2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-03-8

RESPONSE OF STFZ DIODE AS ON-LINE GAMMA DOSIMETER IN RADIATION PROCESSING

Fábio de Camargo[1*], Josemary A. C. Gonçalves[1,2], Kelly C. S. Pascoalino[1], Eija Tuominen[3], Esa Tuovinen[3], Jaakko Härkönen[3] and Carmen C. Bueno[1,2†]

[1] Instituto de Pesquisas Energéticas e Nucleares – IPEN-CNEN/SP
Caixa Postal 11046
05422-970 São Paulo, SP
[*]fcamargo@ipen.br – [†]ccbueno@ipen.br

[2] Pontifícia Universidade Católica de São Paulo – PUC/SP
Rua Marquês de Paranaguá, 111
01303-050 São Paulo, SP

[3] Helsinki Institute of Physics – HIP
University of Helsinki
P.O. Box 64
00014 Helsinki, Finland

ABSTRACT

In this work, it is presented the results obtained with this rad-hard STFZ silicon diode as a high-dose gamma dosimeter. This device is a $p^+/n/n^+$ junction diode, made on FZ Si wafer manufactured by Okmetic Oyj., Vantaa, Finland and processed by the Microelectronics Center of Helsink University of Technology. The results obtained about the photocurrent registered and total charge accumulated on the diode as a function of the total absorbed dose are presented. The diodes's response showed a significant saturation effect for total absorbed doses higher than approximately 15 kGy. To reduce this effect, some STFZ samples have been pre-irradiated with gamma rays at accumulated dose of 700 kGy in order to saturate the trap production in the diode's sensitive volume.

1. INTRODUCTION

Recent developments of radiation tolerant silicon diodes for future high-luminosity High Energy Physics (HEP) experiments at the Large Hadron Colider (LHC) accelerator [1,2] have foreseen applications of these devices in other branches of science [3,4]. In particular, in this work we report on results obtained with a rad-hard Standard Float Zone (STFZ) silicon diode as a high-dose gamma dosimeter for future applications on radiation processing [5]. The dosimetric probe, based on the STFZ device, was designed to operate without bias voltage in the direct current mode as on-line radiation dosimeter. The main advantage of recording real time currents, and consequently dose rates, is to provide continuous data of dose delivered to the product for quality assurance in radiation processing.

The article is outlined as follows: the experimental setup and procedure utilized to study the response of the diode as a high dose gamma dosimeter are described in section 2. The results obtained and discussion about the photocurrent registered and total charge accumulated on the diode as a function of the dose are presented in section 3. The last section is reserved for conclusions.

2. EXPERIMENTAL SETUP

The $p^+/n/n^+$ junction device used (with an active area of 25 mm^2) was made on FZ Si wafers of 300 μm thickness and resistivity about 1400 Ω·cm. This diode has a multiple guard ring (MGR) structure and it was manufactured by Okmetic Oyj (Vantaa, Finland) and processed by the Microelectronics Center of Helsinki University of Technology in the framework of the CERN RD50 Collaboration. Two diodes with similar characteristics from I/V and C/V standard measurements, hereafter referred as FZ#54 and FZ#75, were used in this work. The FZ#54 was not irradiated before using as a dosimeter, while the FZ#75 received a gamma pre-dose of 700 kGy.

Figure 1 shows the dosimetric probe where each diode was put inside a small PolyMethilMetacrylate (PMMA) box to be protected from moisture, light and mechanic vibrations. All guard rings were left floating while the back plane (n^+) of the device was properly grounded. The p^+ front electrode was directly connected, via a 2 m long 50 Ω coaxial cable, to a Fluke 189 multimeter (time resolution of 4 s). The data were acquired with the FlukeView Forms® software. A schematic diagram of the experimental setup used during the measurements is showed in the Figure 2.

