PHOTOELECTRICAL PARAMETERS OF *n*CdS–*p*CdTe THIN-FILM SOLAR CELLS WITH A CdO BUFFER LAYER

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Abstract

The results of the studies of the effect of a CdO buffer layer on the photoelectrical parameters of CdS–CdTe solar cells have been described. It has been found that the formation of a 5–8 nm thick CdO buffer layer leads to an increase in the CdS–CdTe solar cell open circuit voltage (V_{oc}) by 90–140 mV, short circuit current (I_{sc}) by 1.4–3.2 mA/cm^2, and efficiency by 2.8–4.1% at 300 K and an illumination of 100 mW/cm^2.

1. Introduction

Cadmium telluride (CdTe) is one of the main materials for the fabrication of low-cost solar cells, which is stipulated by the theoretically predictable efficiency up to 30% of the single junction device structures based on CdTe [1, 2]. Recently, the efficiency of laboratory samples of CdTe-based solar cells and large area modules of 19.6 and 16.1%, respectively, has been achieved [3]. However, this efficiency is considerably lower than the theoretical limit; therefore, the exploration of the possibilities of enhancing this parameter is important from both theoretical and economical viewpoints.

The key element of these solar cells is the thin-film *n*CdS–*p*CdTe heterostructure. A CdS thin film is used as a "window" for the radiation to the active *p*CdTe layer.

The efficiency of solar cells based on *n*CdS–*p*CdTe heterojunctions is mainly determined by recombination loses at the interface. To enhance the solar cell efficiency, it is necessary to decrease the interface state concentration. For this purpose, different buffer layers formed at the *n*CdS–*p*CdTe hetrojunction interface are used.

The results of the effect of a nanothick CdO buffer layer on the photoelectrical parameters of *n*CdS–*p*CdTe solar cells are described in this paper.

2. Experimental

CdS–CdTe heterojunctions were prepared by successive deposition of CdS and CdTe layers onto glass substrates (2 × 2 cm^2). The substrates were previously covered with a transparent (~80%) conducting (~10^{-3} Ω m) SnO_2 layer deposited by the “quasi-closed space” method. The effect of the source and substrate temperatures on the structure and electrophysical parameters of CdS and CdTe layers was studied to determine the optimum temperatures:

T_{sour} = 580°C and T_{sub} = 390°C for CdS and T_{sour} = 535°C and T_{sub} = 450°C for CdTe.

The CdS layers had the thickness of 0.3–0.6 μm and the electron concentration of 1.6×10^{18} cm^{-3}; the CdTe layers had the thickness of 8–14 μm and the hole concentration of 2×10^{15} to 8×10^{15} cm^{-3}.

Before the deposition of the CdTe layer, a thin CdO layer (5–50 nm) was deposited onto a part of the CdS layer. CdO layers were prepared by magnetron sputtering of a cadmium plate in an oxygen atmosphere at a direct current. CdO layer thickness was controlled by the time of sputtering and determined from the calibration curve of the dependence of the CdO layer thickness on sputtering duration.

The resulting thin-film heterostructures were subjected to a "chloride" treatment to enhance their photosensitivity. For this purpose, the structures were exposed to a methanol–$CdCl_2$ solution for 3–5 h. After that, a heat treatment at 380°C was conducted for 30 min.

The CdS–CdTe heterojunction configuration (Fig. 1) provides measurements of the dependences for elements with and without a CdO layer prepared under similar technological conditions.

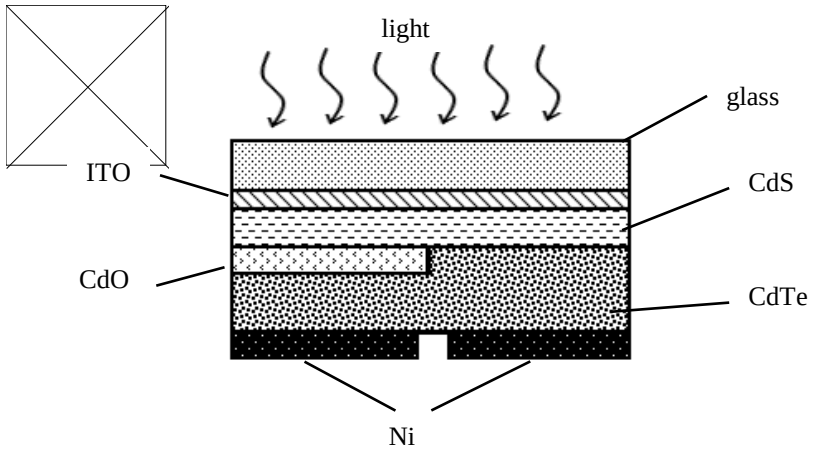


Fig. 1. Cross section of a CdS–CdTe solar cell with a CdO buffer layer.

