films a treatment time of 25 min and about 40 min for the thicker CdTe films (3-5 μm) is required. Prolonged treatment leads to deterioration in cell performance. All device structures were completed with a pure Te layer and Ni contact to the CdTe, which was deposited by the thermal evaporation process in vacuum.

EFFECT OF CDS THICKNESS ON THE PERFORMANCE OF THIN FILM CADMIUM TELLURIDE SOLAR CELLS

In this structure light enters through the SnO_2 and goes through the CdS layer before it reaches the CdTe layer. Optimization of CdS thickness has a direct impact on the photocurrent generated. The most useful parameter is the quantum efficiency of the solar cells. Quantum efficiency allows the determination of the wavelength-dependent response within a solar cell and also helps to resolve the spatial response through the structure. The quantum efficiency depicted in fig. 3 shows the response for a set of solar cells made with different thicknesses of CdS window layer.

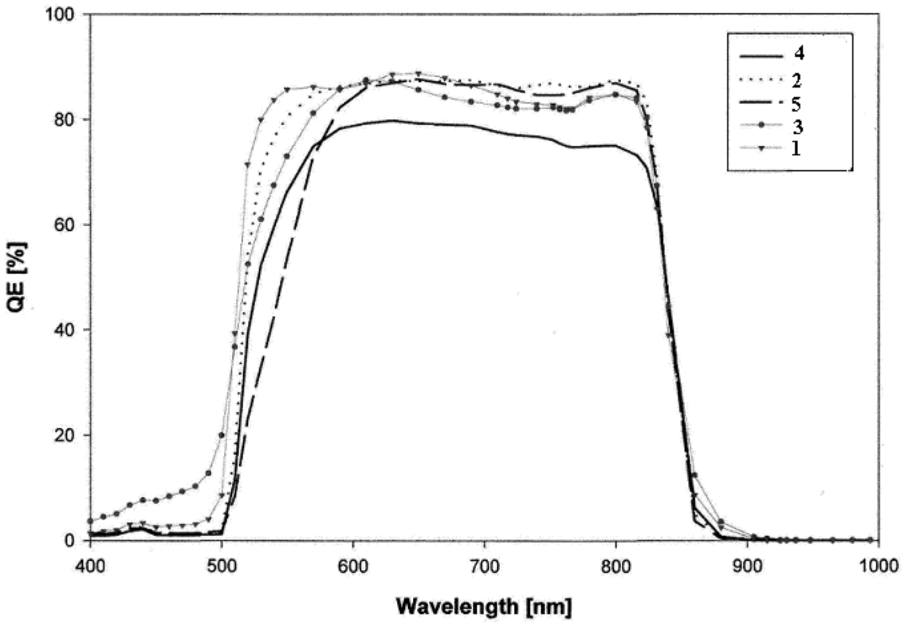

Fig.3. QE of CdS/CdTe solar cells with different thickness of CdS (CdS deposition time, min: 1 - 1; 2 – 2; 3 – 3; 4 – 4; 5 – 5).

Decreasing the window layer thickness increased response in the 400 nm - 500 nm wavelength range (curves 1, 2). In the cell with thick CdS layer (curves 4, 5) some interdiffusion of S and Te across the metallurgical junction probably occurs during film growth or during the post-deposition treatment near 400ºC in the presence of $CdCl_2$. The shape of the spectral response curve 5 hints to the existence of a mixture layer having a band gap narrower than CdS. In the blue region, from 400 to 500 nm, absorption in CdS attenuates the light reaching the CdTe layer, and thus reduces the quantum efficiency of the cell. No carrier collection appears to occur in CdS, either because the minority carrier (hole) lifetime is too low or because other factors create barriers to hole collection As the CdS thickness is further reduced, the quantum efficiency in the region from 400 to 500 nm increases. The quantum efficiency (QE) for four of the cells is reasonably good for wavelengths between the band gap of the CdS window layer and that of the CdTe.

CONCLUSIONS

The variation in short wavelength spectral response with CdS thickness seems to indicate that Te diffuses slowly resulting in incomplete conversion of the CdS layer. The amount of the diffusion of Te into the CdS depends on the CdS thickness and structure and the primary effect of the interdiffusion is to reduce short wavelength spectral response.

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