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Renewable Energy 26 (2002) 113–120

RENEWABLE ENERGY

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Technical note

Metal-insulator-semiconductor solar cell under gamma irradiation

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Received 27 March 2001; accepted 4 April 2001

Abstract

The performance of a home made MIS–p-Si solar cell was experimentally studied under various gamma irradiation doses (up to 500 Mrad). The effect of radiation dose on the $I-V$ and $C-V$ characteristics was investigated in this work. The obtained results showed that all the output parameters of the cells under investigation were degraded with gamma radiation exposure. In addition, the effects of fabrication conditions (metal thickness and adding of antireflection coating) on the cell output parameters were also investigated.

1. Introduction

The metal-insulator-semiconductor (MIS) structure is currently receiving much attention in both terrestrial and space solar cell research work [1–6]. It has several advantages over the p–n junction due to its low temperature processing and low cost and easy way of fabrication [2,3].

The development of a new generation of highly efficient photovoltaic cells with a suitable radiation resistance (AlGaAs–GaAs, InP, Si, MIS–Si, etc.) is of great interest for future space power applications. The radiative particles (gamma, electrons, protons, etc.) in space create defects inside the solar cell material. These defects are

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0960-1481/02/$ - see front matter
PII: S0960-1481(01)00102-1

mainly acting as recombination centers resulting in a reduction in the carrier's diffusion length [7].

The diffusion length of the MIS–Si solar cell could be degraded by up to 96% in a manner similar to p–n Si-solar cells under the same proton irradiation dose [1,3,8]. However, the gamma radiation effect on the CdS/Si, Si and GaAs solar cells' performance has been reported in previous work [9–11].

This paper deals with the gamma irradiation effect on home made MIS–p-Si solar cell output parameters (I_{sc}, V_{oc}, FF, R_s and η) experimentally. The change in the $I-V$ curve and $C-V$ characteristics with gamma dose (up to 500 Mrad) was also studied in this work. In addition, the effects of different transparent metal thickness values and the adding of antireflection coating on the radiation resistance were investigated experimentally in this study.

2. Experimental work

The solar cells investigated in this work have an Al–SiO_x–p-Si (crystalline) structure. The fabrication was completed in five steps. Initially, the p-type wafers were chemically cleaned and the native oxide was etched using HF acid. In the next step, the aluminum back metallization was deposited using a vacuum coating machine. After that, the wafers were sintered at 450°C for 20 min in a dry N_2 environment for growing the SiO_2 layer over the Si-wafer surface. Additionally, the wafers were placed in an evaporator and heated in vacuum for 1 h at 200°C, then an ultra thin Al-layer was evaporated followed by a deposition of a thick Al-grid using a mechanical mask. Finally, some of these wafers were coated by SiO_2 as an antireflection coating layer (dark blue) using a spinning technique.

Four samples (cell 1, 1A, 2 and 3) were fabricated with different thicknesses for the transparent Al-layer. The transparent Al-layer thickness was increased moving from cell 3 through cell 2 till cell 1 and cell 1A. Additionally, cell 1A — which has the same Al-layer thickness as cell 1 — was coated with a layer of SiO_2 as an antireflection coating.

All the solar cell samples were exposed to energetic (^{60}Co) gamma irradiation with a photon energy of 1.25 MeV and absorbed dose of 500 Mrad. In order to study the degradation mechanism of the MIS-solar cell experimentally, both $I-V$ and $C-V$ characteristics were measured in dark and under illumination (AM0) before and after gamma irradiation exposure. The $C-V$ characteristics were measured using an LCZ meter (HP 4027A) with a frequency range from 10 kHz to 1 MHz and d.c. biasing from -40 to +40 V.

3. Results and discussion

Fig. 1 shows the $I-V$ characteristics for cell 1 at different gamma radiation doses (Mrad). Fig. 2 represents the effect of the radiation dose on the output parameters for cell 1. A deterioration is observed for all cell output parameters as the irradiation

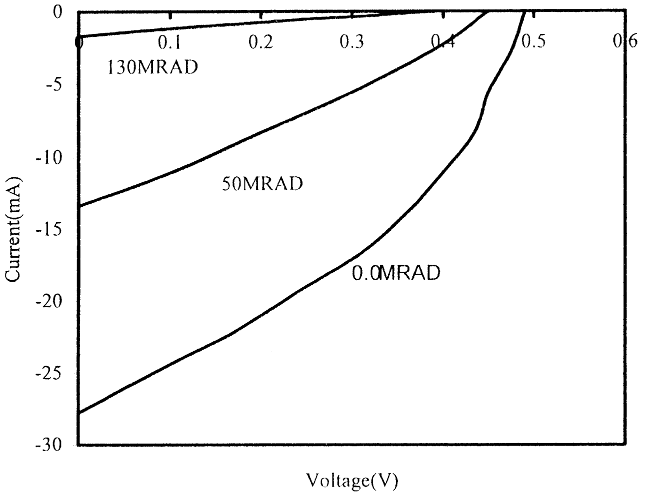

Fig. 1. $I-V$ characteristics for cell 1 at different gamma doses.

