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NEW STUDIES OF THE IONIZING IRRADIATION EFFECTS ON CdS/CdTe HETEROJUNCTION

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Abstract. Cadmium sulfide/cadmium telluride (CdS/CdTe) heterojunction based photovoltaic cells were fabricated in superstrat configuration onto optical glass substrates. CdTe layers were deposited by thermal vacuum evaporation (TVE) and CdS thin films were fabricated by magnetron sputtering, at ambient temperature. The structures were irradiated with protons or alpha particles with 500 keV energies and 10^{11} particles/cm^2 fluencies and the effects of irradiation on their photovoltaic response were analyzed by current-voltage (*I-V*) measurements performed at room temperature. The measured external quantum efficiency values (EQE) of the cells decreased after irradiation.

Key words: cadmium sulfide, cadmium telluride, heterojunction, protons, alpha particles, irradiation.

1. INTRODUCTION

Thin films based photovoltaic cells belonging to the so called "second generation of solar cells" have been widely studied in the last two decades, in an attempt to find alternatives to silicon solar cells [1]. Various materials [2, 3] and deposition methods [4, 5] have been studied in order to improve the photovoltaic performances of such devices. Metal chalcogenide heterojunction based solar cells have shown good photovoltaic performances, with conversion efficiencies close to theoretical estimates, in laboratory conditions [6, 7]. Moreover, reduced mass recommends them for both terrestrial and spatial applications. Cadmium sulfide (CdS) with fundamental absorption threshold in 515–530 nm range, and good mechanical and chemical stability [8, 9, 10] is a prototypical window layer in those photovoltaic cells. Cadmium telluride with its optical bandgap around 1.4 eV and high absorption coefficients is the absorber layer of CdS/CdTe heterojunction [11, 12, 13].

Effects of the ionizing radiations on the photovoltaic response of CdS/CdTe heterojunction based solar cells have been investigated [14, 15, 16], proving that these are suitable materials for space applications. A special attention was given to protons and alpha particles irradiation, due to their important weights in cosmic rays [17] (80% protons and 9% alpha particles).

Here we present our results on the effects of protons and alpha particles (500 keV energies, 10^{11} particles/cm^2) irradiation on CdS/CdTe heterojunction based photovoltaic cells in superstrate configuration. Monte-Carlo numerical simulations results of irradiation processes with protons and alpha particles are also discussed. The energies and fluencies used for ionizing radiations are similar with those hitting artificial satellites orbiting the Earth.

2. EXPERIMENTAL PROCEDURES

2.1. MATERIALS

Optical glass substrates covered with a thin indium tin oxide layer (ITO) with 8–12 Ω/sq resistivities, commercially available from Sigma Aldrich Co., were ultrasonically cleaned in acetone, isopropyl and deionized water, 15 minutes each procedure. The CdS window layer (320 nm thickness) was deposited by RF magnetron sputtering at ambient temperature and 500 rf power, using a commercially available target (99.999% purity from Sigma Aldrich Co.). The working gas was argon (4.6×10^{-3} mbar). CdTe, the absorber layer (2.1 μm thickness), was deposited by thermal vacuum evaporation (TVE), as described in [17]. To complete the photovoltaic structures, a composite copper and gold (Cu/Au) back contact was deposited by TVE. The layer structure of the cells is shown in Fig. 1. The structures were thermally treated in vacuum, at 300 °C for 15 minutes.

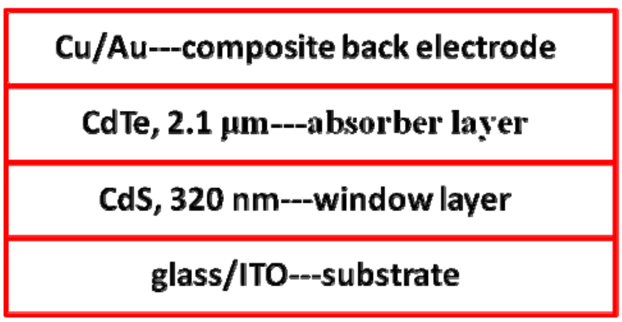

Fig. 1 – Fabricated cells architecture.

