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Evaluation of commercial PIN diodes as gamma radiation dosimeters

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Abstract. The influence of gamma radiation on the current-voltage characteristics of silicon PIN photodiodes S1223 from Hamamatsu was investigated for their use as gamma radiation dose rate sensitive elements. The transfer characteristic and the dependence of the current sensitivity on the absorbed dose rate in the range from 6.7 Gy(Si)/h to 124 Gy(Si)/h were studied. The range of reverse voltages corresponding to the highest current sensitivity of PIN diodes is determined. An analytical expression of the transfer characteristic for the operating mode with maximum sensitivity to gamma radiation is obtained.

1. Introduction

The gamma radiation dosimeters are used for monitoring low and high dose rate in scientific research, industry and medicine. The sensitive elements current is changed in proportion to the total ionized dose under the influence of radiation [1]. The value of the total ionized dose is determined by multiplying the dose rate by the exposure time.

Among the large number of small-sized and low-cost radiation sensors, the PIN diodes have the lowest power consumption, high sensitivity, high reproducibility and stability of characteristics, high quantum efficiency and ability to operate without external voltage [2].

The purpose of this study was to evaluate the possibility of using the commercial PIN photodiodes S1223 as the sensitive elements of gamma radiation dosimeters. In this work, several silicon PIN photodiodes were tested under gamma radiation. The photodiodes were exposed to gamma radiation from microfocus X-ray tube “BC5-Mo” and the induced reverse current as a function of the dose rate was determined.

PIN photodiodes consist of an intrinsic high-ohmic semiconductor layer realized between n^+ and p^+ heavily doped semiconductor regions [3]. The induced photocurrent of the PIN photodiodes exposed to ionizing radiation depends on dose rate, active area of the PIN photodiode, width of the depletion layer, orientation of the photodiode with respect to the radiation source, energy of the radiation source and ambient temperature. Since PIN diodes have a wider depletion layer than PN diodes, their sensitivity to irradiation is higher.

2. Devices Under Test

Silicon PIN photodiodes S1223 provide the following features: excellent linearity with respect to incident light, wide spectral response range, mechanically rugged, compact and lightweight and long life [4]. They also feature high-speed response, high sensitivity and low noise.



The main technical characteristics of S1223 PIN diodes are the photosensitive area size of $2.4 \times 2.8 \text{ mm}^2$, the operating temperature range from -40 to $+100 \text{ }^\circ\text{C}$, dark current at reverse voltage 20 V of 0.1 nA , as well as maximal dark current of 10 nA .

3. Test Setup

During irradiation, the samples were isolated in a special lead irradiation chamber that is impermeable to optical and gamma rays, which contain the gamma radiation source. The samples were installed in a special contacting device. The connection with a measurement system was carried out using a twisted pair. The X-ray tube was controlled by the measurement system, i.e. the dose rate and the time of exposure of gamma radiation to the PIN diodes were set. A computer was connected to the measurement system. For PC connectivity of the measurement system a USB cable was used.

Software and test equipment have provided real-time monitoring of the measured current-voltage characteristics of the samples and displaying on the monitor screen graphs of current versus voltage. Software allows also displaying on the monitor of the current at predetermined voltage values and saving the data to a file.

4. Test Description

Eight test samples were irradiated at the room temperature of about $21 \text{ }^\circ\text{C}$ during radiation exposure, using a gamma ray source.

The dose rate was measured during the exposure to gamma radiation because the radiation induced photocurrent occurs while the PIN diode is irradiated.

The samples were exposed to six different dose rates: $6,4 \text{ Gy(Si)/h}$, $7,8 \text{ Gy(Si)/h}$, 14 Gy(Si)/h , 25 Gy(Si)/h , 50 Gy(Si)/h , and 124 Gy(Si)/h .

The current-voltage characteristics of the samples were measured in the range from 0 to -90 V .

The dark current was changed from approximately 0.17 nA at 0 V up to 0.36 nA at -90 V .

5. Results

S1223 PIN diodes have been exposed to gamma irradiation to investigate the effect of gamma radiation on their current-voltage characteristics. The highest sensitivity to gamma rays by PIN diodes in consequence of radiation exposure is determined.

The reverse current as a function of dose rate at the voltage of 0 , -10 , -20 , -50 , -70 , and -80 V is shown in Fig. 1. This figure let us observe that increasing the dose rate leads to the increase of the reverse current for all the reverse voltages and zero voltage.