The *I–U* dependences of SnO_2–CdS–CdO–CdTe–Ni and SnO_2–CdS–CdTe–Ni structures were studied using a KEITHLEY 4200-SCS measurement unit. The photosensitivity spectra of the heterojunctions were studied using an MDR-23 monochromator with a resolution power of 2.6 nm/mm. All spectra were normalized to the quantity of incident photons.

3. Experimental results and discussion

The high value of surface recombination rate considerably decreases the solar cell output power and conversion efficiency. The current intensity in the solar cell external circuit is given by the formula [1]

$$I = I_0 \left(e^{\frac{eU}{e^{nkT}}} - 1 \right) - I_f \qquad (1)$$

Where I_0 - is saturation current, I_f –is photocurrent. The surface recombination increases saturation current and decreases the solar cell output voltage:

$$U_{xx} = \frac{nkT}{e} \cdot ln\left(\frac{I_f}{I_0} + 1\right) \quad (2)$$

Since I_0 and I_f depend on surface recombination rate, the quantitative comparison of the effect of the CdO buffer layer can be made by coming from the efficiency of I_0 decreasing and I_f increasing in the structures with a CdO buffer layer compared with the structures without this layer.

The studies of *I–U* dependences of *n*CdS–*p*CdTe heterojunctions with and without a CdO buffer layer showed that the presence of a CdO layer does not change the current flow mechanism; however, it decreases saturation current I_o.

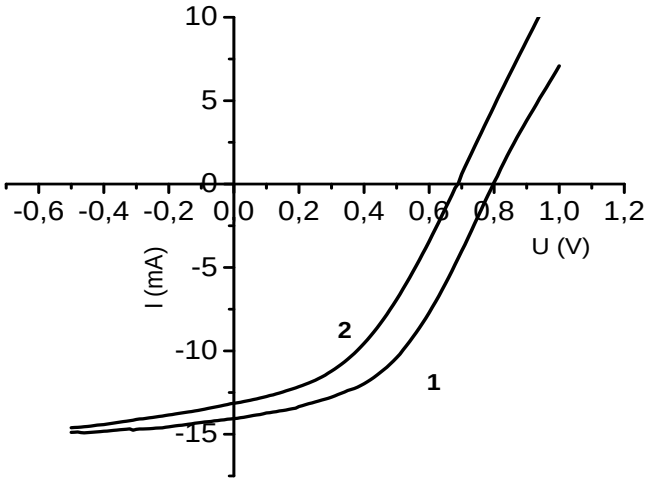


Fig. 2. *I–U* dependences under illumination for SC: (*1*) CdS–CdO–CdTe and (*2*) CdS–CdTe.

The load dependences of the CdS–CdO–CdTe structure (CdO layer thickness of ≈6 nm) (curve *1*) and the *n*CdS–*p*CdTe heterojunction (curve *2*) measured at 300 K and an illumination of 100 mW/см^2 are shown in Fig. 2. The photoelectrical parameters, such as fill factor FF and efficiency of solar energy conversion to electrical one, determined from these dependences are as follows: for *n*CdS–*p*CdTe heterojunction: U_{oc} = 0.69 V, I_{sc} = 26. 53 mA/cm^2, FF = 0.46, ŋ = 7.32%; for the CdS–CdO–CdTe structure: U_{oc} = 0. 8 V, I_{sc} = 25.7 mA/cm^2, FF = 0.42, ŋ = 9.76%. The photoelectrical parameters of a set of structures with and without a CdO layer, which were measured under the same conditions, are given in the table.

Table 1. Open circuit voltage and short circuit current of CdS–CdTe heterojunctions with and without a CdO layer measured at 300 K and an illumination of 100 mW/cm^2

Samples	U_{oc}, V	I_{sc}, mA/cm^2
Г53, CdO	0.77	25.8
-----	0.68	21.4
Г151, CdO	0.81	25.6
-----	0.68	23.2
Г197, CdO	0.79	24.0
-----	0.70	22.0
Г227, CdO	0.78	26.4
-----	0.64	26.0
Г228, CdO	0.77	26.2
-----	0.67	26.0
К136, CdO	0.79	22.4
-----	0.70	20.0
Г176, CdO	0.78	26.2
-----	0.61	19.4
Г177, CdO	0.78	25.2
-----	0.70	22.0

It is evident from the table that all structures containing a CdO layer have higher photoelectrical parameters: U_{oc} by 90–140 mV and I_{sc} by 1.4–3.2 mA/cm^2.