2.2. IRRADIATION PROCEDURE

The structures were irradiated with protons and alpha particles with 500 keV energies and 10^{11} particles/cm^2 fluencies, respectively. Particle beams were perpendicular to the surface of the samples and covered them entirely. The irradiation procedure was performed by using a Cockcroft-Walton Tandetron accelerator.

2.3. CHARACTERIZATION PROCEDURES

Current-voltage characteristics in dark and AM 1.5 conditions were recorded before and after irradiation with protons and alpha particles, using a Keithley 2400 sourcemeter and a Newport-Oriel solar simulator, at room temperature. The effects of protons and alpha particles irradiation were simulated by using Monte-Carlo methods as implemented in the SRIM-2008 package [18].

3. RESULTS AND DISCUSSION

3.1. MONTE-CARLO NUMERICAL SIMULATION

Figure 2 shows simulated alpha particles and protons tracks at 500 keV in the case of CdS/CdTe heterojunction, as obtained by using SRIM-2008 software package.

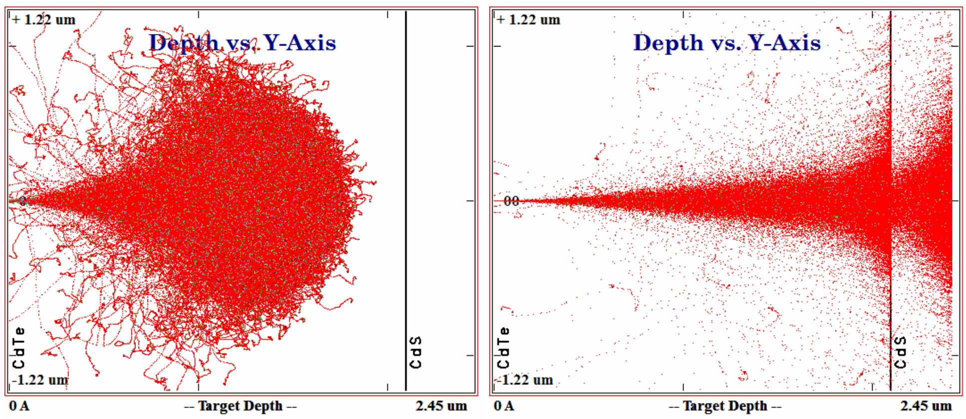

Fig. 2 – Spatial scattering distributions for alpha particles (left side) and protons (right side) with E = 500 keV and F = 10^{11} particles/cm^2. The numerical simulations were made taking into account a CdS/CdTe heterojunction; thickness of the component layers were 320 nm for CdS and 2.1 μm for CdTe, respectively.

Monte-Carlo numerical simulations showed spatial scattering distribution of the alpha particles in the whole absorber layer, with practically no defects induced in the CdS layer or at the CdS/CdTe interface. In the case of protons irradiation with the same energies and fluencies, scattering processes are observed mainly at the CdS/CdTe interface. The same behavior was previously observed [17, 18] for both protons and alpha particles with 3 MeV energies and 10^{13} and 10^{14} particles/cm^2 fluencies. Alpha particles are heavier than protons, so their penetration depth in solid targets is lower than the penetration depth of protons with the same energies.

3.2. IRRADIATION WITH PROTONS

The action spectra of the external quantum efficiency (EQE) of glass/ITO/CdS/CdTe/Cu/Au fabricated cells are shown in Fig. 3.

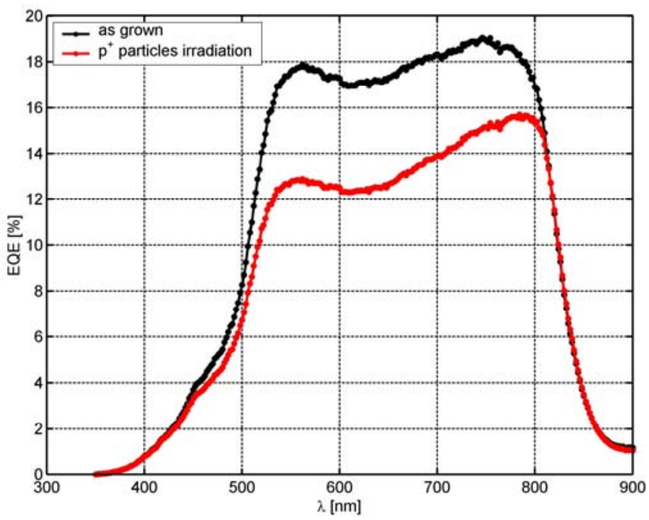

Fig. 3 – Action spectrum of external quantum efficiency of glass/ITO/CdS/CdTe/Cu/Au photovoltaic cells, as grown (black) and after irradiation with protons, E = 500 keV, $F = 10^{11}$ particles/cm^2 (red).