dose is increased. The degradation in the short circuit current (I_{sc}) is a non linear function of radiation dose. The bulk diffusion length is related to the dose by the following equation [7]:

$$\frac{1}{L^2}=\frac{1}{L_0^2}+K\phi$$

Where L_0 and L are the diffusion lengths before and after radiation and K and ϕ are the damage coefficient and incident radiative particle density.

A fast degradation rate in I_{sc} is observed at lower dose followed by slow rate at higher doses as shown in Fig. 2(a). The reduction rate in open circuit voltage (V_{oc}) is much slower than that of I_{sc} — as indicated in Fig. 2(b) — due to the logarithmic dependence of V_{oc} on I_{sc}. It is also shown in Fig. 2(e) that the ideality factor (n) increases with irradiation dose due to an increase in radiation induced defects (N_{ss}) [12] as indicated by the incoming relation [13]:

$$n=1+\frac{qd_iN_{ss}}{\varepsilon_i}$$

where d_i and ε_i are the thickness and permittivity of the insulator layer.

The ideality factor is higher than 2 for all dose values due to the existence of different current transport mechanisms [14]. Conversely, the series resistance (R_s) increases with gamma dose — as shown in Fig. 2(d) — which suggests a decrease in the barrier height [15]. As a consequence, the reduction percentages in I_{sc}, V_{oc}, and relative efficiency (η_{rel}) are 98%, 36% and 95% respectively for doses of 210 Mrad. However, there is an increase in the series resistance and ideality factor by 100% and 57% for the same gamma dose.

The relative variation of I_{sc} for different cells (1, 1A, 2 and 3) with gamma

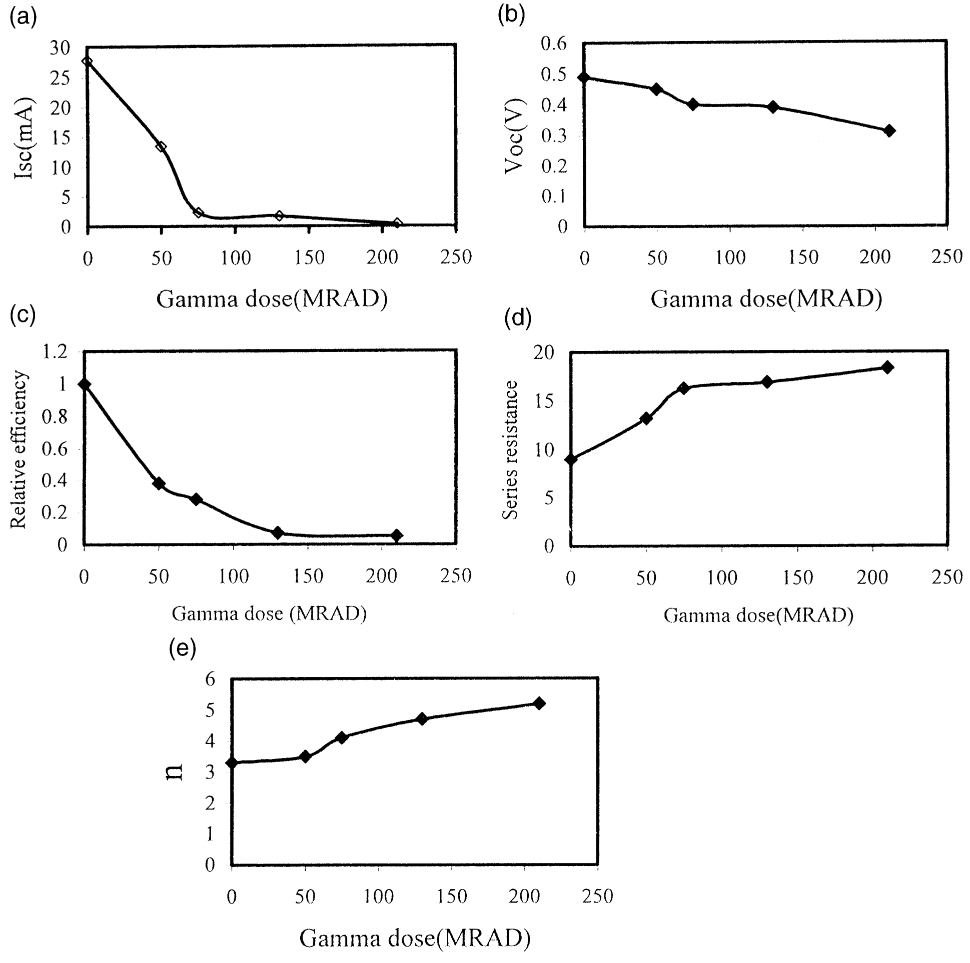

Fig. 2. Variation of the output parameters for cell 1 with gamma dose. (a) I_{sc}, (b) V_{oc}, (c) relative efficiency, (d) series resistance and (e) ideality factor (n).

