Power Silicon Carbide Schottky Diodes as Current Mode γ-Radiation Detectors

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Abstract— **In this paper, the feasibility of using commercial power Silicon Carbide (SiC) Schottky diodes as a current mode γ-radiation detector have been examined. Diodes with almost identical electric characteristics are purchased from two different manufacturers, On Semiconductor and RoHM. They have been tested under gamma radiation exposure from a Co-60 source. The current response during irradiation has been measured for various dose rates with reversed diode bias. Investigated range of dose rates was from 0.258 Gy/h to 26.312 Gy/h, and reverse diode bias values were 10 V, 20 V, 50 V, 100 V and 200 V. Tested Schottky diodes produce stable current response for the investigated dose rates. Although the manufacturers are different, the results show that the dosimetric characteristics of these diodes have an excellent match. Sensitivity was proportional to the applied reverse bias voltage. A simple power-law can very well describe the dependence of measured radiation-induced current on dose rate.**

I. INTRODUCTION

Material that could replace silicon in ionizing radiation detectors may be Silicon Carbide (SiC) because of its wider band-gap and better signal-to-noise ratio due to significantly lower leakage current [1–4]. Another advantage of Silicon Carbide is that it has higher displacement energy than silicon, and therefore exhibits much higher resistance to radiation-induced damage [3, 5]. For radiation detectors, charge collection is a crucial parameter; since SiC has a high electrical breakdown voltage, it allows operation at higher bias, resulting in a higher electrical field in the component [6]. Furthermore, SiC detectors can operate at higher temperatures than silicon due to high thermal conductivity [7].

Current mode detectors are used for monitoring medium and high dose rate radiation by measuring the radiation-induced continuous current, which is proportional to the dose rate. The use of SiC detectors in the current mode has potential applications in medicine, military, industry, space exploration and scientific research. The properties of the detector are also the stability and repeatability of the current read-out and fast response. This paper aims to extend the research of the usability of low-cost commercial power Silicon Carbide Schottky diodes for the current mode dosimetry.

The structure of a SiC Schottky diode, illustrated in Fig. 1, consists of two main layers: SiC epitaxial layer and SiC substrate layer. The epitaxial layer is a lightly doped region, usually n-type, representing the active region for radiation detection. Thus, a wider epitaxial layer contributes to higher radiation sensitivity. The substrate layer is a heavily doped region, n+ type, usually significantly thicker than the epi-layer.

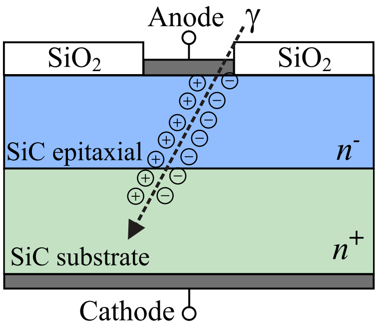

Fig. 1. Illustration of SiC Schottky diode cross-section.

The Schottky diode is achieved by placing a metal contact over the epitaxial layer, while another metal contact is applied to the back of the substrate layer. When an ionizing particle hits the SiC structure, electron-hole pairs are generated in the epitaxial and substrate layers. While the electron-hole pairs induced in the substrate eventually recombine, the internal electric field will collect the electron-hole pairs in the epitaxial layer. In the current mode, the collected charge will result in the stable current which can be measured by connecting appropriate electrometer between the diode's contacts [8].

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II. Experimental Setup

There were two different Power Silicon Carbide Schottky diodes in this experiment with almost identical electrical characteristics, model FFSH15120A (**Diode 1**) purchased from On Semiconductor and model SCS215KG (**Diode 2**) purchased from RoHM. Both diodes have reverse voltage 1200 V and continuous forward current 15 A as the main characteristic. However, the main differences are the values of total capacitive charge and packaging.

The experiment consists of measuring the induced current with different reverse bias during gamma irradiation. Investigated range of dose rates was from 0.258 Gy/h to 26.312 Gy/h, and reverse diode bias values were 10 V, 20 V, 50 V, 100 V and 200 V. Each measurement was performed measuring 60 seconds leakage current with reverse diode bias, then 180 seconds continuing with γ-radiation exposure, and after that 60 more seconds measuring leakage current. Different dose rates were achieved at different distances of DUTs from γ-soruce. The experiment was conducted in controlled laboratory conditions using a Co-60 γ-radiation source at the Institute of Nuclear Sciences "Vinča", Belgrade, Serbia.

III. Results and Discussion

Leakage current values of two different Power Silicon Carbide Schottky diodes in this experiment as a function of applied reverse bias are shown in Fig. 2.