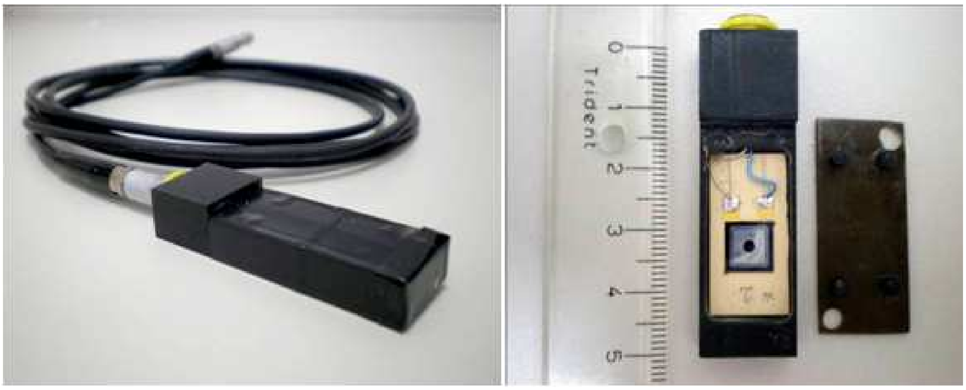

Figure 1. Dosimetric probe based on STFZ diode.

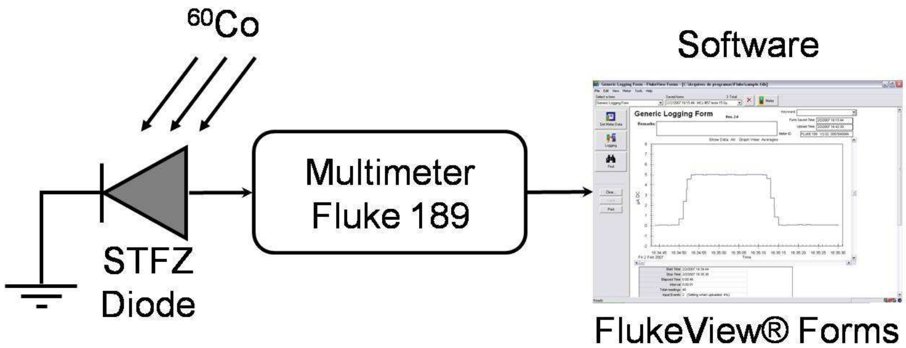

Figure 2. Schematic diagram of the experimental setup used during the measurements.

The irradiation was performed at IPEN-CNEN/SP using a ^{60}Co source (Gammacell 220 – MDS Nordion) at a dose rate of ≈ 2.3 kGy/h with traceability through the International Dose Assurance Services (IDAS) from International Atomic Energy Agency (IAEA). With no bias voltage, the diode was placed in the central position of the ^{60}Co irradiation chamber and irradiated in consecutive steps from 5 kGy up to 50 kGy to achieve an accumulated dose of 275 kGy. It took approximately 120 h irradiation time to reach the total absorbed dose in device. After each step, the source was switched off to measure the current noise of the dosimetric probe. The temperature during exposure was typically 25 ± 3 ºC.

3. RESULTS

The current response of the FZ#54 diode under ^{60}Co gamma radiation within different exposure times is shown in Figure 3. The sensitivity dependence on the dose is clearly evidenced by a fast decay of the diode's photocurrent for accumulated doses of about 30 kGy, followed by a slower decrease at higher doses.

