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Gamma-Ray Irradiation Effects on CdTe Solar Cell Dosimeter

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Abstract

In this paper, compact and higly radiation-tolerant radiation dosimeter without voltage-bias application using solar cell such as CdTe is proposed for severe radiation environment near a nuclear reactor pressure vessel. First, γ-ray tolerance of a CdTe solar cells was investigated. It was found that the CdTe solar cell has sufficient tolerance against γ-ray exposure with greater than 3 MGy. It was demonstrated that γ-ray induced current density increased linearly with increasing γ-ray intensity in the range up to approximately 1.5 kGy/h. In addition, γ-ray sensitivity was successfully increased by a stack of CdTe solar cells with parallel connection.

1. Introduction

Radiation measurement technology is one of the most important issues to establish safety for decommissioning the Fukushima Daiichi nuclear power station (FDNPS), because dose distribution measurement for identification of fuel debris location, and radiation level monitoring during decommission works are necessary. Therefore, developing a high dose-rate radiation detection system functioning under severe environment such as high-level radiation, high temperature and high humidity is required. Gamma dose-rates near the reactor pressure vessel (RPV) are predicted to be as high as >100 Gy/h, because the nuclear fuel debris and ^{137}Cs are being trapped [1]. In addition, no power operation is desired for detector in view of minimizing a danger of explosion due to residual hydrogen in the reactors. Furthermore, a compact detector is required in order to be able to introduce the detector through a small hole with a diameter of approximately 10 cm. We have proposed a radiation dosimeter using a solar cell, which do not require voltage bias application. Furthermore, the proposed dosimeter has the features of ultra-compactness, lightweight, and high radiation tolerance. In this work, we investigated the γ-ray tolerance and the γ-ray detection characteristics of CdTe solar cell detector.

2. Experimental Procedure

In this work, we employed superstrate-type polycrystalline CdTe thin-film solar cells with a glass / indium tin oxide (ITO) / n-CdS / p-CdTe structure. The CdTe (approximately 6 μm in thickness) and CdS (approximately 60 nm in thickness) polycrystalline thin films were fabricated using close-spaced sublimation (CSS) and chemical vapor deposition (CVD) techniques, respectively [2-4].

For evaluation of γ-ray tolerance and γ-ray induced current generation, we utilized the ^{60}Co γ-ray source facility at Institute for Integrated Radiation and Nuclear Science, Kyoto University. In the case of γ-ray tolerance evaluation, the γ-ray dose rate was set to be approximately 1~1.5 kGy/h [5], while in the case of γ-ray induced current measurement, the dose rate was varied in the range from 0.21 to 1.58 kGy/h by adjusting the distance from the ^{60}Co γ-ray source to the sample.

3. Gamma-ray tolerance of the CdTe solar cells

First, γ-ray tolerance of the CdTe solar cells was investigated. γ-ray irradiation was divided into multiple time-frames. After reaching each γ-ray dose, current-voltage (*I-V*) characteristics of the cells were measured under simulated solar light (AM 1.5, 100 mW/cm^2) without γ-ray exposure. Final γ-ray dose was 3.04 MGy.

The short-circuit current decreased in the early stage of dose because of coloring of the glass substrate due to γ-ray absorption [5], but essential cell degradation was not observed. As a result, the CdTe solar cell was found to have sufficient tolerance against γ rays with greater than 3 MGy.

4. Gamma-ray-induced current of CdTe solar cells

Figure 1 shows typical *I-V* characteristics of the CdTe solar cell under the γ-ray irradiation. The current generation due to carriers by γ-ray absorption was observed as solar cell operation under light. The current density increased with increase of the γ-ray dose rate. Figure 2 indicates the dependence of generated current density of the CdTe solar cell on γ-ray dose rate with various reverse bias voltages. Radiation-induced current density increased linearly in the range up to approximately 1.5 kGy/h. Note that even in the case that the applied voltage is zero, significant current generation and its linearity can be confirmed. This result suggests that dose rate can be measured using the solar cells without voltage application. The slope of current density increased with increase in the reverse bias voltage which is probably due to increase of the depletion layer width owing to the reverse bias. These results suggest that the increase in the thickness of CdTe absorption layer would be effective for improvement of γ-ray sensitivity.