The peaks at 525 nm and 780 nm, corresponding to fundamental absorption thresholds of CdS and CdTe can be easily identified. The structure of the spectra is similar for both as grown and irradiated photovoltaic cells but lower EQE values were measured after irradiation with protons. This fact is related to the defects introduced at CdS/CdTe interface and the corresponding increase of the recombination rate of photogenerated carriers.

The fourth quadrants of current-voltage (*I*-*V*) characteristics recorded in AM 1.5 conditions are shown in Fig. 4 and the photovoltaic parameters are summarized in Table 1.

While open circuit voltage (V_{oc}) and fill factor (FF) retain their value after protons irradiation; the short-circuit current slightly decrease after irradiation with protons, due to increased recombination rates at CdS/CdTe interface.

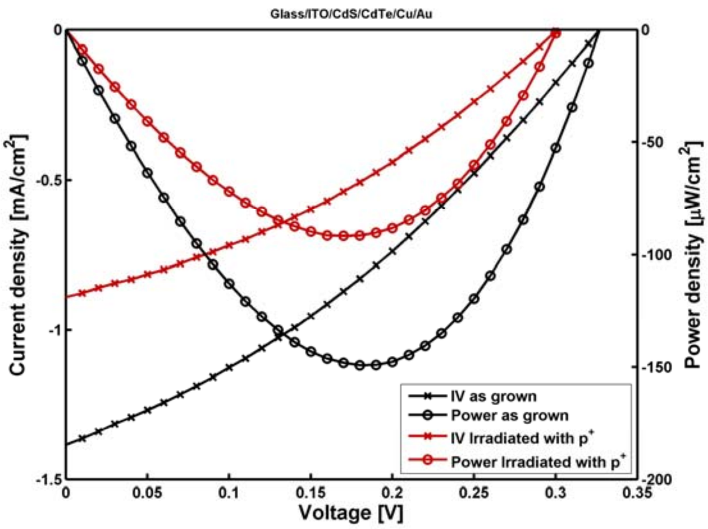

Fig. 4 – Current-voltage characteristics and power density of as grown glass/ITO/CdS/CdTe/Cu/Au photovoltaic cells (black) and after irradiation with protons, E = 500 keV, $F = 10^{11}$ particles/cm^2 (red).

Table 1

Parameters characterizing the photovoltaic response of CdS/CdTe structures, as grown and irradiated with protons

Sample: glass/ITO/CdS/CdTe/Cu/Au					
as grown			protons irradiation: E = 500 keV, $F = 10^{11}$ particles/cm^2		
J_{sc} (μA)	V_{oc} (V)	FF (%)	J_{sc} (μA)	V_{oc} (V)	FF (%)
3.5	0.3	32	2.2	0.3	34

3.3. IRRADIATION WITH ALPHA PARTICLES

EQE action spectra of glass/ITO/CdS/CdTe/Cu/Au structures before and after irradiation with alpha particles (E = 500 kev, $F = 10^{11}$ particles/cm^2) are shown in Fig. 5.

EQE values decreased after irradiation with alpha particles, similar with the behavior noticed in the case of irradiation with protons, but, in addition, a significant change in the structure of the spectra was observed. Due to defects introduced mainly in CdTe, the recombination rate of the carriers generated by the photons with wavelengths in the 550–800 nm range increases significantly, which induces the observed decrease of EQE.

