Short-term repeatability of a rad-hard EPI diode applied in electron processing dosimetry

Thais C. dos Santos, Josemary A. C. Gonçalves, Ioana Pintilie and Carmen C. Bueno

***Abstract*– The rad-hard EPI diode was characterized envisaging its application in on-line 1.5 MeV electron beam dosimetry in radiation processing. As expected from a current sensitivity loss (13.5%) to the accumulated dose up to 750 kGy, the EPI diode exhibited good short-term repeatability (CV = 1.9%) which is better than that required for CTA dosimeters, routinely applied in radiation processing. The dose-response curve of the EPI diode was fitted by a second order polynomial function for doses up to 775 kGy. In addition, some preliminary studies on the radiation damage effects induced in this diode using a Capacitance Deep Level Transient Fourier Spectroscopy system are presented. The results showed that up to almost 1.5 MGy only 3 defects (VO, V_2 and C_iO_i) can influence the carrier lifetime and current generated. Further radiation damage studies are under way.**
***Keywords*: EPI diode, radiation processing, dosimetry.**

I. INTRODUCTION

Silicon detectors have been used for several years in a variety of nuclear and particle physics experiments that require mainly good energy and special resolution, high efficiency and fast response [1]. However, ordinary silicon devices are very prone to radiation damage effects which are responsible for a gradual long-term sensitivity decay [2]. Considerable effort has been made to develop radiation tolerant silicon detectors for High Energy Physics experiments [3]. The dosimetric characteristics of some rad-hard devices have been investigated in our group in both radiation processing and clinical electron beam dosimetry [4,5]. Despite of the higher radiation tolerance of these devices, our results have still shown a sensitivity decay with the dose, attributed to the reduction of the minority carrier lifetime/diffusion length as a function of the dose. Theoretically, at some accumulated dose, the diffusion length becomes comparable with the detector thickness and, for higher doses, the current starts to decrease. This effect can be calculated, but in radiation processing applications the sensitivity loss of the device probably will be stronger than that simulated due to heavy gamma/electron irradiation. This assumption motivated us to investigate the dosimetric characteristics of diodes processed on thin n-type epitaxial layers with high radiation damage tolerance. In this work we present the preliminary results obtained with a rad-hard epitaxial (EPI) silicon diode processed at the University of Hamburg [6] as on-line dosimeter in electron processing. Some preliminary studies on the radiation damage effects induced in this diode is also presented.

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II. MATERIALS AND METHODS

The EPI diode, produced by University of Hamburg, was processed on n-type 50 μm thick epitaxial silicon layer with nominal resistivity of 64.4 Ω.cm, grown on a 300 μm thick highly doped n-type Czochralski (Cz) silicon substrate [6]. In order to use the diode as a dosimeter, it was housed in a black polymethylmethacrylate PMMA probe to provide protection from mechanical stress, light and moisture. An entrance window of 3.6 mg/cm^2 thick aluminized mylar foil was glued on top of the probe to reduce the electron beam energy loss. The planar pad (p+) of the diode, with an active area of 5x5 mm^2 was directly connected through low-noise coaxial cable to the input of a Keithley 6517B electrometer. All current measurements were carried out with the diode unbiased and the guard rings floating.

