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EFFECTS OF ALPHA PARTICLES IRRADIATION ON THE PHOTO-ELECTRICAL PROPERTIES OF CdS/CdTe HETEROJUNCTIONS

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The effects of irradiation with energetic alpha particles on the electrical properties of CdS/CdTe thin films photovoltaic cells were studied. The irradiation energy and the fluency of alpha particles were 3 MeV and 10^{13} alpha particles/cm^2, respectively. The samples were fabricated in „superstrate" configuration, with a CdS thin film as window layer and CdTe as an active layer. The films were deposited by conventional thermal vacuum evaporation. To improve the structural properties of the obtained samples thermal and chemical treatments were made. The photovoltaic response of the structures was analyzed before and after alpha particles irradiation and the results were compared.

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1. Introduction

Photovoltaic cells based on cadmium sulphide (CdS)/cadmium telluride (CdTe) heterojunction were intensively studied in the last decade, as an alternative to the conventional ones, based on silicon [1-3]. Several groups of researchers focused on getting higher conversion efficiencies and values as high as 16,5% were reported [4-6]. The interest in such type of photovoltaic structures is justified by their low cost production [7], good chemical and mechanical stability [8] and small weight which recommends them for space applications. In addition, their physical properties [9-13] recommend CdS and CdTe as suitable candidates for such type of applications.

The physical and chemical properties of CdS/CdTe photovoltaic cells can be improved by thermal and chemical treatments; cadmium chloride ($CdCl_2$) is most used for the activation of CdS/CdTe cells [14]. It was observed that after $CdCl_2$ activation CdTe grains are increased [15] and the recombination centers are reduced or even removed [16, 17]. Moreover, the defects near the CdS/CdTe interface are significantly reduced [18]. $CdCl_2$ "wet" treatment seems to have reproducibility issues; oxychlorides and other impurities can appear in the process [19]. These problems can be avoided by a $CdCl_2$ "dry" treatment.

The effect of electron and proton irradiation on the physical properties of the component layers was reported in several papers, [14, 20-25], but just few refers to the influence of ionizing radiations on the performances of photovoltaic cells based on these materials [26, 27]. Taking into account that protons represent 80% of cosmic rays and alpha particles 9%, it is important to establish the effects of irradiation with those particles on the CdS/CdTe heterojunction photovoltaic cells for space applications. Here we report our results on the effects of energetic

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alpha particles on the performance of CdS/CdTe photovoltaic cells. The energy and fluency of alpha particles were 3 MeV, and 10^{13} alpha particles/cm^2, respectively.

2. Experimental details

Glass/ITO/CdS/CdTe($CdCl_2$)/Cu/Au photovoltaic cells were prepared in superstrate configuration and their photovoltaic response was characterized before and after irradiation with alpha particles.

Polycrystalline CdS thin films were deposited by thermal vacuum evaporation (TVE) on optical glass substrates covered with indium tin oxide (ITO). CdS powder (Merck, 99.999%) was sublimated at 740°C from a single source; the pressure was maintained constant during the deposition, at 3.2×10^{-4} mbar and the substrate temperature was 250°C. Thin films with 75 nm thickness have been prepared.

Next CdTe was deposited by TVE, at 600°C and the same pressure as for CdS films; the thickness of CdTe films was 2100 nanometers. After this step the structures were thermally treated in situ at 200°C for 20 minutes.

To activate the photovoltaic structures, a treatment with $CdCl_2$ was made. For samples that were to be irradiated with alpha particles, a "wet" $CdCl_2$ treatment was performed: the samples were immersed in a $CdCl_2/CH_3OH$ solution for 15 seconds and then were thermally treated at 200°C, in an evacuated chamber ($\sim 10^{-4}$ mbar).

To complete the photovoltaic structure back electrodes were deposited by thermal vacuum evaporation - a copper (Cu) thin layer (50 nm), followed by a gold (Au) film (100 nm). After Cu deposition a thermal treatment for 30 minutes at 150°C was performed.

The active area of the resulting photovoltaic cells was 0.4 cm^2.

The obtained samples were subjected to irradiation with alpha particles using a Van der Graaf accelerator, the radiation beam being directed along the normal to the surface of the samples. Irradiation was carried out in an evacuated chamber, at ambient temperature; the energy of the incident particles was 3 MeV, while the fluency was of 10^{13} alpha particles/cm^2.

The photovoltaic performance of the structures was analyzed using a Newport-Oriel 150 solar simulator, in AM 1.5 conditions. The action spectra for all prepared samples were plotted and the external quantum efficiency (EQE) values were calculated.

