

Radiation Damage Study on the Electrical Properties of Si Diodes

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Abstract. The aim of this work was to study the radiation damage effects on the electrical properties of Float Zone (FZ) and Magnetic Czochralski (MCz) diodes. The effects were evaluated by measuring the reverse current and capacitance of these devices as a function of the reverse voltage. The irradiation was performed in the Radiation Technology Center (CTR) at IPEN-CNEN/SP using a ⁶⁰Co irradiator (Gammacell 220 – Nordion) with a dose rate of about 2 kGy/h. Samples were irradiated at room temperature in five steps up to an accumulated dose of 603 kGy.

Keywords: rad-hard Si diodes, radiation damage, gamma radiation.

PACS: 80.85.60.Dw

INTRODUCTION

Silicon detectors have been employed in High Energy Physics (HEP) experiments mainly due to their fast response, good spatial resolution and high signal-noise ratio. However, the very high radiation doses expected in these experiments have pushed researches through the development of Si devices more tolerant to radiation damage [1]. Among several approaches to enhance the radiation hardness of semiconductors are the improvements of the Float Zone (FZ) and Czochralski (Cz) techniques used for the fabrication of high-purity substrates [2]. Recent developments in crystal growth Czochralski technology with a magnetic field, called Magnetic Czochralski (MCz), have enabled production of MCz wafers with high resistivity for detector applications [3]. These results also lead to the development of rad-hard FZ and MCz silicon devices to be used in the tracking systems of colliding beam experiments. In this work, the radiation tolerance of these FZ and MCz diodes, produced at Helsinki Institute of Physics, has been investigated by measuring their electrical characteristics as a function of the absorbed dose. This method is based on the fact that the substantial macroscopic effect of radiation damage is an increase of reverse current and a change of full depletion voltage that can lead to an initial type inversion of the diode [2]. In order to evaluate the possibility of using both FZ and MCz diodes for high dose gamma dosimetry [1], it was compared the dynamic measurements of current,

capacitance and full depletion voltage of these devices, after gamma radiation exposure.

MATERIALS AND METHODS

The devices investigated in this work were processed on 300 μm n-type FZ and MCz Si substrates with useful areas of 25 mm^2 . The diodes were housed in a black PMMA chamber to be protected from mechanical stress, moisture and light. The irradiation was performed in the Radiation Technology Center (CTR) at IPEN-CNEN/SP using a ^{60}Co irradiator (Gammacell 220 – Nordion) with a dose rate of about 2 kGy/h. Samples were irradiated at room temperature in five steps up to an accumulated dose of 603 kGy.

After each step of irradiation, current and capacitance measurements were carried out as a function of the reverse voltage using a home-made electronic circuit designed with the OPA656U [4] operational amplifier. All these measurements were performed taken into account the recommendation of the RD50 collaboration report for Si diodes [5-6].

RESULTS

Capacitance and reverse current of diodes were measured as a function of the reverse bias in the range of 0 V up to the full depletion voltage of each device. The I-V curves of FZ and MCz, obtained after each step of gamma irradiation, are presented in Figures 1a and 1b, respectively. The results evidence an increase of the reverse currents with the accumulated dose due to the defects presented in the bulk of the devices. These defects can be play as trapping center and moreover, they also can emit alternatively electrons and holes which leading to this increase of the current. However, after an accumulated dose of 603 kGy, the maximum reverse current, at the full depletion voltage, do not exceed 0.4 μA .

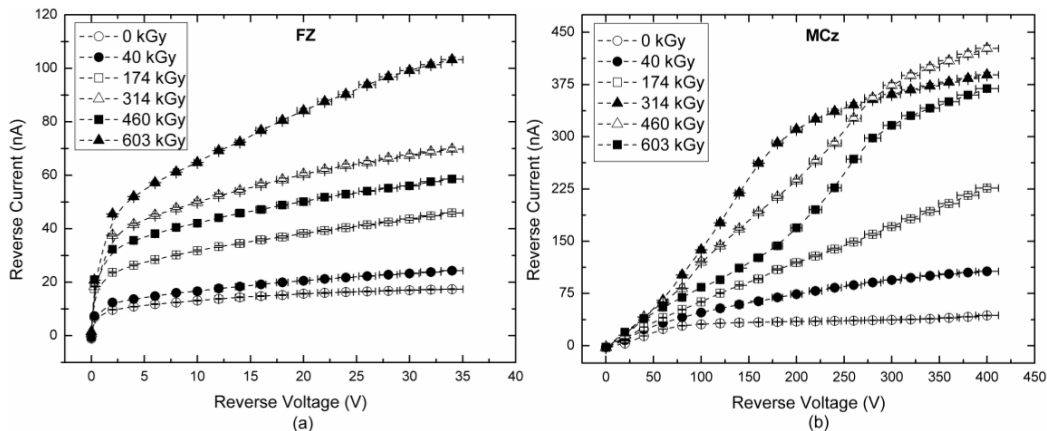


FIGURE 1. Curves I-V of FZ (a) and MCz (b) devices obtained after each step of irradiation.