The irradiation was performed with 1.5 MeV electron beam from a DC 1500/25/4 – JOB 188 Electron Accelerator with a fluence of 3.9.10^{13} e/cm^2 and radiation field size of 2.5 x 100 cm^2. First of all, to mitigate the predictable current sensitivity loss of any semiconductor device at the beginning of irradiation, the EPI diode was pre-irradiated with 1.5 MeV electrons at a dose of 25 kGy [7]. To reproduce the experimental conditions often use for electron processing with this accelerator, the dosimetric probe was placed on a conveyor belt together with a thermopar (type K) to monitor the temperature during all steps of irradiation. In the worst condition (highest absorbed dose) the temperature varied from 25°C to 40°C. The velocity of the conveyor, 5.6 cm/s, which corresponds to an average dose rate of 14 kGy/s, led to an absorbed dose of 6.25 kGy each forward and backward pass of the diode in the electron radiation field. The current signals induced on the diode during the conveyor movement in each pass were registered as a function of the time for doses up to 750 kGy (120 passes). The coefficient of variation (CV) of the last 10 peak current signals, corresponding to absorbed doses between 687.5 kGy and 750 kGy, were used to investigate the short-term repeatability of the diode. Due to the lack of internationally acceptable recommendations regarding the procedures suitable for dynamic semiconductors dosimeters applied in radiation processing, the calculation of CV was made following the same procedure suggested by ISO/ASTM-51276 [8] for routine cellulose triacetate (CTA) dosimetry systems. The dose-response curve of the EPI diode was achieved through the integration of the current signals versus time as a function of the accumulated dose. To foresee how radiation induced defects will affect the current sensitivity of this EPI diode, six identical samples were irradiated with 1.5 MeV electrons in a dose range up to 1.5 MGy at the same experimental conditions (current accelerator, conveyor velocity and field size) used in this work. The preliminary results about these defects were obtained with a Capacitance Deep Level Transient Fourier Spectroscopy (C-DLTFS) system [9]. The standard DLTS spectra were recorded in a temperature range between 30 and 280 K.

III. RESULTS

The first five current waveforms induced on the diode during the conveyor movement in the electron radiation field are presented in Fig.1. An expanded view of one of these current signals (inset in the top corner of Fig. 1) shows that the peak current value is achieved when the diode just passed underneath the electron accelerator window. The currents registered outside the uniform radiation field during the diode transit time (≈ 15 s) are mainly due to scattered radiation. However, small variations on the accelerator current or conveyor velocity gave rise changes in the profile of the current signal as a function of the exposure time. The background current (90 nA), measured between each step of irradiation with the electron beam on, was almost 10^4 higher than the dark current of the diode (4 pA). These values kept constant during all the 120 steps of irradiation (dose of 750 kGy). Nevertheless, the peak current induced on the diode slightly decreased with the accumulated dose as can be seen in Fig. 2, where the first five current signals are compared with those consecutively registered at the end of irradiation. To quantify this current sensitivity loss, the peak current of each pass of the EPI diode was normalized to that value registered at the beginning of irradiation and plotted as a function of the accumulated dose (Fig. 3). The experimental uncertainties of these results (0.3%) were restricted to the electrometer precision due to difficulties of measuring those from variations in the accelerator parameters, such as current and conveyor belt velocity. Despite of this, the maximum current sensitivity loss (13.5%) of the EPI diode even after accumulating 750 kGy, is much smaller than that measured with MCz, DOFZ and FZ devices irradiated with Co-60 gamma-rays [4]. Regarding the short-term repeatability of the diode, it was investigated through the peak currents coefficient of variation (CV) measured during the last 10 steps of irradiation which are presented in Fig.4. With this procedure, the CV obtained (1.9%) is smaller than that required for CTA dosimeters [10], routinely used in electron processing dosimetry. It is important to note that the CV obtained added the accelerator instabilities (traceable through the current waveforms), which are covered up in static dosimeters such as CTA.

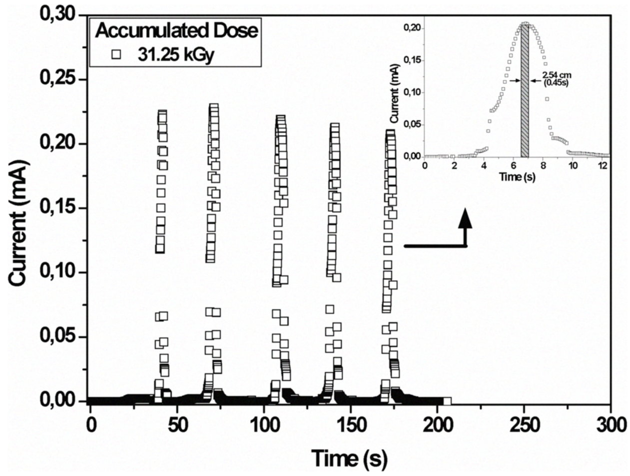

Fig. 1. The first five current waveforms induced on the EPI diode during the conveyor movement in the 1.5 MeV electron radiation field. In the top corner, an expanded view of one of these current signals.