irradiation dose is illustrated in Fig. 3. It is clear that the thinner the transparent metal thickness, the higher the radiation resistance. The above behavior can be understood by classifying the radiation induced defects into two categories, firstly the bulk defects and secondly the surface defects. Since the MIS solar cell is a surface device, we expected that the former defect would be the dominant one. The degradation could be due to the creation of a radiation defect which compensates the positive charges at the oxide/semiconductor interface [3] and consequently leads to a reduction in the cell output parameters through a reduction in the barrier height [15]. The above mechanism is associated with chemical bonding changes and migration in the transparent Al layer and thin oxide layer [3]. This explains the increase of degradation rate for the cells with thick transparent metal. The effect of adding antire-

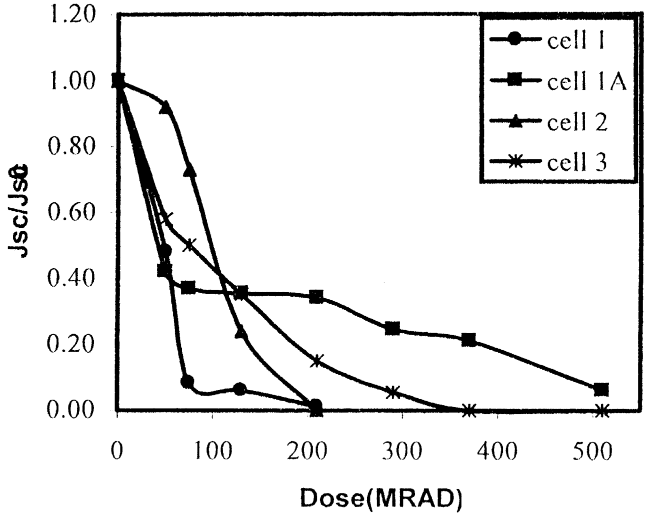

Fig. 3. Variation of the relative short circuit current density with gamma dose value for cells 1, 1A, 2 and 3.

flection coating to cell 1A on the cell performance degradation rate is also illustrated in Fig. 3. The radiation resistance is enhanced by using AR-coating. This effect can be explained by considering the fact that the AR-coating is effective in reducing the induced radiation surface defects [16]. This behavior was confirmed by considering the effect of radiation dose on the $C-V$ characteristics for cell 1 (without AR-coating) and cell 1A (with AR-coating) as shown in Fig. 4, inducing almost no detectable shift for cell 1A while the shift of the $C-V$ curve (Fig. 4) to more positive voltage for cell 1 with radiation dose, is partially due to the compensation of positive oxide charges by induced defects at the Si/SiO_2 interface which lowers the band bending and also the bulk defects [17].

The variation of the barrier height is estimated by considering the following expression of the junction capacitance [18]

$$\frac{1}{C^2}=\frac{1}{qN_a\varepsilon_s}(V-V_{bi})$$

where ε_s is the semiconductor permittivity, N_a is the concentration of the acceptor atoms and V_{bi} is the built-in potential.

Fig. 5 shows a plot of $1/C^2$ vs applied voltage for cell 1. A reduction in the build in potential and hence a reduction also in barrier height are obtained with increasing the radiation dose. The passivation of the cell surface by using AR-coating which leads to a minor shift in the $C-V$ curve (Fig. 4) suggests that the higher shift in the $C-V$ curve (Fig. 4) is mainly attributed to the surface defects. The existence of the interface states is confirmed by considering $C-V$ curve shift to a higher capacitance value with a decrease in frequency for radiation doses of 50 Mrad as shown in Fig. 6.