In order to improve the sensitivity of CdTe dosimeter devices, we propose stacking the CdTe solar cells with parallel connection. Figure 3 depicts the dependence of current density of a stacked two CdTe solar cells with parallel-connection on dose rate of irradiated γ rays (no bias voltage). The current densities of each of the CdTe solar cells placed on (a) top and (b) bottom in the stack are also shown. The induced current was found to increase linearly with increase in the dose rate, and the induced current density of the stacked cells coincided with the summation of (a) and (b). This result indicates that γ-ray sensitivity was successfully improved by applying the stacked structure with parallel connection.

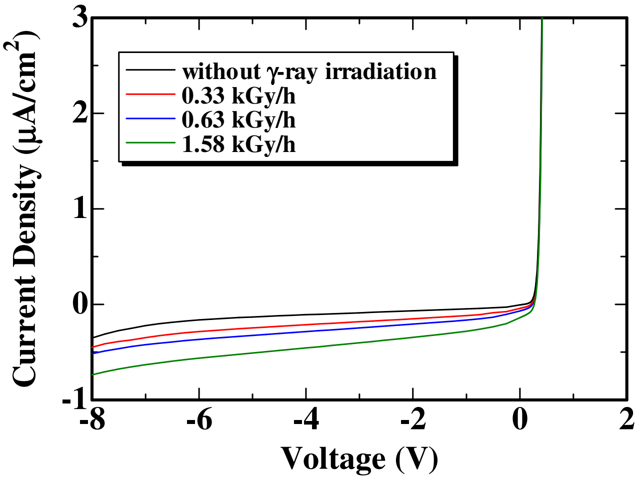

Fig. 1 *I-V* characteristics of the CdTe solar cell under the γ-ray irradiation.

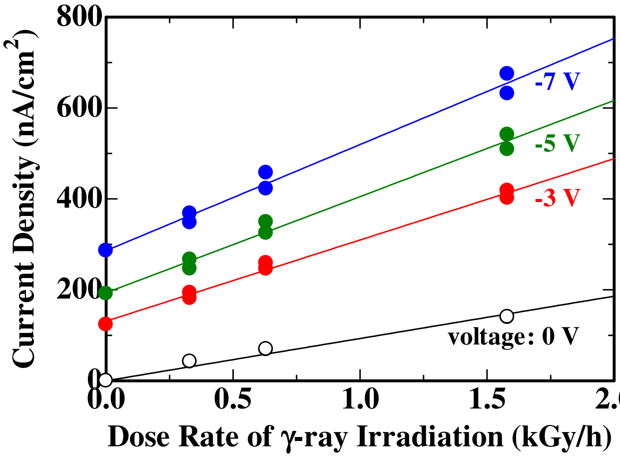

Fig. 2 Dependence of current density of the CdTe solar cell on irradiated γ-ray dose rate with various reverse bias voltages.

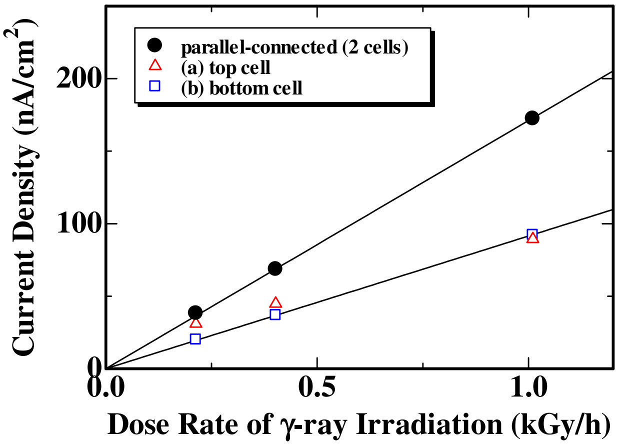

Fig. 3 Dependence of current density of the stacked two CdTe solar cells with parallel-connection on irradiated γ-ray dose rate (no bias voltage application). The current densities of the CdTe solar cells placed as (a) top cell and (b) bottom cell in the stack are also shown.

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