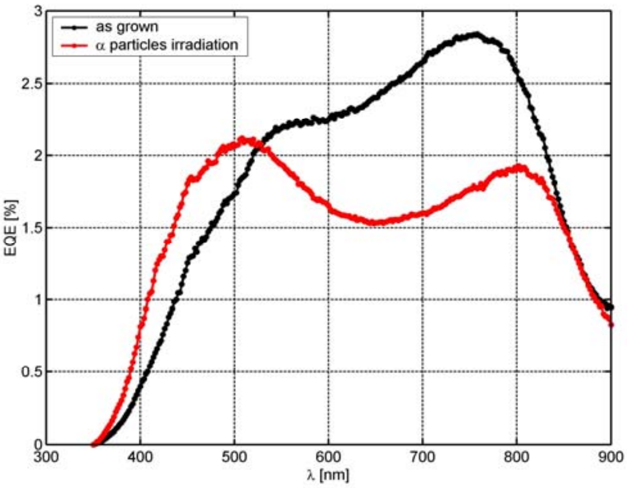

Fig. 5 – Typical EQE action spectra of glass/ITO/CdS/CdTe/Cu/Au photovoltaic cells before (black) and after irradiation with alpha particles, E = 500 keV, F = 10^{11} particles/cm^2 (red).

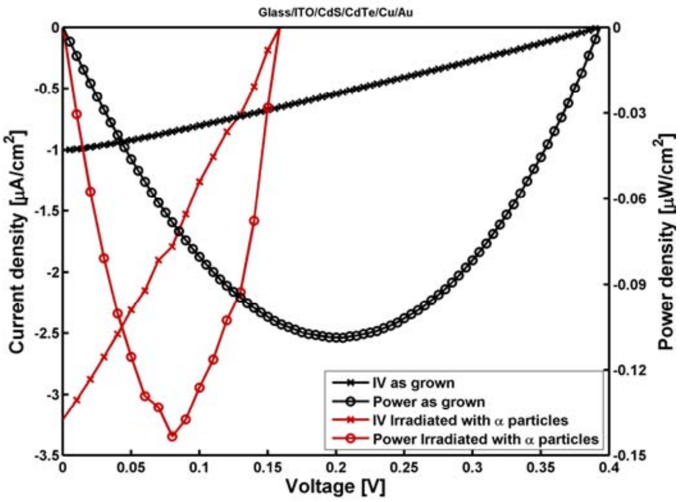

Fig. 6 – Current-voltage characteristics and power density of as grown glass/ITO/CdS/CdTe/Cu/Au photovoltaic cells (black) and after irradiation with alpha particles, E = 500 keV, F = 10^{11} particles/cm^2 (red).

An unexpected effect is the EQE increase in the 300–500 nm photon wavelengths range, indicating an extension, introduced by irradiation, of the CdS/CdTe heterojunction charge space region on the CdS side. This may be related to increased densities of V_{Cd} and Te point-like defects acting as acceptors introduced in CdTe layer by irradiation with alpha particles, which lowers the Fermi level and increases the charge transfer from CdS at CdS/CdTe interface.

The fourth quadrant of current-voltage characteristics recorded in AM 1.5 conditions are shown in Figure 6 and the photovoltaic parameters are summarized in Table 2.

Table 2

Parameters characterizing the photovoltaic response of CdS/CdTe structures, as grown and irradiated with alpha particles

Sample: glass/ITO/CdS/CdTe/Cu/Au					
as grown			alpha particles irradiation: E = 500 keV, F = 10^{11} particles/cm^2		
J_{sc} (μA)	V_{oc} (V)	FF (%)	J_{sc} (μA)	V_{oc} (V)	FF (%)
2.5	0.4	27	8.0	0.2	28

For both as grown and irradiated with alpha particles photovoltaic cells, the fill factor (FF) and open circuit voltage (V_{oc}) have similar values while short-circuit current (J_{sc}) values increased more than three times after irradiation. This is probably related to the observed extension of EQE spectra at photon energies above those corresponding to CdS bandgap.

4. CONCLUSIONS

CdS/CdTe heterojunction based photovoltaic cells fabricated in superstrate configuration were irradiated with protons and alpha particles with 500 keV energies and 10^{11} particles/cm^2 fluencies. In the case of irradiation with protons a decrease of EQE values was detected over the active layer range, without altering the structure of the EQE action spectra. In the case of irradiation with alpha particles, a significant change of the structure of EQE spectra was observed, with an increase of EQE at photon energies slightly above the bandgap of CdS and a pronounced decrease at photon energies corresponding to charge carriers photogeneration in CdTe layer. This is explained by a lowering of the Fermi level in CdTe due to acceptors introduced by irradiation, which in turn induces an extended space charge region on the CdS side at CdS/CdTe heterojunction.

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