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Evaluation of a multi-guard ring (MGR) structure diode as diagnostic X-ray dosimeter

F. Camargo[a], H.J. Khoury[b], C.R. Nascimento[b], V.K. Asfora[b], C.C. Bueno[a,c,*]

[a]Instituto de Pesquisas Energéticas e Nucleares IPEN-CNEN/SP, Caixa Postal 11049, São Paulo SP 05422-970, Brasil
[b]Universidade Federal de Pernambuco, Av. Prof. Luiz Freire 1000, Recife PE 50740-540, Brasil
[c]Pontifícia Universidade Católica de São Paulo, Rua Marquês de Paranaguá 111, São Paulo SP 01303-050, Brasil

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Abstract

In this paper, we describe the results obtained for the evaluation of a multi-guard ring (MGR) structure diode as diagnostic X-ray dosimeter. This device was developed in the framework of R&D programs for the future CMS experiment at the Large Hadron Collider (LHC) with high radiation hardness to fulfill the requirements from this accelerator environment. In order to use the MGR diode as a dosimeter, it was connected in the photovoltaic mode to the input of an integrating electrometer and positioned at the center of an X-ray beam, beside a previously calibrated ionization chamber. The dependence of the diode response on the X-ray beam doses was evaluated for 35–90 kV X-ray generator bias supply, with doses in the range of 50 μGy–5 mGy. The good linearity of the dose–response curve obtained showed the MGR diode dosimeter to be a reliable alternative method for diagnostic X-ray dosimetry.

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Keywords: Silicon detector; Photon dosimetry; Radiation protection; Rad-hard silicon detector; X-ray dosimetry

1. Introduction

The widespread application of silicon diodes in several branches of science [1–8] has been motivated by the development of devices that exhibit low leakage current, moderate capacitance and thin dead layers [9–10]. However, radiation damage in standard silicon detectors imposes constraints on their applicability in harsh environments such as those found in nuclear physics and elementary particle laboratories. Indeed, there has been a great effort to improve the radiation tolerance of Si devices in the framework of R&D programs for the future experiments at the Large Hadron Collider (LHC) [11–12]. To fulfill the requirements of this accelerator environment, a rad-hard silicon diode with a multi-guard ring (MGR) structure, which posseses low leakage current and excellent timing properties, was developed for the CMS experiment [13]. These diode characteristics encouraged us to investigate its performance for diagnostic X-ray dosimetry.

2. Experimental setup

The MGR diode, with active area of 4 mm^2, was processed out of 300 μm thick n-type substrate with a resistivity of about 3.0 kΩ × cm. The frontal layer (p^+) was created by ion implantation, type (Al/p+/n/n+/Al), and had an MGR structure [10] around the contact pad (Fig. 1). The thicknesses of the Al (maximum 2 nm) and SiO_2 (650 nm) front layers of the diode were measured by RBS technique at the Laboratory of Material Analyses by Ion Beams (LAMFI) of São Paulo University.

Measurements of leakage current density (current per unit of useful area) and capacitance of this device as a function of the reverse bias voltage are presented in Figs. 2 and 3, respectively.

It is observed that the leakage current density, measured with a Semiconductor Parameters Analyzer (HP4156C),

*Corresponding author. Instituto de Pesquisas Energéticas e Nucleares IPEN-CNEN/SP, Caixa Postal 11049, São Paulo SP 05422-970, Brasil. Tel.: +55 11 3816 9292x248; fax: +55 11 3816 9186.
E-mail address: ccbueno@ipen.br (C.C. Bueno).

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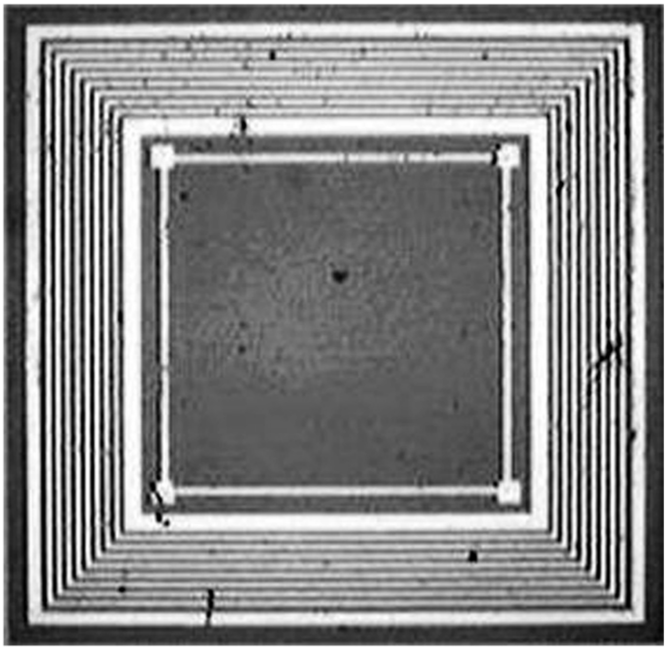

Fig. 1. Photograph showing the diode's multi-guard ring structures, signal electrode and effective area.

