



Effect of electron irradiation on the properties of CdTe/CdS solar cells

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Abstract

Polycrystalline CdTe/CdS solar cells are used in space, as well as terrestrial, applications. The results of the studies on the effect of 8 MeV electron irradiation on p-CdTe/n-CdS thin film solar cells prepared by radio frequency (RF) sputtering are presented in this article. Solar cell parameters like short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF), conversion efficiency (η), saturation current (I_s) and ideality factor (n) have been considered. CdTe thin film solar cells exhibit good stability against electron irradiation up to 100 kGy.

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1. Introduction

Cu(InGa)Se₂ (CIGS) and CdTe are the most promising materials for non-silicon polycrystalline thin-film solar cells. Polycrystalline thin-film CdTe solar cells have drawn considerable attention because of their low cost, high efficiency and stable performance. The properties of CdTe such as a direct band gap of 1.45 eV and high optical absorption coefficient [1,2] make it an attractive material for space, as well as terrestrial, photovoltaic applications. A few micron thick CdTe film absorbs more than 90% of the incident light having photon energy above the band gap. Hence, solar cells can be fabricated with less quantity of CdTe with a depletion layer width comparable to the film thickness. As a result, a large fraction of carriers are generated within the depletion layer allowing more efficient collection [3]. This reduces recombination at grain boundaries, a major problem encountered in other polycrystalline materials. Thin absorber film can reduce the material cost providing high specific power (ratio of output power to the weight), which makes it attractive for space applications. CdTe/CdS solar cells can be prepared using a variety of

deposition techniques like screen printing, radio frequency (RF) sputtering, vacuum evaporation, metal organic chemical vapor deposition (MOCVD), spray pyrolysis, close spaced sublimation (CSS) and electrodeposition (ED) [3–7]. Each technique has its own advantages and shortcomings. CdTe/CdS solar cells with the highest conversion efficiency of 16.5% have been prepared using the CSS method [8]. It is reported that polycrystalline CdTe/CdS solar cells perform better than single-crystal CdTe/CdS cells [9].

Solar cells have been widely used in satellites, space stations and space vehicles as power sources, which operate in radiation environments. A high concentration of electrons, protons, neutrons and α particles are present in space, which can cause permanent damage in solar cells leading to operational failure. In solar cells, displacement damage is the dominant mechanism of degradation. The displacement damage induced by particle irradiation produces traps acting as recombination centers reducing the minority carrier lifetime and the diffusion length. This leads to a reduction in solar cell power output [10] and its failure over a period of time [11]. Therefore, apart from efficiency, stability against particle irradiation is an important requirement for space borne devices. In this article, results of the studies on the effect of 8 MeV electron

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irradiation on the properties of CdTe/CdS solar cells are presented.

2. Experimental

CdTe/CdS cells used in the present work were grown in a superstrate configuration, on Pilkington Tec 7 glass substrates. The substrates were cleaned following standard procedures and both CdTe and CdS films were deposited using the RF sputtering technique. The thickness of the films was approximately 2.0 μm for CdTe and 0.13 μm for the CdS film. The CdTe/CdS heterostructure was vapor chloride treated at 390 $^{\circ}\text{C}$ for 30 min under a flow of dry air. Pseudo-ohmic contact to CdTe was obtained by vacuum evaporating 3 nm of Cu followed by 50 nm Au. The Cu diffusion was achieved by annealing the contacts at 150 $^{\circ}\text{C}$ for 35 min.

The areas of the solar cells were determined by the area of the Cu/Au deposit and two batches of devices with areas 0.072 and 0.122 cm^2 were prepared. The current–voltage (I – V) characteristics of the solar cells under dark and illumination were measured using a computer interfaced Keithley 236 source/measure unit. The cells were illuminated under AM 1.5 condition. The intensity of the light source was adjusted to 100 mW/cm^2 using an intensity meter, Suryamapi. Capacitance measurements of the devices at various frequencies were made under dark condition using a Keithley 3322 LCZ meter.