The results of $1/C^2$ as a function of the reverse voltage of both diodes are depicted Figures 2a (FZ) and 2b (MCz). These curves exhibit the typical dynamic capacitance response of junction diodes due to the growth of their depletion layer thicknesses with the polarization bias. Moreover, the results obtained with both diodes irradiated at different accumulated doses agree within the experimental errors. Figures 3a (FZ) and 3b (MCz) show the full depletion voltages of the FZ and MCz devices, obtained from the $1/C^2$ vs V curves with a method developed in our group and published elsewhere [7], as a function of the accumulated dose. It is evidenced that the full depletion voltages of both devices do not change, within the experimental uncertainties, even when they are irradiated with doses up to 603 kGy.

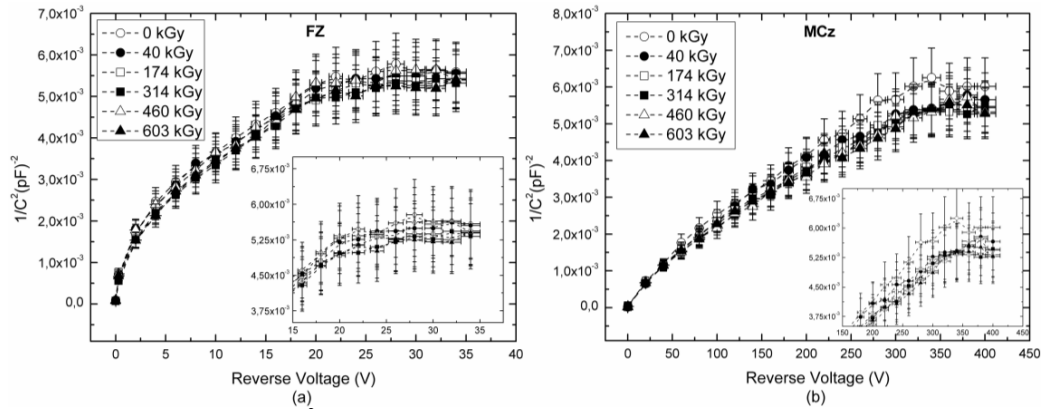


FIGURE 2. Curves $1/C^2$ as a function of the reverse voltage of FZ (a) and MCz (b) devices.

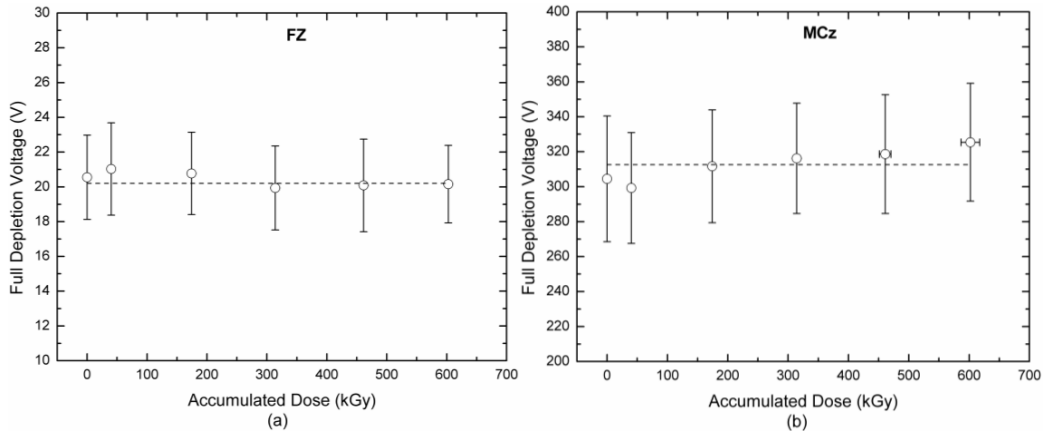


FIGURE 3. Full depletion voltage of FZ (a) and MCz (b) devices as a function of the accumulated dose.

CONCLUSIONS

The studies of the radiation damage influence on the electrical characteristics of FZ and MCz diodes showed a reverse current growth with the increase of the accumulated dose. However, even for doses up to 603 kGy, the capacitances and the full depletion

voltages of both diodes kept constant within the experimental errors. From these results, it is possible to conclude that the radiation hardness of these devices investigated enable them to be applied in high-dose semiconductor dosimetry in radiation processing. Work in this direction is currently in progress in our research group.

ACKNOWLEDGMENTS

The collaboration of Eng. Elizabeth S. R. Somessari and Eng. Carlos Gaia da Silveira from Gammacell-220 and Panoramic staff is highly acknowledged. The authors thank the assistance of Carlos Alberto Souza and Helio Antonio Paes from Gammacell-220 staff. One of us, Kelly C. S. Pascoalino, is grateful to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the award of a scholarship (contract nº133904/2008-3). This work was partially supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under contract nº 310493/2009-9.

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