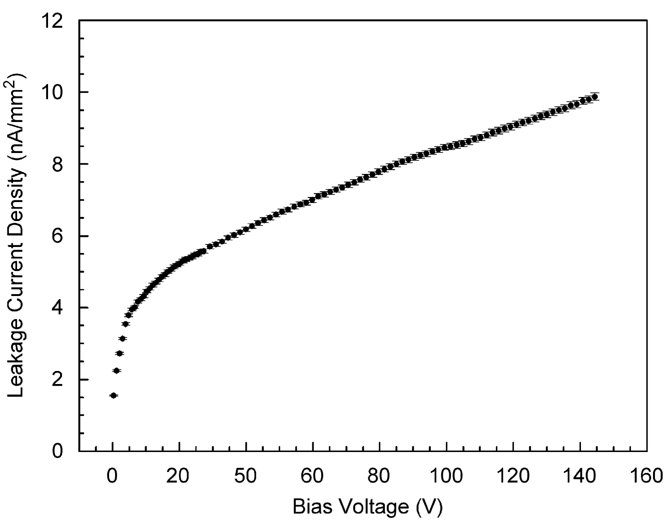

Fig. 2. Diode's leakage current density as a function of the bias voltage. The guard-rings are floating.

increases with voltage, but even when 100 V is applied, its value never exceeded $10\,nA/mm^2$. On the other hand, the diode's capacitance, measured at a frequency of 1 MHz with a computer-based Capacitance Measurement System (Keithley K182CV), decreases with a polarization bias as a result of the depletion layer growth. It can be seen that for voltages above 40 V the capacitance does not decrease further significantly, which led us to expect the same behavior for the diode's depletion zone thickness. At this condition, the depletion region depth was estimated as being 300 μm.

In order to use the MGR diode as dosimeter, it was connected in the photovoltaic mode to the input of the

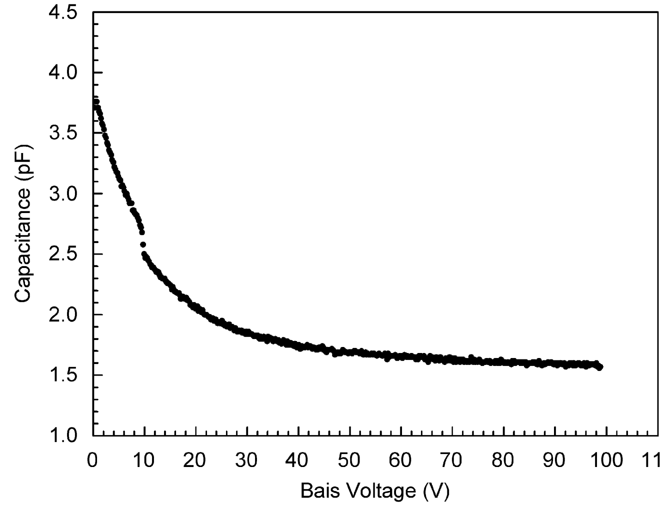

Fig. 3. Diode's capacitance as a function of the bias voltage.

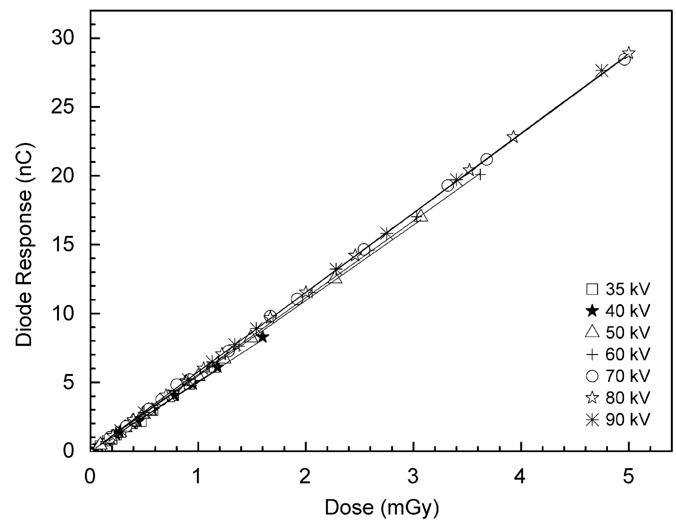

Fig. 4. Diode response for different X-ray generator bias supply and the same total filtration of 2.5 mm Al.