The solar cells were irradiated with 8 MeV electrons from a Microtron Accelerator. The devices were exposed to electrons at doses ranging from 0.1 to 100 kGy at room temperature. Typical dose rates for space vehicles in higher inclinations, due to trapped Van Allen electrons, are 1–10 krad (Si)/year. Therefore, the accumulated dose will not exceed 100 kGy for a satellite mission. The delivered doses were measured using a Fricke dosimeter. The devices were irradiated from the backside to minimize the darkening effect of the glass substrate due to electron irradiation.

3. Results and discussion

3.1. I – V characteristic under illumination

The results for the devices with different areas were similar and, therefore, only the results for cells with area 0.072 cm^2 are presented. Fig. 1 shows the illuminated I – V characteristics of CdTe/CdS solar cells irradiated with 8 MeV electrons at various doses, under AM 1.5 illumination condition. Solar cell parameters like short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) were calculated from these I – V characteristics.

The FF of a solar cell is defined by [10]

$$\text{FF} = \frac{I_m V_m}{I_{sc} V_{oc}}, \quad (1)$$

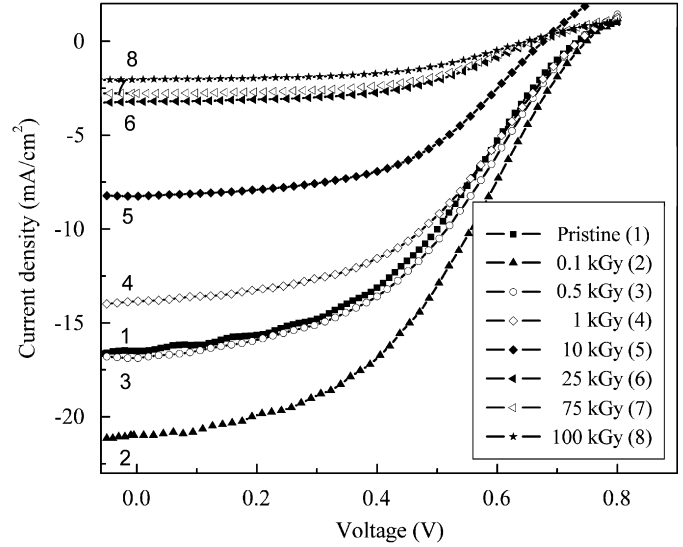


Fig. 1. I – V characteristics of CdTe/CdS solar cell at various doses of 8 MeV electrons under AM 1.5 illumination conditions.

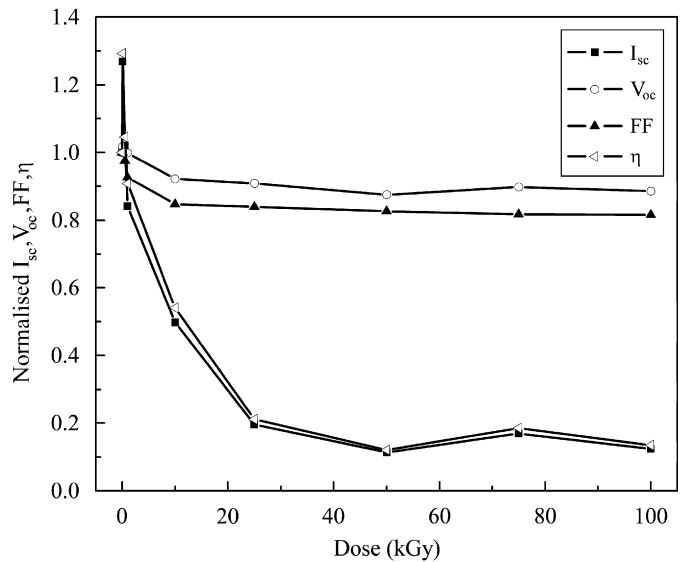


Fig. 2. Normalized solar cell parameters as a function of dose.

where I_m and V_m are the current and the voltage at the maximum power point on the I – V curve. The efficiency of a solar cell is given by [10]

$$\eta = \frac{I_m V_m}{P_{in} A}, \quad (2)$$

where P_{in} is the incident solar power and A is the area of the solar cell.