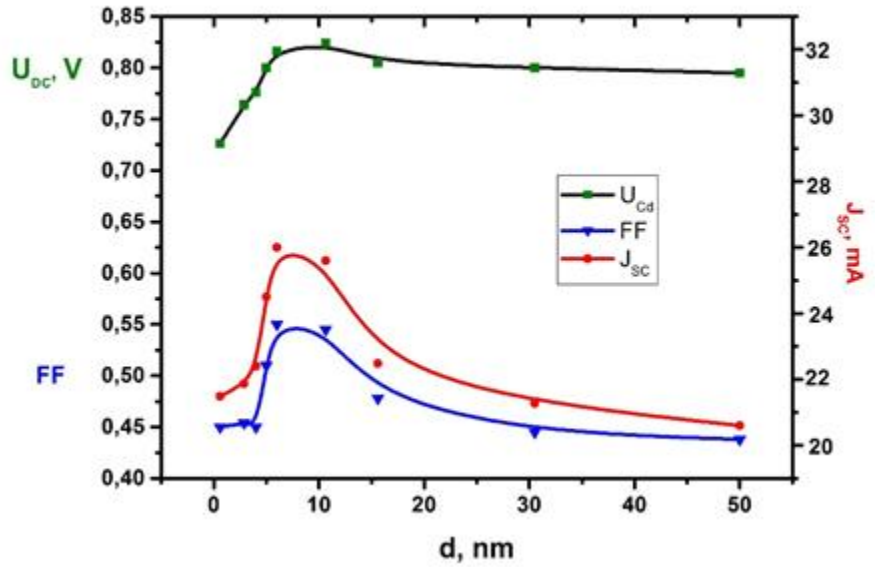


Fig. 3. U_{oc} , I_{sc} ,FF, and efficiency as a function of the CdO buffer layer thickness for the CdS–CdO–CdTe SC.

Dependences of U_{oc} , I_{sc}, FF, and efficiency of solar energy conversion into electrical on CdO layer thickness for the *n*CdS–*p*CdTe heterojunction with a buffer CdO layer at the interface, which were measured at 300 K and an illumination of 100 mW/cm^2, are shown in Fig. 3.

It is evident that the CdO layer thickness has a significant effect on the short circuit current and fill factor of the load characteristic; for open circuit voltage, it sharply increases at low values of CdO layer thickness; for thicknesses higher than 10 nm, U_{oc} remains unchanged at a level of ~0.8 V.

From the analysis of the given dependences it was determined that the optimum thickness of the CdO layer is 5–8 nm. This finding is attributed to the fact that, at low thicknesses, the CdO layer is tunnel-transparent for charge carriers, while at high thicknesses, this layer blocks the charge carrier flow.

The study of the photoluminescence of the CdTe layers at luminescence excitation through a CdS layer showed that, in the case of formation of a CdO layer, the luminescence spectral distribution does not change and its intensity increases by 1.4–1.6 times. This feature indicates that the introduction of a CdO buffer layer leads to a decrease in the concentration of recombination centers at the *n*CdS–*p*CdTe heterojunction interface.

The sensitivity spectral region for *n*CdS–*p*CdTe heterojunctions with and without a CdO layer is located in a wavelength region of 0.50–0.83 μm (Fig. 4); that is, it is limited by the photon energy close to the band gap of the heterojunction component materials. The spectral sensitivity is fairly homogeneous and exhibits sharp edges, which indicate the absence of the predominant effect of volume recombination on charge carrier collection. The presence of a CdO layer does not change the shape of the sensitivity spectral dependence and only increases the sensitivity.

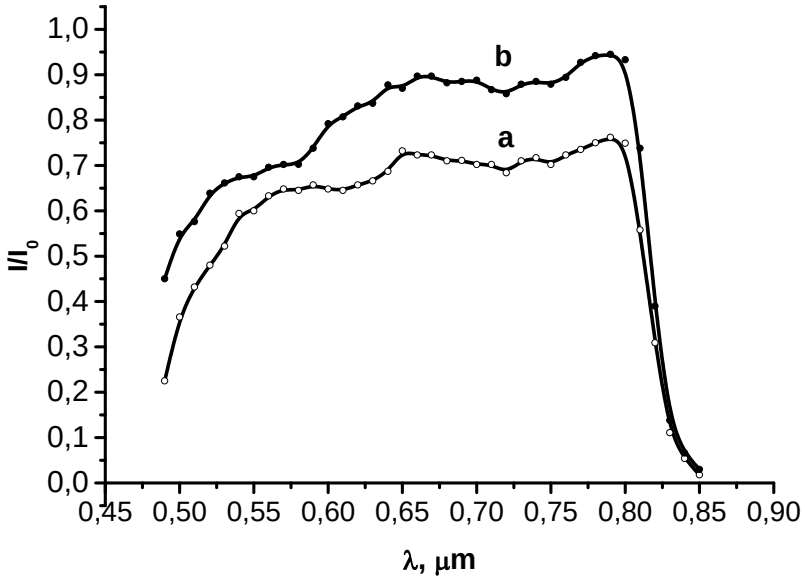


Fig. 4. Photosensitivity spectrum of (a) CdS–CdTe and (b) CdS–CdO–CdTe SC.

4. Conclusions

The formation of a thin (5–8 nm) CdO layer at the *n*CdS–*p*CdTe heterojunction interface leads to a decrease in the recombination center concentration, which results in an increase in the efficiency of the solar energy conversion to electrical one by 2.8–4.1%.

References

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