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Development of Brazilian Low-Cost PIN Diodes for low-dose radiation processing applications

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1. Introduction

Accurate monitoring of ionizing radiation is fundamental across several fields, particularly in medical radiodiagnosis and radiation processing, where delivering the correct dose is essential for safety and quality. Traditionally, semiconductor detectors, such as PIN diodes, have been widely used for their high sensitivity, compact size, and room-temperature operation [1, 2]. However, reliance on imported technologies poses a challenge to Brazil's scientific and economic autonomy in the nuclear and medical sectors [3, 4]. In this context, developing domestic devices is a strategic priority. The Brazilian fabrication of large-area PIN diodes aims not only to reduce costs but also to establish manufacturing protocols that meet the specific demands of the national market. This work presents the characterization of a 12 x 12 mm^2 PIN diode developed at the Integrated Systems Laboratory (LSI-USP) as a dosimeter for low-dose (< 100 Gy) radiation-processing applications. The experimental results focus on analyzing the dose rate, dose-response linearity, and Signal-to-Noise Ratio (SNR) in low-dose applications using ^{60}Co gamma rays from a Panoramic irradiator at dose rates ranging from 2.0 to 20.8 Gy/h.

2. Methodology

The PIN diodes were fabricated from high-resistivity (> 20 kΩ · cm) silicon wafers grown by the Float Zone (FZ) method, with a <100> crystallographic orientation and a thickness of 400 μm. The process followed a low-cost microfabrication route developed at the Integrated Systems Laboratory (LSI-USP). The device geometry (12 x 12 mm) was defined by conventional optical lithography. The fabricated device is shown in Figure 1. For radiation response tests, the device was exposed to ^{60}Co gamma rays from a Panoramic irradiator (FIS 60–04, Yoshizawa Kiko Ltd) installed at the Technology Radiation Center of the Nuclear and Energy Research Institute (CETER-IPEN). This geometry allows products and dosimeters to be irradiated at different distances from the ^{60}Co source, covering dose rates from 2.0 to 20.8 Gy/h. Calibration was performed using standard reference alanine dosimeters (3.2%, k = 2). Real-time current measurements were obtained using a diode assembled in a light-tight probe and directly connected in short-circuit mode to a Keithley electrometer, model 6517B.

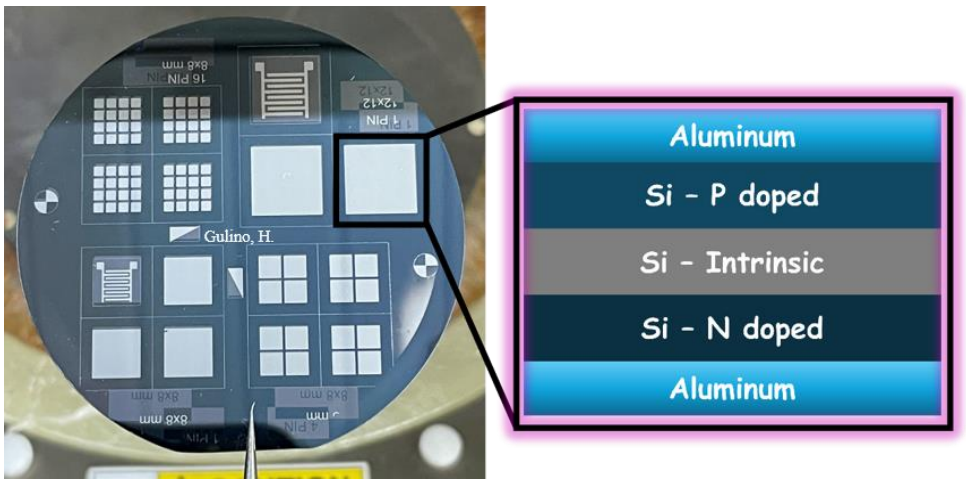

Figure 1: Final result of PIN diode fabrication on the silicon wafer.

3. Results and Discussion

The repeatability of five consecutive current signals (20 s each) measured at the same dose rate and accumulated dose yielded a coefficient of variation (CV) of less than 0.6%, even at the highest dose rate (20.8 Gy/h), as shown in Figure 2. Figure 3 shows the current as a function of the reference dose rate from 2.0 to 20.8 Gy/h. Each point is the average of five consecutive measurements. The results show that the dose-rate response is linear with respect to the current signals, with a current sensitivity of (2.71 ± 0.06) nA.h/Gy. This linearity is essential for ensuring the predictability and calibration of the detector in radiation processing applications. The device's dark current remained low, ranging from 0.85 nA to 1.10 nA during testing. The dose response also exhibited linear behavior up to an accumulated dose of 87.5 Gy. Above this dose, a decrease in the current measured by the diode (and consequently in the dose-response curve) was observed, reaching 12% at a cumulative dose of 185 Gy (Figure 4).

