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Accumulated dose stability parameters in p-type and n-type silicon diodes

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1. Introduction

The development of radiation-hard silicon diodes to face the harsh radiation environment in high-energy physics experiments has renewed interest in applying them in gamma radiation processing dosimetry. The operating principle of diode-based dosimeters relies on measuring the radiation-induced currents delivered by non-polarized diodes throughout the exposure time. An electrometer promptly reads the current signal, linearly dose rate dependent. The offline integration of the current signal provides the charge generated in the sensitive volume of the diode, expected to be proportional to the absorbed dose. It holds within a certain dose limit since departures from linearity between charge and dose have been observed for a few tens kGy [1-3]. The origin of such a nonlinear dose response is related to radiation damage effects that shorten the diffusion length of the minority carriers, reducing the sensitive volume of the diodes. Therefore, different doping types (n or p) must play a meaningful role in the diode's response stability at increasing accumulated doses. This work aims to check whether this statement holds in high-level dosimetry applications by investigating the dose response of n- and p-type silicon diodes processed through a similar Magnetic Czochraslki (MCz) technique. The experimental approach is focused on the current sensitivity decay as a function of the accumulated doses for both diodes.

2. Methodology

The diodes used in this work are produced by Si grown by the MCz method and processed at the Microelectronics Center of the Helsinki University of Technology (Finland) [4]. The electrical and structural characteristics of these diodes, such as total depletion voltage (V_{FD}), leakage current at total depletion voltage ($I_F@V_{FD}$), useful area (A), chip thickness (d), resistivity (ρ), and type of doping, are presented in Table I.

Each diode, conductively glued on a ceramic plate, is enclosed in a black acrylic (PMMA) case to be protected against light and mechanical stress. The readout electrode (p^+ front pad) is directly connected, via coaxial cable, to the input of a Keithley® 6517 electrometer to record the output currents from the diode. The short-circuit current mode is achieved with the grounded backplane (n+) electrode and the guard ring structure floating. For analysis, the acquired current signals, i.e., current amplitude

as a function of the exposure time, are transferred online to a computer with an interface programmed in LabView®.

Irradiations are performed in a Nordion Gammacell 220 at a 1.535 kGy/h dose rate, previously calibrated with standard reference alanine dosimeters (2.75%, k = 2). During irradiations, the output currents are continuously acquired as a function of the accumulated dose. Comparative analyses of the current sensitive decay and the enhanced leakage current are carried out to address the radiation damage level in both diodes.

Table I: Electrical and structural characteristics of the MCz diodes.

Diode	V_{FD} (V)	$I_F@V_{FD}$ (nA)	A (mm^2)	d (µm)	ρ (kΩ.cm)	Type
MCz	350	0.4	25	300	0.9 - 1	n
	117	1.2	25	300	0.9 - 1	p

3. Results and Discussion

Fig.1 shows the output currents continuously delivered by MCz (p) and MCz (n) diodes when irradiated up to 175 kGy. The currents are normalized to those acquired at the beginning of irradiation to ease the visualization of the two independent data sets. Regardless of the doping type, both diodes suffer from radiation damage effects that manifest in a current sensitivity drop with increasing accumulated doses. However, the p-type doping favors the radiation tolerance of the MCz (p) diode with a sensitivity drop of 20%, well below that achieved by the MCz (n) diode (65%) at 175 kGy.

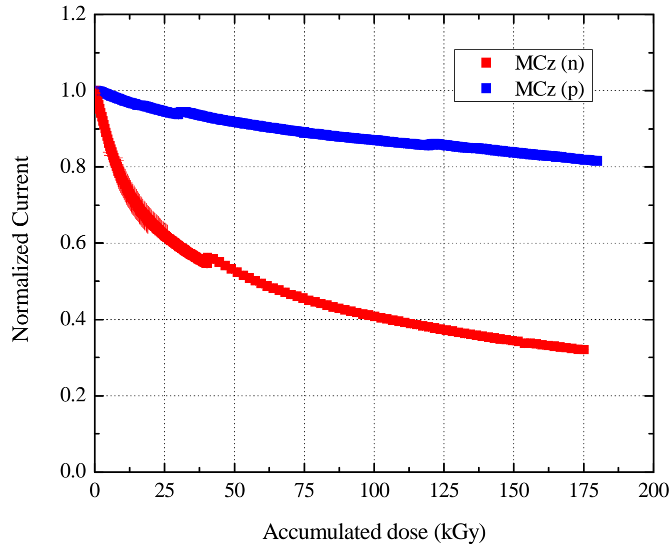

Figure 1: Normalized current as a function of accumulated dose for diodes MCz (n) and MCz(p).

These results corroborate the greater radiation endurance of p-type diodes, reported in the literature about diode-based dosimeters applied in medical dosimetry [5-8]. In these applications, similar to the one herein described, the diodes operate without externally applied voltage. Under this condition, the diffusion current due to the excess minority carriers produced on each side of the junction greatly contributes to the output current signal. For this, each minority carrier (electrons on the p-side and holes on the n-side) diffuses toward the depletion zone and, if it reaches the junction edge, is swept by the built-in potential and collected. Physically, only minority carriers produced outside the junction at a distance from its edge equal to or less than their diffusion length can be collected. So, the sensitive volume of the diode depends on the minority carrier diffusion length, which is strongly affected by radiation damage effects. As the diffusion length of electrons (p) is much greater than that of holes (n), the sensitive volume changes with increasing accumulated dose might be, comparatively, smaller. Consequently, the p-type diode response is expected to be more stable.

4. Conclusions

A comparative investigation concerning the doping type influence on the accumulated dose stability of n- and p-type MCz diodes is reported in this work. The experimental approach involves analyzing the sensitivity decay with increasing doses accumulated in these diodes. The results evidence a less pronounced drop in sensitivity of the p-type than that recorded for the n-type diode when both underwent 175 kGy. This behavior can be ascribed to the working principle of the diode in the short-circuit current mode and the differences between the diffusion lengths of minority carriers in n- and p-type silicon materials. Further studies on the accumulated dose influence on the response stability of both diodes are underway.

Acknowledgments

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