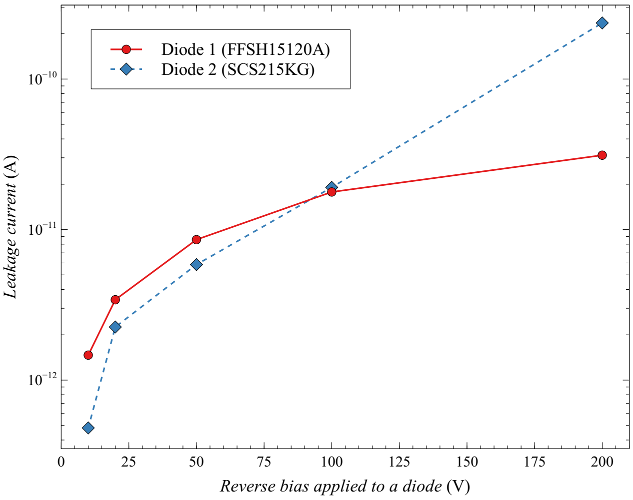

Fig. 2. Leakage current of SiC Schottky diodes with different applied reverse bias.

Waveforms of the radiation-induced current response of the investigated SiC diodes are shown in Figures 3 to 6. For the sake of clarity, only the waveforms for the minimum and maximum reverse bias values with different dose rates are presented.

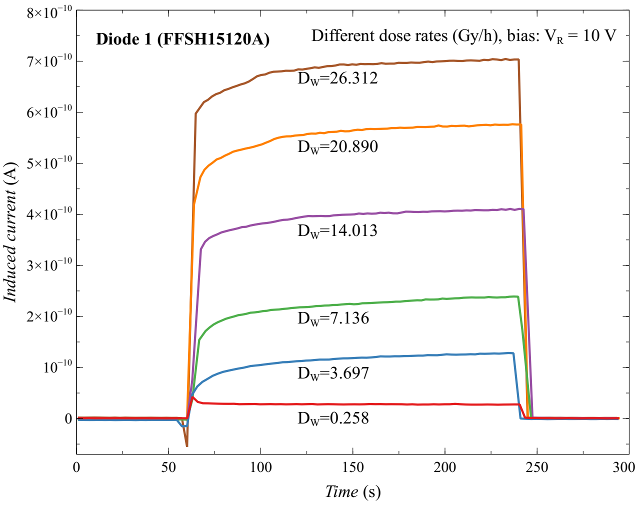

Fig. 3. Radiation-induced current for different dose rate with 10 V reverse bias for Diode 1.

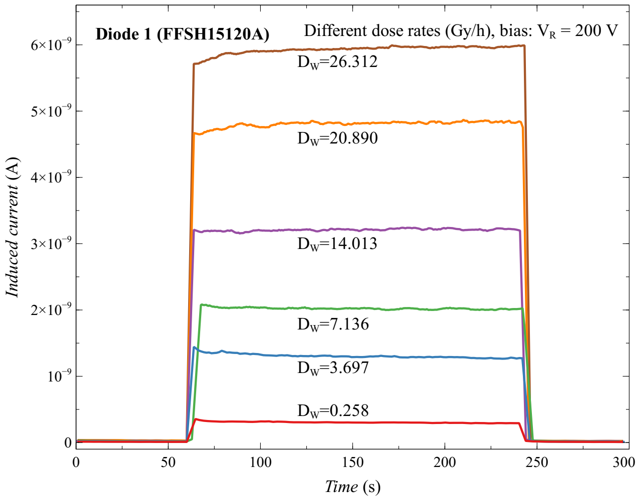

Fig. 4. Radiation-induced current for different dose rate with 200 V reverse bias for Diode 1.

During all irradiation sessions, the induced current was stable, and it increased with dose rate and bias voltage. After stopping the irradiation session, the current fell to the pre-irradiation leakage level. The radiation-induced current was significantly higher than the leakage current without radiation exposure, suggesting that they can be easily differentiated, enabling precise determination of radiation dose rate.

The functional relation between the induced current and the dose rate is defined in accordance with the reference [9]:

$$I = I_0 + (a * \dot{D}^b), \tag{1}$$

where I denotes measured current, I_0 is the dark current, $\dot{D}$ is the dose rate, a is the linearity coefficient, and b is the fitting parameter which represents the current sensitivity with respect to dose rate.

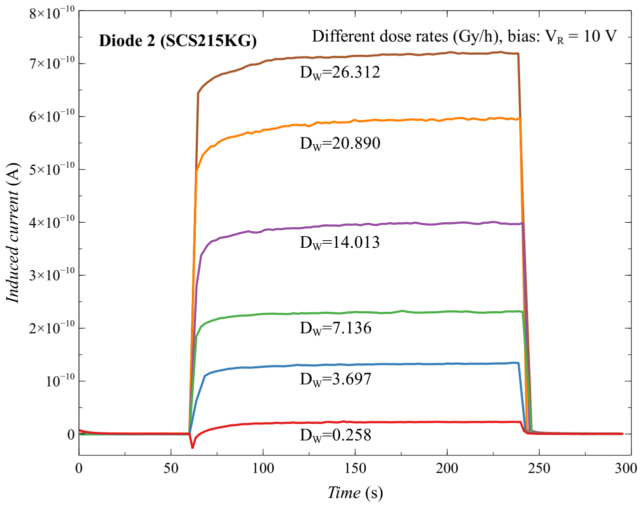

Fig. 5. Radiation-induced current for different dose rate with 10 V reverse bias for Diode 2.