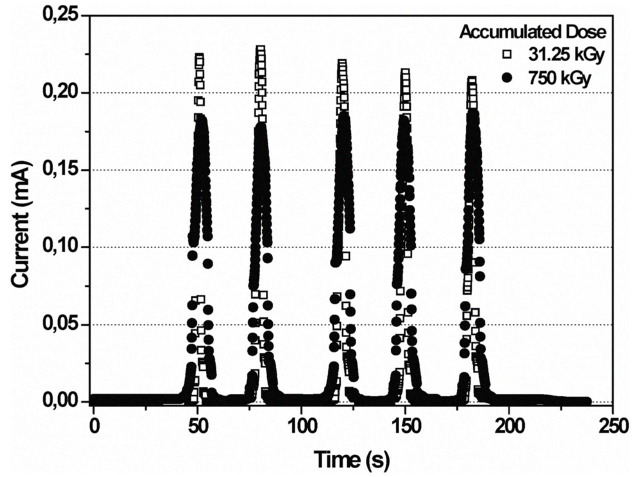

Fig. 2. For comparison, the first five current signals (accumulated dose of 31.25 kGy) plotted together with those consecutively measured at the end of irradiation.

The dose-response of the EPI diode was also investigated by plotting the charge generated (integration of the current signal versus time) as a function of the accumulated dose. These results, depicted in Fig. 5, are well fitted by a second order polynomial function (correlation coefficient ≈ 0.999).

Studies about radiation induced defects that possible affect the current sensitivity of this EPI diode has been performed using the Capacitance Deep Level Transient Fourier Spectroscopy (C-DLTFS) system. The standard DLTS spectra of identical EPI diodes irradiated with 1.5 MeV electrons up to a fluence of $3.9.10^{13}$ e/cm^2 were recorded in a temperature range between 30 and 280 K. The DLTS spectrum of one EPI sample irradiated with 31.25 kGy is presented in Fig. 6. The defect investigations showed that up to almost 1.5 MGy only 3 defects can influence the carrier lifetime and current generated: VO, V_2 and C_iO_i, with defect introduction rates of $4.25x10^{11}$ kGy^{-1}cm^{-3}, $3.84x10^{10}$ kGy^{-1}cm^{-3} and $3.6x10^{11}$ kGy^{-1}cm^{-3}, respectively. Further radiation damage studies are under way.

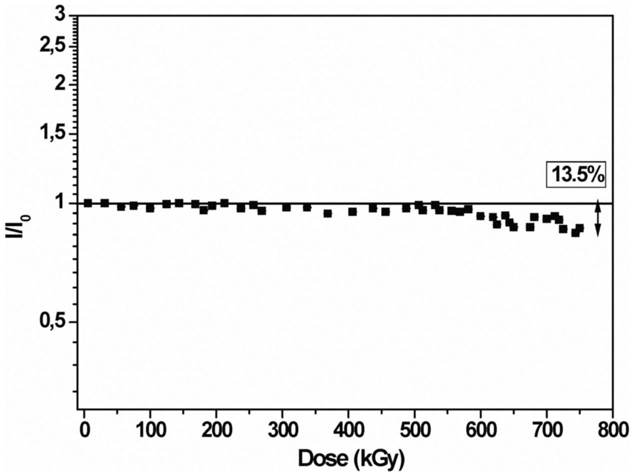

Fig. 3. Normalized peak current (I) measured in each step of irradiation to the peak current (I_0) at the beginning of irradiation as a function of the accumulated dose. Experimental uncertainties (0.3%) are smaller than the symbols size.