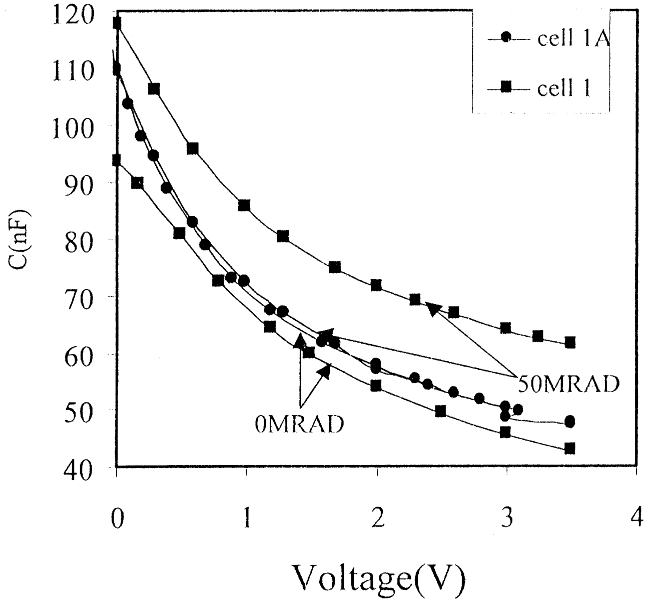

Fig. 4. $C-V$ characteristics for cell 1 and 1A at 10 kHz and before and after a gamma dose of 50 Mrad.

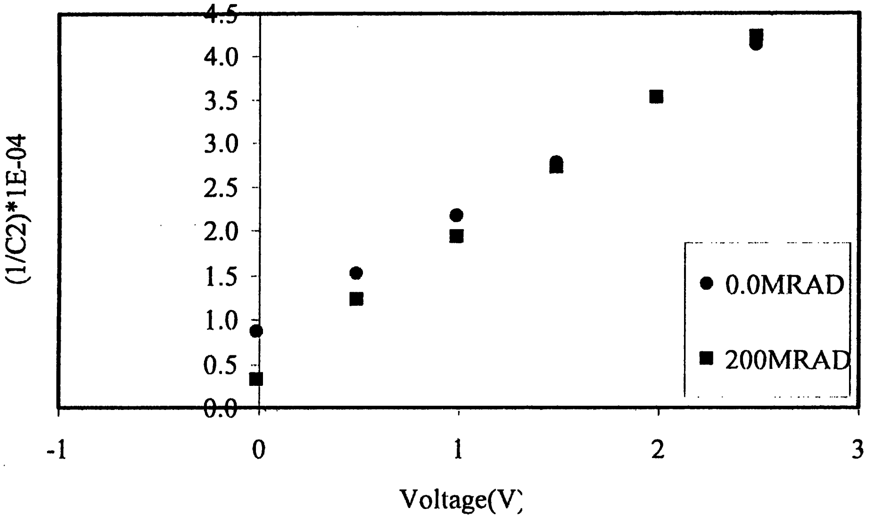

Fig. 5. $(1/C^2)$ vs voltage for cell 1 at 10 kHz and before and after a gamma dose of 200 Mrad.

4. Conclusion

The degradation in the performance of the MIS p-Si solar cell was studied under various fabrication conditions and gamma irradiation doses. A deterioration was

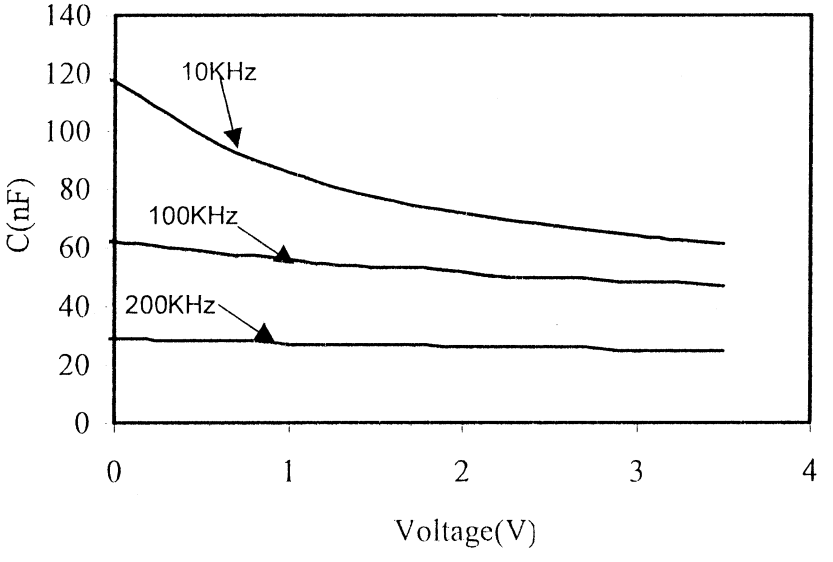

Fig. 6. $C-V$ characteristics for cell 1 under a gamma dose of 50 Mrad at different frequencies.

observed for all output parameters of the cell with increasing radiation dose. On the other hand, the $C-V$ characteristic manifests that there is an increase in the interface states at the insulator/semiconductor interface after exposure to gamma radiation. The radiation resistance of the MIS cell was enhanced as the thickness of the transparent Al-layer is decreased, as well as for cells with antireflection coating.

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