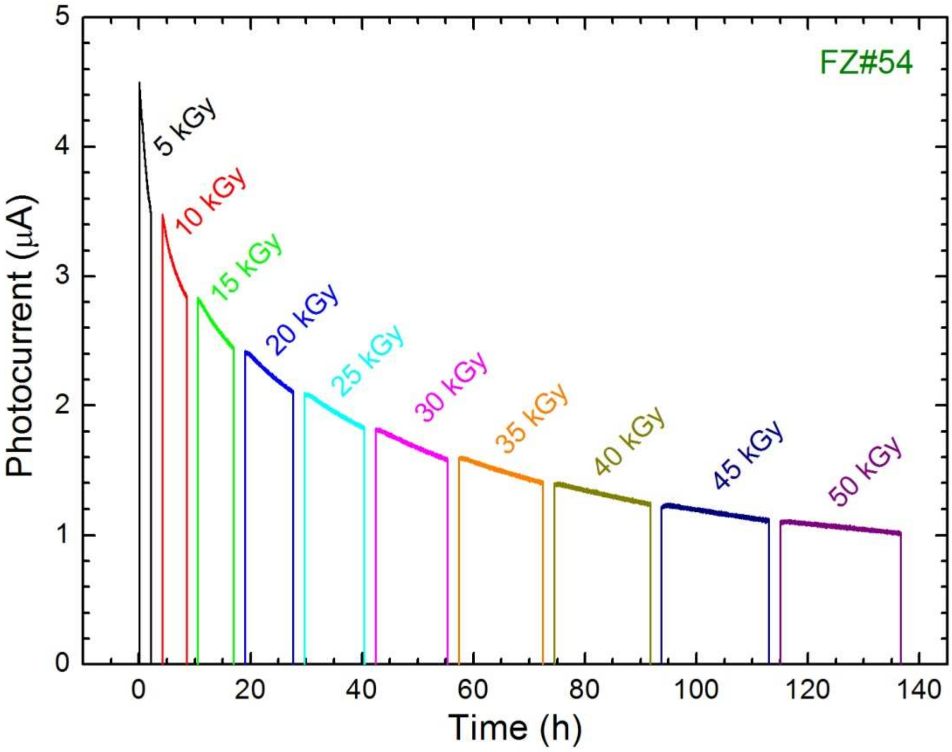

Figure 3. Current response of the FZ#54 diode for successive exposure times at 2.33 kGy/h.

From Fig.2, it was expected a less pronounced sensitivity decay at accumulated doses higher than approximately 300 kGy. In order to improve the diode response stability, by reducing its sensitivity dependence on the dose, the FZ#75 sample was pre-irradiated with ^{60}Co gamma rays with a dose of about 700 kGy.

Indeed, in Figure 4, the current response of the FZ#75 diode, evaluated for accumulated doses up to 275 kGy, presents very stable current signals. For a dose rate of 2.31 kGy/h, the average photocurrent value was about 0.6 μA. It is important to note that, even being less sensitive, the unbiased diode photocurrent to dark current ratio is about 10^3.

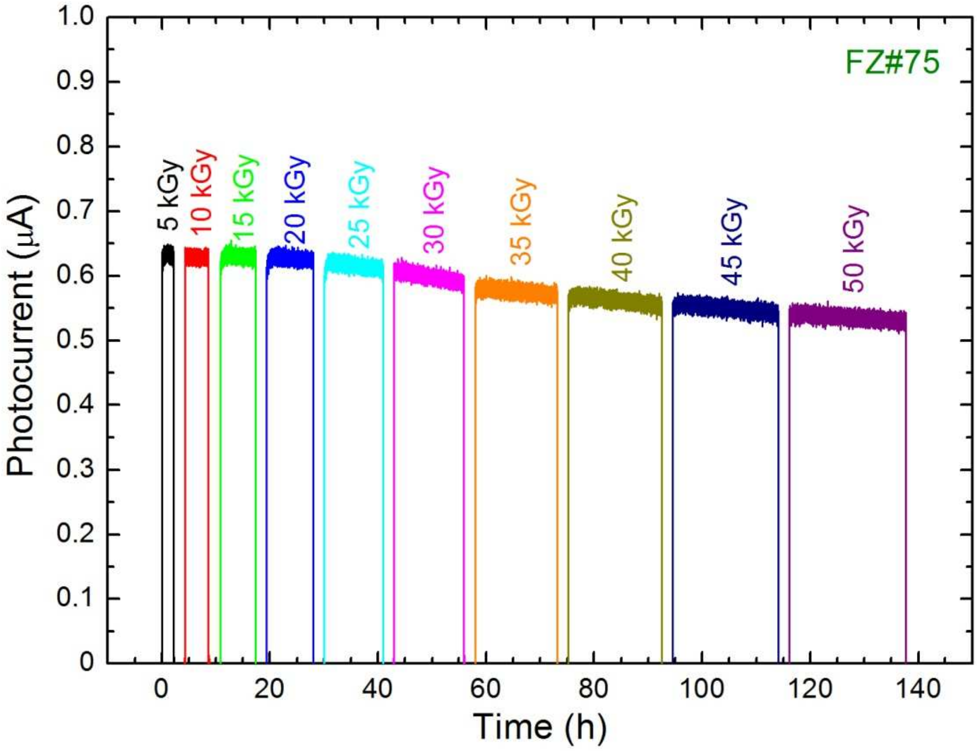

Figure 4. Current response of the FZ#75 diode for successive exposure times at 2.31 kGy/h.

