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MCz diode response as a high-dose gamma radiation dosimeter

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Abstract

This work presents the preliminary results obtained with a high-resistivity magnetic Czochralski (MCz) silicon diode processed at the Helsinki Institute of Physics as a high-dose gamma dosimeter in radiation processing. The irradiation was performed using a ^{60}Co source (Gammacell 220, MDS Nordion) within total doses from 100 Gy up to 3 kGy at a dose rate of 3 kGy/h. In this interval, the dosimetric response of the diode is linear with a correlation coefficient (r^2) higher than 0.993. However, without any irradiation procedure, the device showed a small sensitivity dependence on the accumulated dose. For total dose of 3 kGy, the observed decrease was about 2%. To clarify the origin of this possible radiation damage effect, some studies are under way.

Keywords: Gamma dosimetry; Silicon diode; High-dose; MCz diode; Rad-hard Si diode

1. Introduction

Silicon detectors have been used for many years in a variety of nuclear and particle physics experiments that require good energy and spatial resolution, high efficiency, fast response, low sensitivity to magnetic fields and noncryogenic operation. However, some future high energy physics experiments have demanded the development of silicon detectors which can be used to perform in extremely harsh radiation levels. Recent technological advances have led to the production of high-resistivity magnetic Czochralski (MCz) silicon which has become a promising material for the development of radiation tolerant detectors (Härkönen et al., 2005a, b; RD50 Status Report, 2002/2003; Luukka, 2006).

This work presents the preliminary results obtained with a rad-hard MCz silicon diode processed at the Helsinki Institute of Physics as a high-dose gamma dosimeter in radiation processing.

2. Material and methods

The MCz diode consisted of n-type bulk material with p^+-implants for the pad of the detector (Härkönen et al.,; 2005a, b Luukka, 2006). The device, with approximately 0.36 cm^2 area and 300 μm thickness, has a multiple guard ring (MGR) structure around the contact pads as can be seen in Fig. 1.

In order to use the diode as a dosimeter, it was enclosed in a chamber of black PMMA to provide protection from mechanical stress, light and moisture. Without any pre-irradiation procedure, the guard rings were left floating and the signal electrode (p^+) was connected through low-noise coaxial cables to the input of a Keitley 670 electrometer.

The irradiation was performed using a ^{60}Co source (Gammacell 220, MDS Nordion) at a dose rate of 3 kGy/h with traceability through the International Dose Assurance Services (IDAS) from IAEA. The diode was placed in the central position of the Gammacell and the exposure times were selected to achieve total doses from 100 Gy up to 3 kGy.

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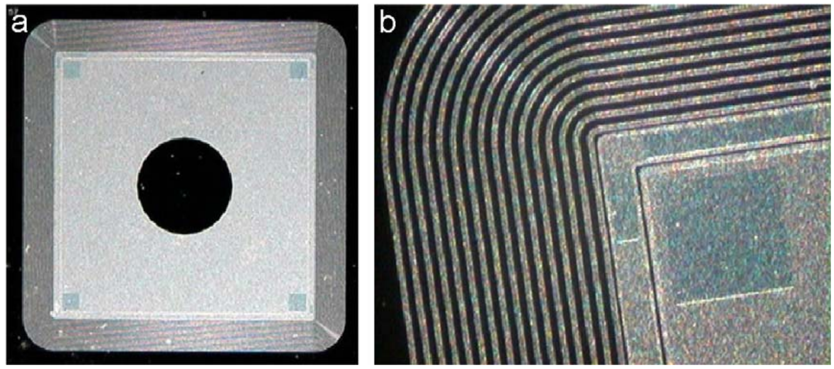

Fig. 1. The MCz diode photographs. (a) General view. (b) Detail of MGR structure and pads.

3. Results

The dynamic current and capacitance measurements of the device were measured in a voltage range between 0 and 500 V. The leakage current of the unbiased diode at room temperature (typically 22 °C) was 3.2 pA. The capacitance results obtained (Fig. 2) showed that for voltages above 305 V the capacitance does not change significantly, which led us to expect the same behavior for the diode's depletion zone thickness. Indeed, at this condition, the diode was fully depleted and the depletion region depth was estimated as being 300 μm.

The current response of the unbiased MCz diode during irradiation with ^{60}Co gamma sources, under 100 Gy of total dose, is shown in Fig. 3. The leakage current was subtracted from the photocurrent measurements performed with the electrometer adjusted for timing resolution of 10 s.

The photocurrent signal was stable during the irradiation and it was about 10^6 higher than the dark current of the diode. Indeed, the average radiation-induced current was about 4.8 μA at a dose rate of 3 kGy/h. The rise time of the current response when the radioactive source was switched on was about 1.5 s.

However, even when irradiated at the same dose rate, the photocurrent of the diode for higher total doses decreased during the exposure time, as can be seen in Fig. 4. This current response of the diode, exposed to a total dose of 3 kGy, showed a current relative variation of about 2% during the exposure time. This behavior may be related to some damage effects associated with the generation of traps in the crystal structure. In spite of this apparent sensitivity dependence on the accumulated dose, the MCz diode's response as a function of the gamma-ray doses in the range of 100 Gy to 3 kGy was quite linear as can be seen in Fig. 5. Indeed, the released charge obtained by integrating the current curves over the irradiation time as a function of the total dose shows a linear response with a correlation coefficient (r^2) higher than 0.993.

However, for a total dose of 3 kGy, it is possible to observe a tendency for saturation. To clarify this possible damage effect and to extend the dose range of applications of this diode, some studies are underway. The first approach is to pre-irradiate the diode with higher doses and measure the current signal as a function of the time to achieve the stable response of this device.