Fig. 2 shows changes in the cell parameters of the CdTe/CdS solar cells, normalized to their initial value, as a function of electron dose. At a very small dose of 0.1 kGy, an increase in the values of all the cell parameters is observed. This can be due to an increase in the minority carrier lifetime in the base region (in the bulk with respect to the incident light) caused by the passivation of recombination centers [12]. Above 0.1 kGy, a remarkable reduction in the values of short circuit

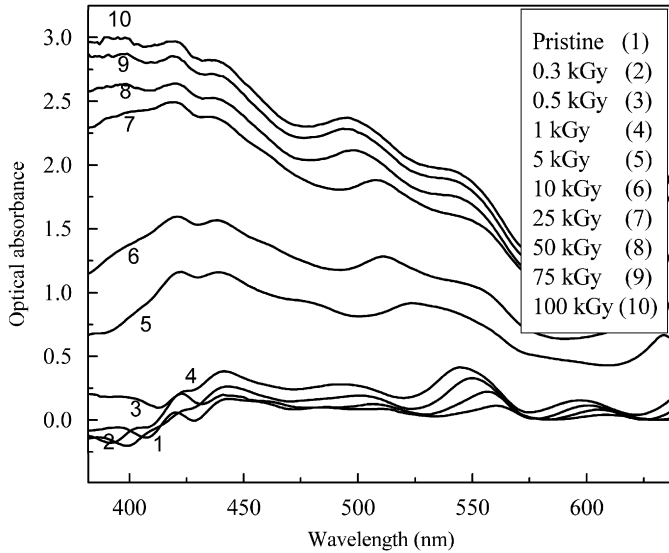


Fig. 3. Optical absorbance of Tec 7 glass as a function of wavelength, at various electron doses.

current and efficiency is observed with an increase in electron dose. The other cell parameters such as FF and V_{oc} do not seem to be affected much by irradiation. Even after an electron dose of 100 kGy, the normalized values of FF and V_{oc} remain above 77% and 88%, respectively. The decrease in the conversion efficiency of the devices is mainly due to the decrease in the values of I_{sc} . It was observed that the glass substrate of the solar cell turned brown after irradiation and the darkening increased with electron dose. Fig. 3 shows the absorbance of the glass substrate as a function of wavelength before and after irradiation. It can be seen that the darkening of the glass substrate starts beyond a dose of 1 kGy. Above 25 kGy, the absorbance of glass substrate did not change much with dose. The darkening is due to ionization followed by the creation of color centers in glass by the 8 MeV electrons. The decrease in the short circuit current and also efficiency to the observed extent may not be due to any degradation of the semiconductor or the junction, but can be attributed to the darkening of the glass substrate due to irradiation. Batzer et al. [13] and Romeo et al. [14] have reported similar results for CdTe/CdS solar cells on glass substrates irradiated with electrons of 1 and 3 MeV and protons of 5–15 MeV. Therefore, CdTe solar cells on glass substrates upon irradiation may exhibit lower efficiency due to the darkening of glass but not necessarily due to any degradation in the semiconductor material. Space quality glass substrates, which remain transparent even after electron irradiation, need to be used.

3.2. Dark $I-V$ characteristics

The forward dark $I-V$ characteristics follow the expression [10,15]

$$I = I_s \exp\left(\frac{qV}{nkT}\right), \quad (3)$$

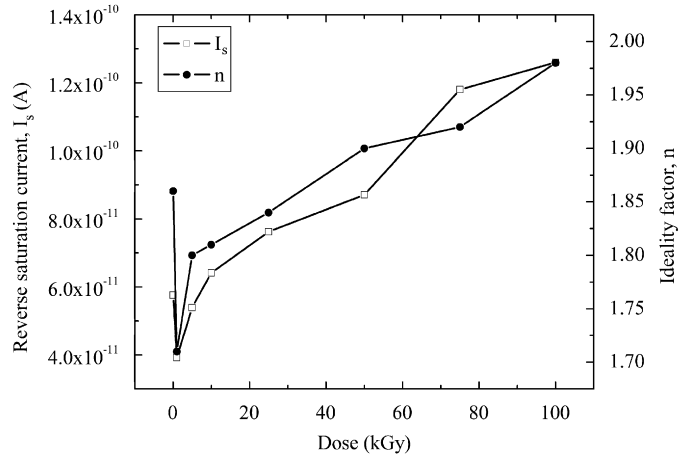


Fig. 4. Reverse saturation current and ideality factor of CdTe/CdS solar cell as functions of dose.

where I_s is the saturation current, n is the device ideality factor, κ is the Boltzmann constant, q is the charge and T is the temperature.