To compare the stability response of the FZ#54 and FZ#75 devices, the average current signals of each exposure, normalized to the average current at 5 kGy of both diodes, are plotted in Figure 5 as a function of the accumulated dose up to 300 kGy. Within this dose range, the sensitivity decrease of FZ#75 was only 10%, against 70% for FZ#54.

This stability is also evidenced in Figure 6 which shows the released charge in both devices, obtained by integrating the current signals over the exposure times, as a function of the accumulated dose. As can be seen, for doses higher than 15 kGy the FZ#54 shown a significant saturation, probably due to point defects created in its volume by the gamma radiation. Conversely, within the whole dose range it was observed a quadratic response of the FZ#75 device with a correlation coefficient (R^2) of 0.99998 as was shown in the Figure 6. These results suggested that pre-irradiation with 700 kGy was enough to achieve the stable response of this device.

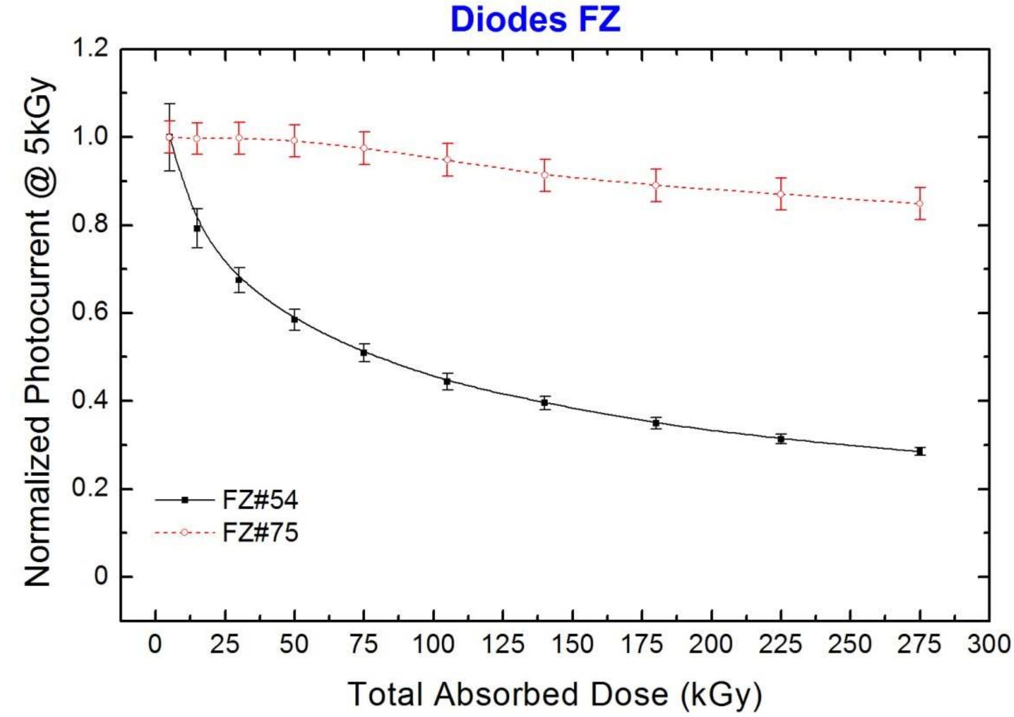

Figure 5. Average current signals of each successive exposure, normalized to the average current at 5 kGy of both diodes, as a function of the total absorbed dose.