3. Results

The I-V characteristics measured in dark (Fig.1) for Glass/ITO/CdS/CdTe($CdCl_2$)/Cu/Au photovoltaic cells, before and after alpha particles irradiation, were analyzed by using the modified Shockley equation:

$$I = I_0\{exp[\beta(V - IR_s)] - 1\} + \frac{V - IR_s}{R_{sh}} \tag{1}$$

where: I_0 is the reverse saturation current, R_s - the series resistance, R_{sh} - the shunt resistance.
The values of the parameters in eq. (1) were determined following the procedure described in [27] and are collected in Table I.

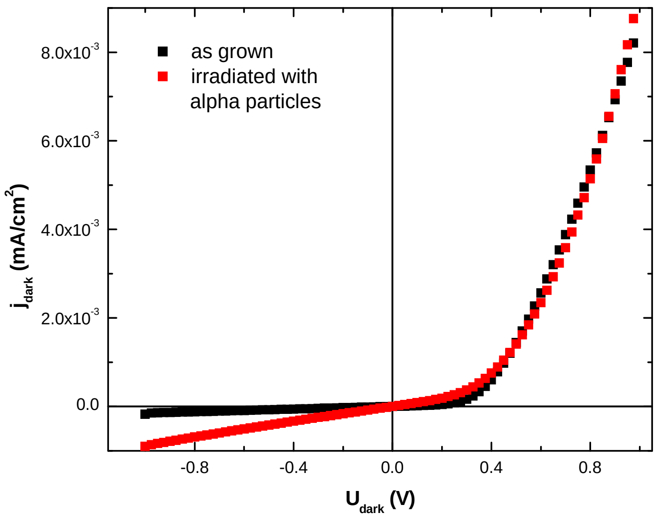

Fig. 1. I-V dark characteristics before and after alpha particles irradiation for Glass/ITO/CdS/CdTe/CdCl$_2$/Cu/Au photovoltaic cells

Table 1. The calculated values for shunt and series resistances and the quality diode factor for Glass/ITO/CdS/CdTe(CdCl$_2$)/Cu/Au prepared structures.

Structure	R_s (KΩ)	R_{sh} (MΩ)	n	Type of CdCl2 treatment
Glass/ITO/CdS/CdTe(CdCl$_2$)/Cu/Au (as grown)	110	16	3.4	wet
Glass/ITO/CdS/CdTe(CdCl$_2$)/Cu/Au (alpha particles irradiation)	53	3	6.5	wet

Irradiation with alpha particles in the above mentioned conditions results in altering the shunt resistance (reduced by a factor of 5) and the quality factor (increased by a factor of two; this parameter is associated to recombination in the space charge region of the heterostructure – the irradiation introduces defects which are effective in increasing the recombination rate).
The action spectra were recorded at room temperature, before and after alpha particles irradiation, using a set-up containing a Newport Oriel monochromator controlled by a computer; the obtained results are presented in Fig.2.

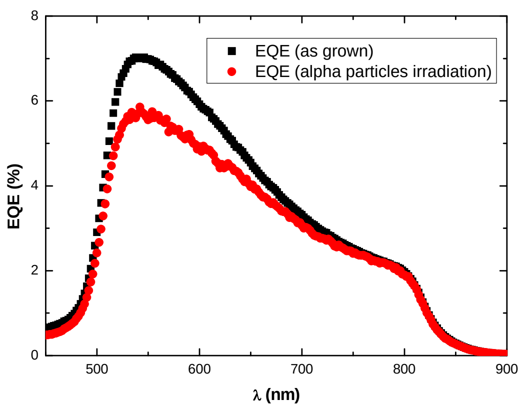

Fig. 2. External quantum efficiency (EQE) before and after alpha particles irradiation for Glass/ITO/CdS/CdTe(CdCl$_2$)/Cu/Au photovoltaic structures.

EQE values decreased after irradiation; the decrease is more pronounced at photon energies close to CdS band gap (2.33 eV, corresponding to a wavelength of 532 nm). This suggests an increased photon absorption at energies below the gap in the window layer outside the space charge region, due to optically active defects introduced by irradiation.

I-V characteristics in the fourth quadrant were recorded at room temperature in AM 1.5 conditions, before and after alpha particles irradiation (Fig.3). The calculated values for short circuit current, open circuit voltage and fill factor, before and after irradiation, were summarized in Table II.