The diode ideality factor, n was calculated from the slope of the $I-V$ characteristics and the reverse saturation current I_s was obtained by extrapolating the straight line portion of $I-V$ curve. Fig. 4 shows the variations of saturation current and ideality factor as function of dose. A gradual increase in both the parameters with electron dose was observed above 10 kGy. The increase in the saturation current is not very significant even at a dose of 100 kGy. The recombination centers introduced by electron irradiation decreases the minority carrier diffusion length. It is well known that at comparatively low doses of electron irradiation, the degradation is due to the decrease in minority carrier diffusion length [16]. As the actual cumulative doses encountered by satellites during space mission will be less than 100 kGy, going by the minimal degradation of the cell observed with an irradiation up to a dose of 100 kGy, CdTe/CdS solar cells is expected to be stable in space environment. It has also been shown that most of the radiation damage in thin films can be removed by a low temperature annealing [17]. Thus, CdTe/CdS solar cells have good radiation stability against electron irradiation, which makes it suitable for use in space missions.

3.3. Capacitance as a function of frequency

Fig. 5 shows the variation of capacitance with frequency for the CdTe/CdS solar cells irradiated with 8 MeV electrons, measured under dark condition at 1 V. The capacitance decreases with increase in frequency. The capacitance value decreased from 1300 to 692 pF for the frequency variation from 100 to 100 kHz, for unirradiated sample. The corresponding decrease in capacitance for a sample irradiated with a dose of 100 kGy is from 1700 to 654 pF. The decrease in capacitance with frequency indicates the existence of deep levels near the CdTe/CdS interface [18]. The difference in the decrease in capacitance

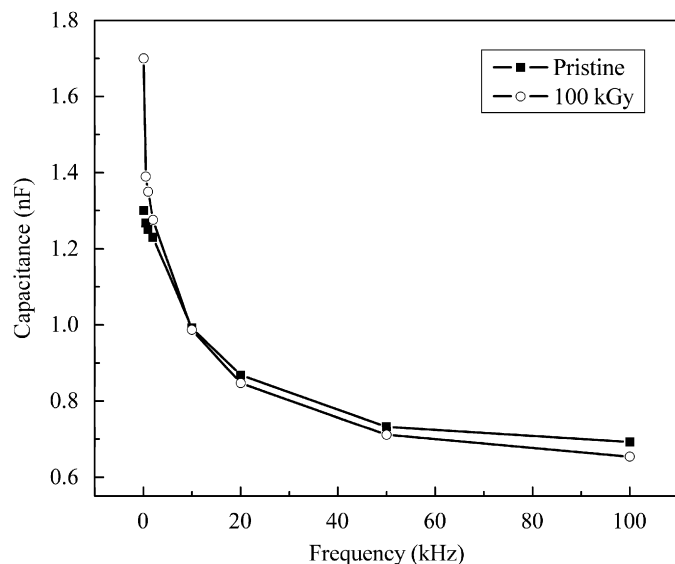


Fig. 5. Variation of capacitance with frequency at 1 V for unirradiated and electron irradiated CdTe/CdS solar cell.

with frequency between unirradiated and irradiated samples is not too large, indicating that irradiation has not contributed significantly to the concentration of deep level defects.

4. Conclusions

The effect of 8 MeV electron irradiation on the properties of CdTe/CdS solar cells under dark and illumination conditions has been studied and the following conclusions were drawn.

An increase in the solar cell parameters was observed at a dose of 0.1 kGy. A large decrease in the values of I_{sc} and η was observed after irradiation at higher doses with only a slight decrease in the values of V_{oc} and FF. As the glass substrate undergoes darkening upon irradiation, the decrease in I_{sc} and efficiency is mainly attributed to the darkening of glass rather than degradation of the semiconductor.

A slight increase in the value of I_s and n values were observed with electron irradiation above a dose of 10 kGy. This may be due to the generation of recombination centers, which decrease the minority carrier diffusion length.

Capacitance variation with frequency indicates that irradiation does not contribute significantly to the increase of deep level defects.

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