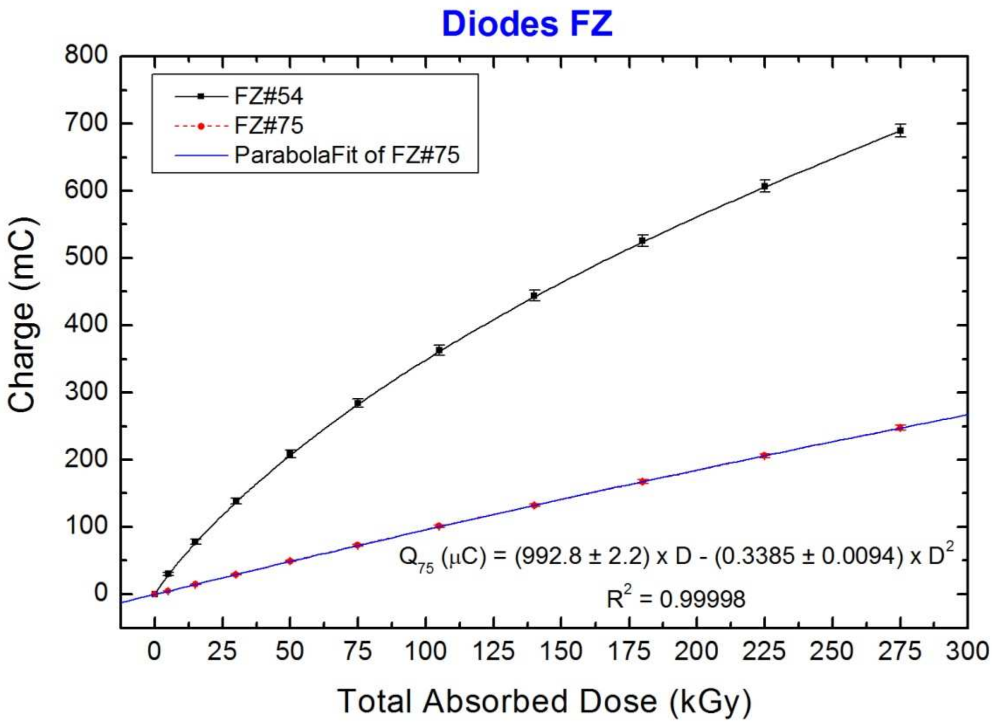

Figure 6. Dosimetric response of FZ #54 and #75 devices as a function of the total absorbed dose.

4. CONCLUSIONS

STFZ diodes have been characterized as on-line ^{60}Co gamma radiation dosimeters from 5 kGy up to 275 kGy. In this dose range, the sensitivity decrease of the FZ#54 diode was about 70% which led to a significant saturation on its charge versus dose response. This effect, due to gamma radiation induced point-defects in the crystal bulk, was reduced by pre-irradiating the FZ#75 diode with a gamma dose of 700 kGy. With this device, it was observed stable and reproducible current signals with a sensitivity decrease of about 10% within the whole range of dose studied. Furthermore, the FZ#75 diode exhibited a quadratic dosimetric response.

Despite of being preliminary, these results have shown that pre-irradiated STFZ devices can be used as on-line gamma dosimeter in radiation processing applications for doses up to 275 kGy.

ACKNOWLEDGMENTS

The authors thank Eng. Elizabeth S. R. Somessari and Eng. Carlos Gaia da Silveira, from Gammacell staff, for the collaboration during the irradiation procedures.

The technical collaborations of MSc M. T. Biasoli and Marinalva Muniz Rocha from Renato Archer Information Technology Centre are highly acknowledged.

Fábio de Camargo and Kelly C. S. Pascoalino are grateful to FAPESP and CNPq, respectively, for the award of scholarship. This work was supported by FAPESP (project 03/12720-6) and partially by CNPq (contract 303138/2006-8).

REFERENCES

1. G. Lindström, et al., "Radiation hard silicon detectors – developments by the RD48 (ROSE) collaboration", *Nuclear Instruments and Methods in Physics Research*, vol. A466, pp.308-326 (2001).

2. RD50 - Radiation hard semiconductor devices for very high luminosity colliders, "RD50 Status Report", http://rd50.web.cern.ch/rd50/doc/status-reports.html (2008).

3. M. Casati, M. Bruzzi, M. Bucciolini, D. Menichelli, M. Scaringellab, C. Piemonte and E. Fretwurst, "Characterization of standard and oxygenated float zone Si diodes under radiotherapy beams", *Nuclear Instruments and Methods in Physics Research*, vol. A552, pp.158-162 (2005).

4. F. Camargo, J.A.C. Gonçalves, H.J. Khoury, C.M. Napolitano, J. Härkönen and C.C. Bueno,"MCz diode response as a high-dose gamma radiation dosimeter", *Radiation Measurements*, vol. 43, Issues 2-6, pp.1160-1162 (2008).

5. ICRU Report 80: Dosimetry Systems for Use in Radiation Processing. *Journal of the ICRU*, vol. 8, n°. 2 (2008).