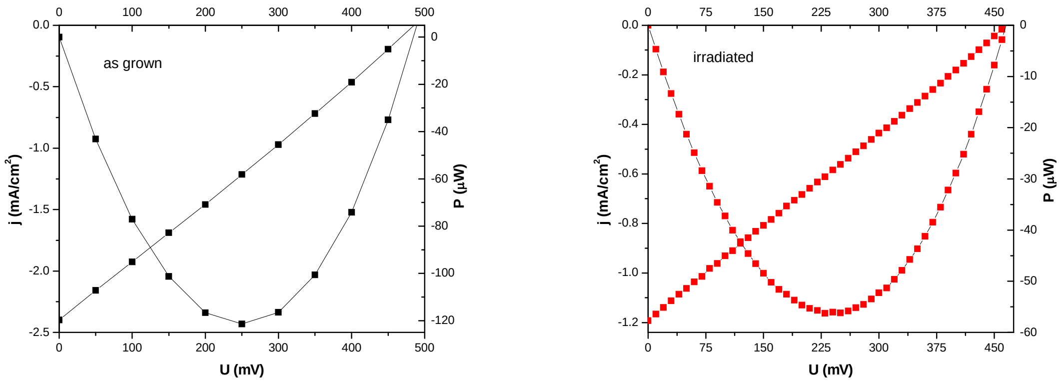

Fig. 3. I-V characteristics in the fourth quadrant before (left) and after (right) alpha particles irradiation for Glass/ITO/CdS/CdTe($CdCl_2$)Cu/Au photovoltaic structures.

Table II. Parameters characterizing the photovoltaic response before and after irradiation with alpha particles.

Structure	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)
Glass/ITO/CdS/CdTe($CdCl_2$)/Cu/Au (as grown)	2.4	475	26
Glass/ITO/CdS/CdTe($CdCl_2$)/Cu/Au (alpha particles irradiation)	1.175	460	25

The irradiation results in a reduction of the short-circuit current by a factor of two; the open-circuit voltage and the fill factor are only slightly reduced.

The software package SRIM-2008 was used in full colision cascade mode to simulate the alpha particles irradiation damage in our structures (Fig.4).

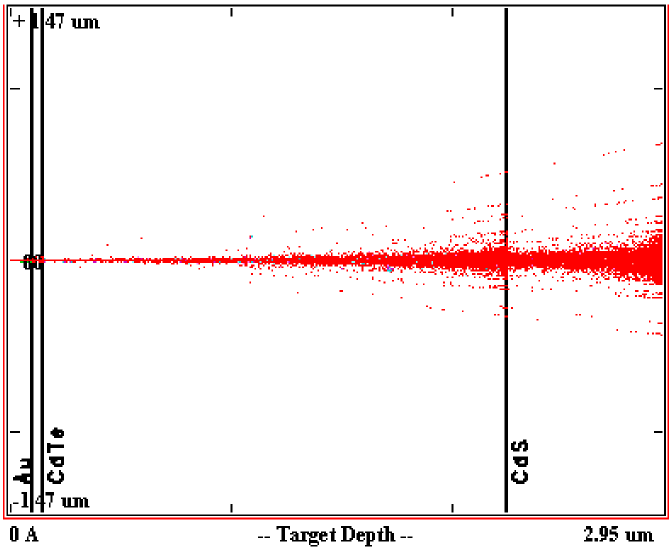

Fig. 4. Monte-Carlo simulation of 3 MeV alpha particles scattering distribution.

The simulation suggests that significant damage occurs at interfaces, particularly at the CdTe/CdS interface. Moreover the inter-diffusion of S and Te recoil atoms occurs at this interface. These results are consistent with the observed effects:

– the density of electrically active defects, acting as recombination centers introduced near CdS/CdTe interface, increases, which results in the observed increase in the quality factor of the heterostructure and the reduction of the short-circuit current;

– irradiation damage is important in the CdS window layer; this may alter optical properties of this layer. Disorder-induced band tails can account for the increase of the optical absorption at photon energies below bandgap, which explains the reduction of EQE values in that spectral region.

4. Conclusions

Photovoltaic structures based on CdS/CdTe heterojunction were prepared by thermal vacuum evaporation and their endurance to irradiation with energetic alpha particles (3 MeV, 10^{13} particles/cm^2) was tested. The influence of alpha particles irradiation was investigated by electrical characterization of the obtained samples.

After irradiation with alpha particles, the series and shunt resistances decreased significantly, while the heterostructure quality factor increased by a factor of two. Moreover, the external quantum efficiency was reduced at photon energies below and near CdS optical threshold.

The photovoltaic parameters characterizing the structures were also altered by irradiation; the most important change consists in the reduction by a factor of two of the short-circuit current. The open circuit voltage and the fill factor were less affected.

The observed (significant) changes are related to the defects introduced mainly at the CdS/CdTe interface, and must be considered when the CdS/CdTe solar cells are designed for use in space applications.

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