The current sensitivity is equal to the reverse current per dose rate. The current sensitivity as a function of the dose rate and the reverse voltage is depicted in Fig. 2. This figure shows that the current sensitivity increases with increasing reverse voltage and decreasing dose rate.

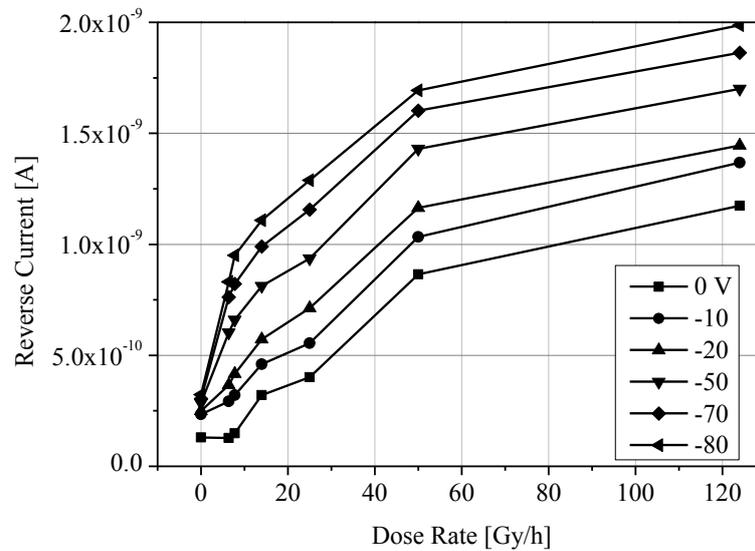


Figure 1. Reverse current versus dose rate at 0 V and the reverse voltage of -10, -20, -50, -70, and -80 V.

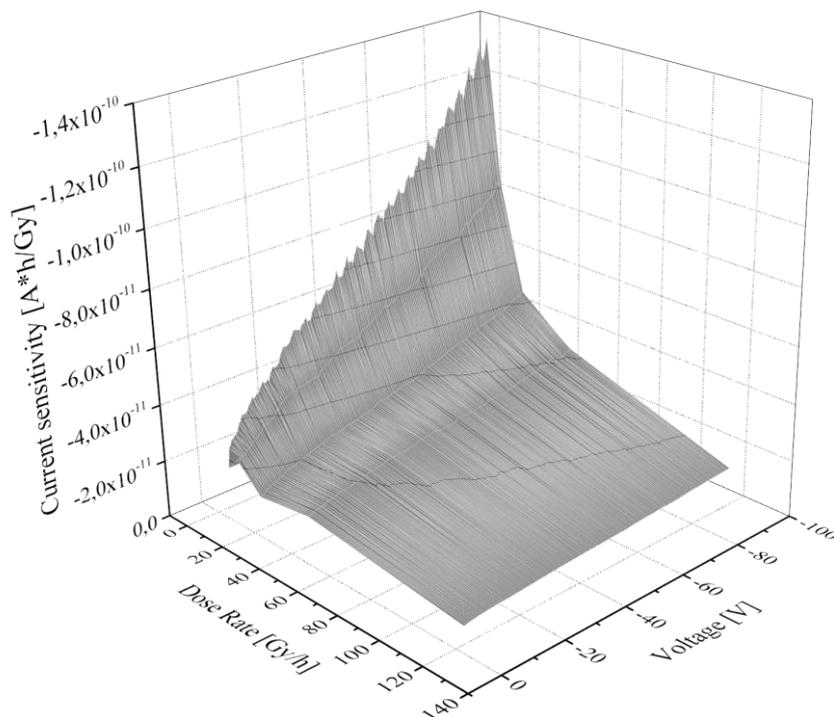


Figure 2. Current sensitivity as function of the dose rate and the reverse voltage.

Figure 3 shows the dependences of the current sensitivity on the dose rate for voltages of 0 V, -10 V, -20 V, -50 V, -70 V, and -80 V. This figure let us observe that increasing dose rate leads to the decrease of the current sensitivity for all the reverse voltages and zero voltage.