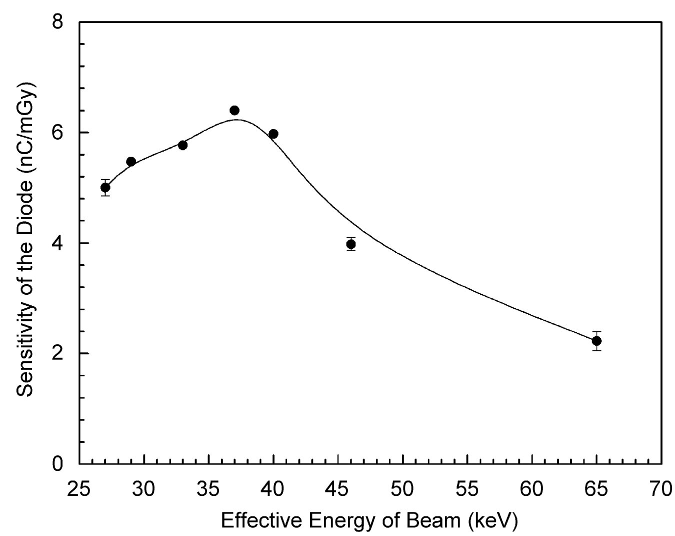

Fig. 5. Sensitivity of the MGR diode as a function of the beam effective energy.

integrating electrometer of Standard Imaging, model CDX 2000A, which has the range from 0.01 to 999,999.99 nC and a leakage current of 10^{-15} A at STP. Initially, the reproducibility of the MGR diode response was evaluated by consecutively irradiating the diode with the same dose. Measurements of the dose–response curve were performed with the device positioned at the center of a 20 cm × 20 cm X-ray beam, beside a Radical 2026C previously calibrated ionization chamber. The X-ray equipment used for the irradiation of the detectors was a diagnostic set (EDR 750B) with a three-phase generator and an X-ray tube with total filtration of 2.5 mm Al. By changing the additional filtration and the bias supply, it was possible to modify the X-ray beam energy in order to evaluate the energy dependence response of the MGR diode.

3. Results

The results of 10 consecutive measurements taken for the same dose and irradiation parameters indicated that the response of the MGR diode is reproducible within $\pm 1.8\%$.

Fig. 4 shows the results of the MGR response to X-ray beams for doses in the range of 50μGy–5 mGy, where each point represents the average of three measurements. The figure shows the results obtained with different X-ray generator bias supply and the same total filtration of 2.5 mm Al. The correlation coefficient (r^2) was, in all cases, higher than 0.9997, indicating that the device has a linear dose–response relationship in the range of doses investigated.

Fig. 5 shows the response of the diode versus the effective energy of the X-ray beam. It is observed that the energy dependence curve of the MGR is higher than that for ionization chambers. This behavior can be explained by the higher effective atomic number of the semiconductor junction.

4. Conclusion

The data obtained in this work compared with the response of ionization chambers and commercial diode dosimeters led us to conclude that the MGR device is suitable to be used in X-ray dosimetry.

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References

[1] C.C. Bueno, et al., Appl. Rad. Isotop. 61 (2004) 1343.
[2] C.C. Bueno, et al., Nucl. Instr. and Meth. A 371 (1996) 460.
[3] J.P. Kirkland, et al., Nucl. Instr. and Meth. A 266 (1988) 602.
[4] R. Cesareo, et al., Nucl. Instr. and Meth. A 428 (1999) 171.
[5] J.I. Trombka, et al., Nucl. Instr. and Meth. A 428 (1999) 199.
[6] V.R. Murty, K.R.S. Devan, Rad. Phys. Chem. 61 (2001) 495.
[7] N.A. Pavel, Nucl. Instr. and Meth. A 478 (2002) 1.
[8] C.R. Appoloni, et al., X-ray Spectr. 31 (2) (2002) 124.
[9] C.C. Bueno, et al., Nucl. Instr. and Meth. A 533 (2004) 435.
[10] J.A.C. Gonçalves, et al., IEEE Nucl. Sci. Symp. Rec. 3 (2004) 1928.
[11] RD50 Status Report 2004; CERN-LHCC-2004-031, LHCC-RD-005 available in 〈http://cern.ch/rd50/〉.
[12] M. Moll, Nucl. Instr. and Meth. A 565 (2006) 202.
[13] K. Borer, et al., Nucl. Instr. and Meth. A 440 (2000) 5.