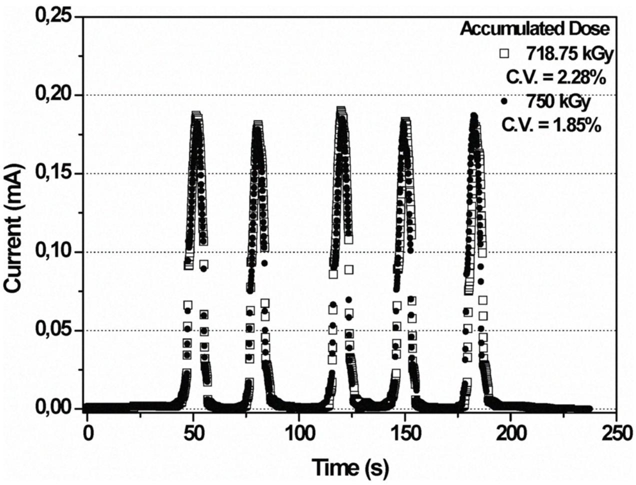

Fig. 4. For comparison, the ten current signals induced on the diode at the end of the irradiation.

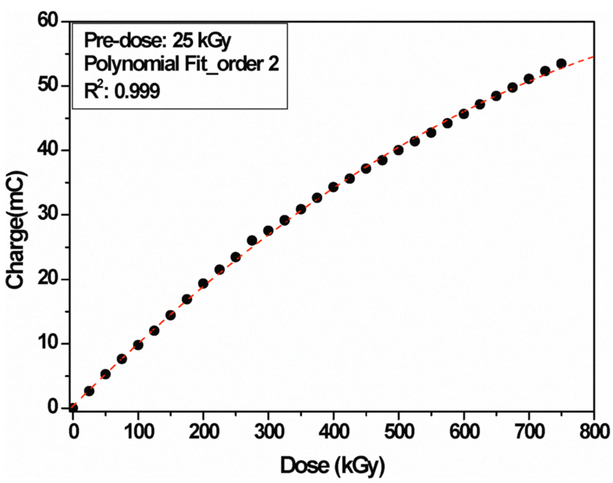

Fig. 5. Dose response-curve of the EPI diode for accumulated doses up to 750 kGy.

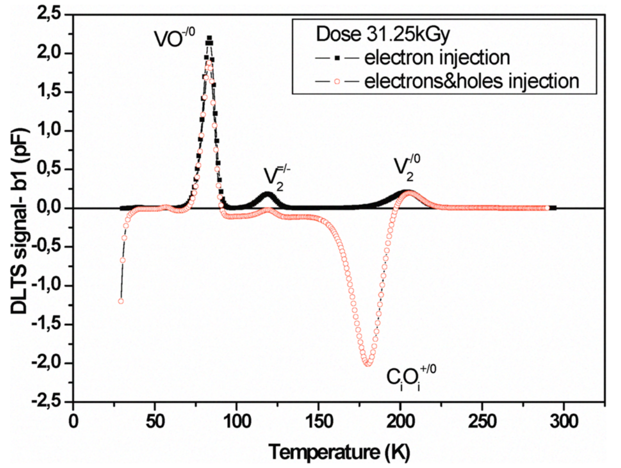

Fig. 6. DLTS spectra for EPI diode irradiated with 1.5 MeV electrons with a fluence of $3.9.10^{13}$ e/cm^2.

IV. Conclusions

The rad-hard EPI diode was characterized envisaging its application in on-line 1.5 MeV electron beam dosimetry in radiation processing. Within a dose range up to 750 kGy, it was observed a current sensitivity loss (13.5%) much smaller than those found with MCz, DOFZ and standard FZ diodes irradiated with gamma rays from Co-60, previously investigated in our group. As expected from this small sensitivity dependence on the accumulated dose, the EPI diode exhibited good short-term repeatability (CV = 1.9%) which is better than that required for CTA dosimeters, routinely applied in radiation processing.

About the defect investigations up to 1.5 MGy, only VO, V2 and CiOi can influence the carrier lifetime and current generated. Further investigation will be undertaken regarding radiation damage effects and long term reproducibility of the EPI diode response.

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