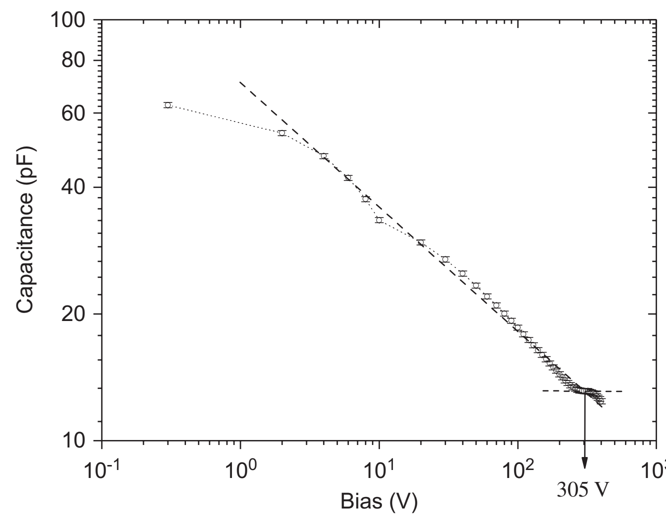

Fig. 2. CV curve of the MCz diode.

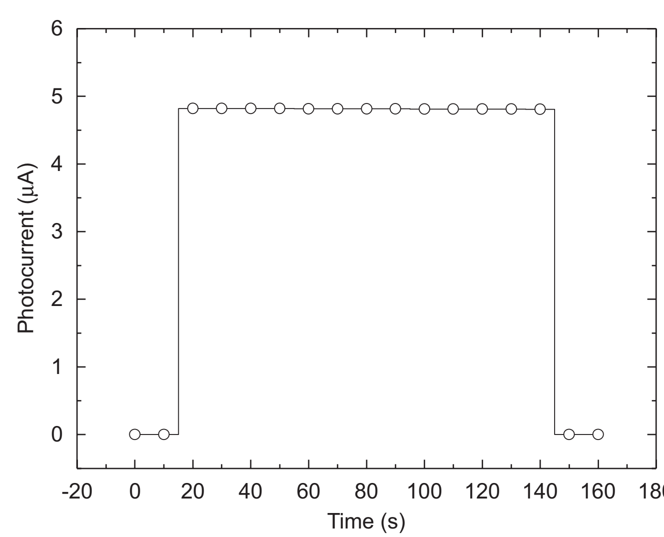

Fig. 3. MCz diode photocurrent as a function of time for 100 Gy. Time resolution of electrometer is 10 s.

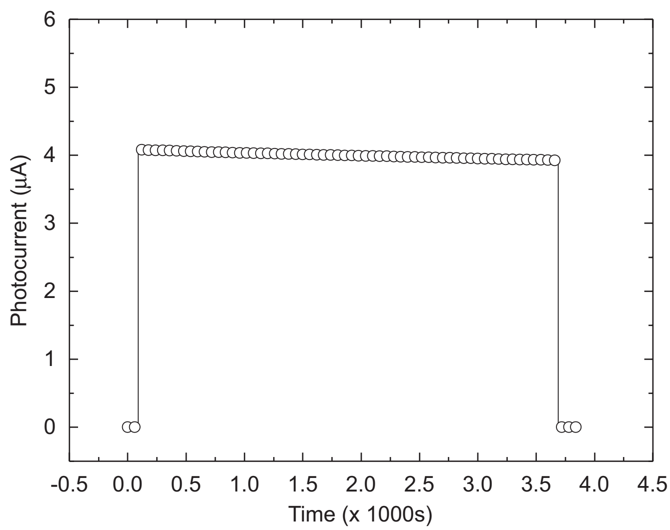

Fig. 4. MCz diode photocurrent as a function of time for 3 kGy. Time resolution of electrometer is 60 s.

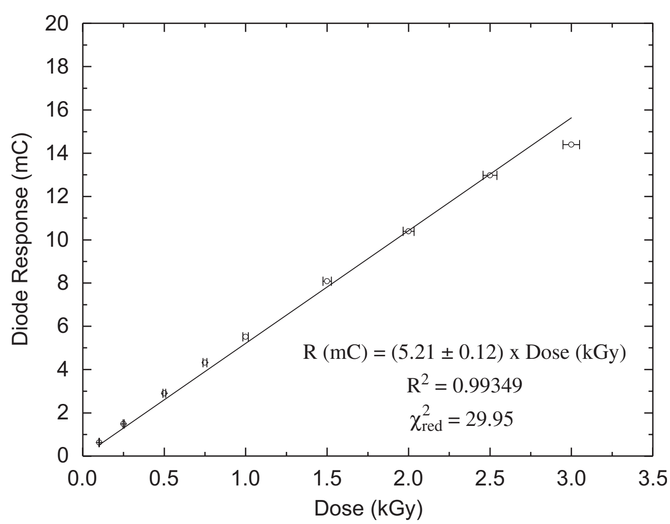

Fig. 5. MCz diode response as a function of doses at room temperature.

The reproducibility of the MCz dosimetric performance still remains to be investigated.

4. Conclusions

Despite being preliminary, the results obtained have shown that the MCz diode can be used as a dosimeter for gamma doses up to 3 kGy with linear response. However, the device showed a small sensitivity dependence on the accumulated dose. Indeed, when the diode was exposed to a total dose of 3 kGy, the correspondent photocurrent decreased during the exposure time with a relative variation of about 2%. To clarify the origin of this possible radiation damage effect, some studies are under way.

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