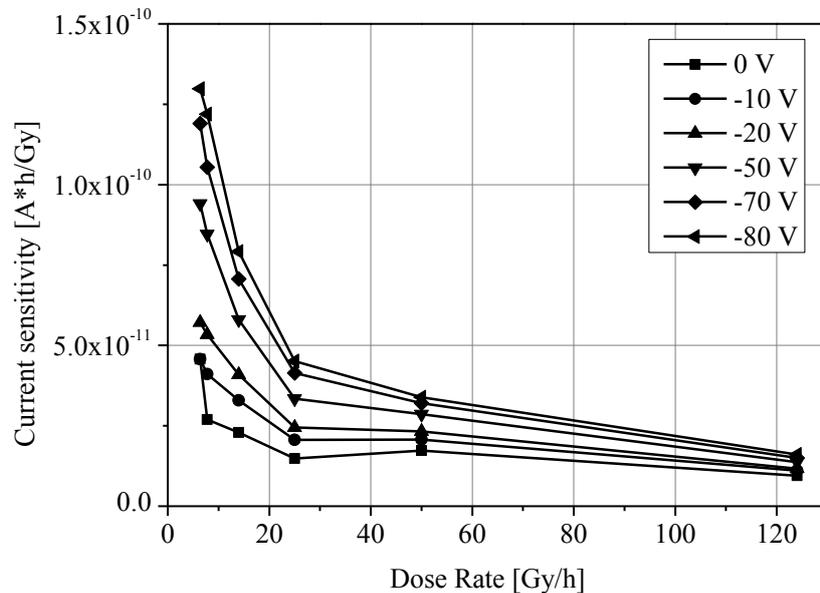


Figure 3. Current sensitivity versus dose rate at 0 V and the reverse voltage of -10, -20, -50, -70, and -80 V.

Hence, the maximum current sensitivity of PIN diodes corresponds to reverse voltages of more than -70 V.

6. Relation Between Reverse Current and Dose Rate

It is possible to derive a mathematical expression for the dependence between the reverse current and dose rate, using the obtained results.

The experimental data of reverse current as function of the dose rate H at the reverse voltage of -80 V (fig. 4) has been fitted with the various power functions. The best accuracy has a fitted equation of the PIN diodes reverse current I :

$$I = a \cdot H^b,$$

where a and b are the approximation coefficients. The values of both coefficients are equal to $b = (29.4 \pm 1.9) \cdot 10^{-2}$ and $a = (5.05 \pm 0.3) \cdot 10^{-10} \text{ A} \cdot (\text{h/Gy})^b$. The reduced chi-square for this approximation is 0.14205963, coefficient of determination equals 0.98023117.

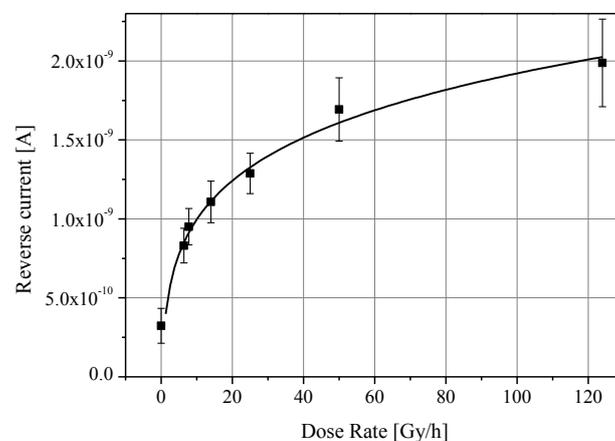


Figure 4. Reverse current as function of the dose rate at the reverse voltage of -80 V.

7. Conclusions

In this work, the silicon PIN photodiodes S1223 from Hamamatsu were irradiated with gamma rays at six different dose rates: 6,4 Gy(Si)/h, 7,8 Gy(Si)/h, 14 Gy(Si)/h, 25 Gy(Si)/h, 50 Gy(Si)/h, and 124 Gy(Si)/h.

The current-voltage characteristics of PIN diodes are measured. The transfer characteristic and the dependence of the current sensitivity on the absorbed dose rate were determined using of these current-voltage characteristics.

Acquired results have shown that the reverse current increases in direct proportion to the dose rate. A transfer characteristic and the dependence of the current sensitivity on the dose rate in the range of reverse voltages from 0 V to -90 V were obtained. It is found that current sensitivity increases with increasing reverse voltage and decreasing dose rate. The range of reverse voltages corresponding to the highest sensitivity of PIN diodes is determined. For the reverse voltage of -80 V, the dependence of the reverse current on the dose rate was approximated by a power function. Numerical values of the approximation coefficients are obtained. Thus, the analytical expression of the transfer characteristic for the operating mode with maximum sensitivity to gamma radiation is obtained.

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