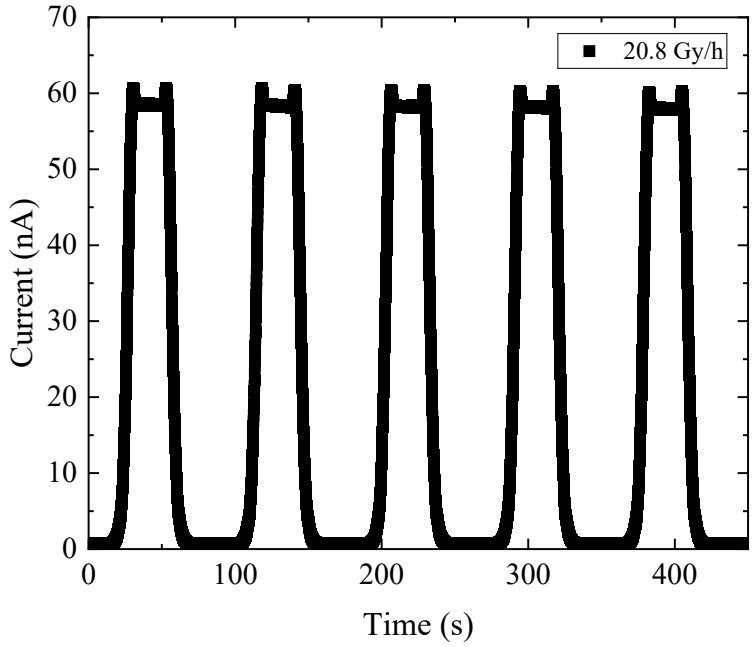

Figure 2: Repeatability of five current signals consecutively registered by switching on and off the source. Irradiations were performed with a dose rate of 20.8 Gy/h.

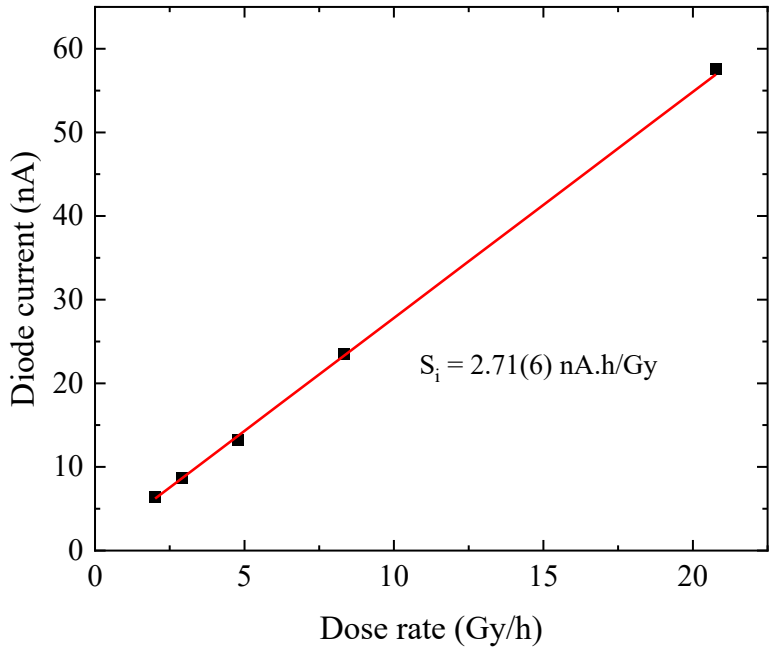

Figure 3: The induced current in the PIN diode as a function of the dose rate.

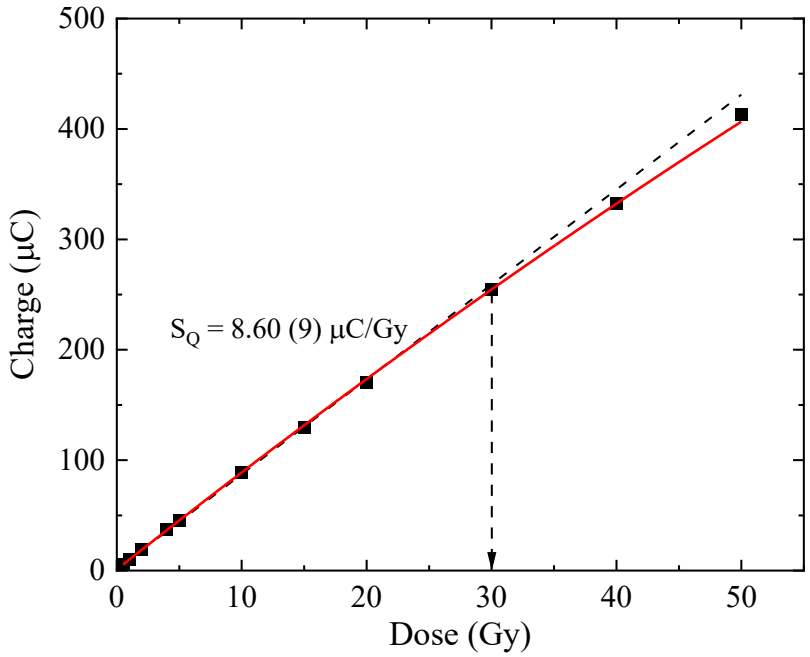

Figure 4: Dose response curve for the PIN diode.

4. Conclusions

This work successfully demonstrated the technical feasibility of fabricating large-area (144 mm^2) PIN diodes in Brazil for low-dose radiation processing applications. The developed low-cost microfabrication process proved effective, yielding devices with low dark currents (1 nA) and high operational stability up to 180 Gy. Characterization under ^{60}Co gamma rays confirmed a strictly linear dose response within the

range of 0.5 – 50 Gy. The sensor exhibited a very good SNR of 60. This national fabrication batch demonstrates promising prospects for integration into -ray beam monitoring systems, contributing to the strengthening of nuclear instrumentation technology in the country. In summary, the development of this batch of PIN diodes represents a significant advancement for Brazil's technological sovereignty in the radiation detector and dosimetry areas. Future perspectives include testing these devices with different areas and thicknesses and optimizing the packaging to further enhance system robustness.

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