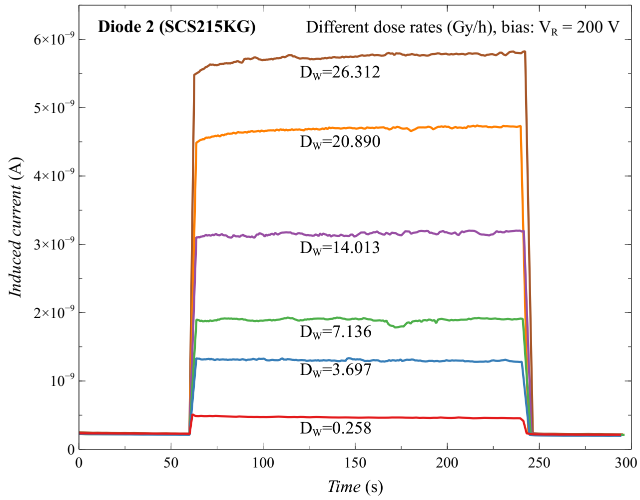

Fig. 6. Radiation-induced current for different dose rate with 200 V reverse bias for Diode 2.

In order to express the obtained results in the form of relation 1, the mean values of the measured radiation-induced current were calculated for all dose rates, and the dark current values were calculated as the mean values from the leakage current with reverse bias before irradiation step.

Figure 7 illustrates the variation of the mean radiation-induced current of Diode 1 and Diode 2 with respect to the dose rate for bias voltage levels of 10, 20, 50, 100, 200 V. It can be observed that the power relation 1 fits the measured results very well. The values of the dark currents, linearity coefficients a, sensitivity coefficients b and the fitting correlation coefficients R^2 are given in Table I.

It can be noticed that parameter a is increasing with the reverse bias values, but parameter b has the same value because it shows the diodes' sensitivity. The average value of parameter b is 0.8664. To obtain these parameters, the data are processed in the program Curve Expert Pro 2.7.3.

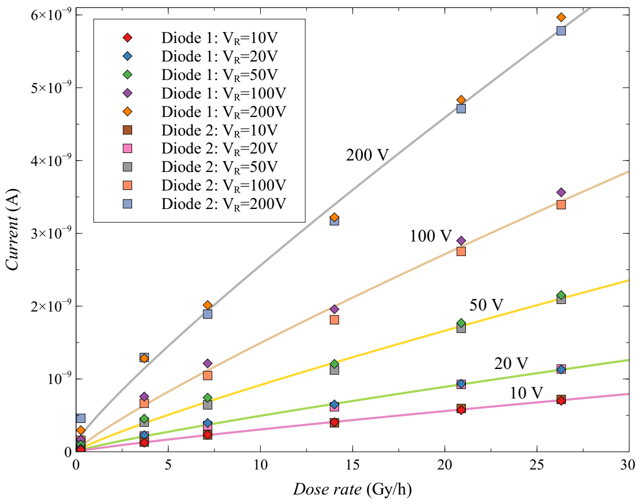

Fig. 7. Mean radiation-induced current as a function of dose rate.

TABLE I

FITTING PARAMETERS FOR RELATION 1

V_R	$I_0\ [10^{-12}A]$	$a\ [10^{-11}]$	b	R^2
$10V$	1	4.132	0.8688	0.992
$20V$	3	6.837	0.8562	0.994
$50V$	7	12.462	0.8633	0.991
$100V$	15	20.024	0.8683	0.995
$200V$	125	32.411	0.8756	0.993

The transition from the leakage current to the radiation-induced current for the lowest and highest dose rates are illustrated in Fig. 8 and Fig. 9 for Diode 1, respectively. For the sake of clarity, graphs for other dose rates and for Diode 2 are not shown in this paper. As can be observed in Fig. 8, a current overshoot was observed at the start of each irradiation session, and after that a stable current was maintained throughout the irradiation session. Because the current overshoots occurred only at the start of irradiation, their effect on the current measurement accuracy is negligible. The transient current overshoots at the start of irradiation have been reported for diamond detectors [10, 11], and similar explanation can be applied in this case since the physics of the electron-hole pair generation and recombination is similar for both diamond and SiC detectors. Generally, the origin of the current overshoot is attributed to the build-up of the internal field during irradiation. The overall electric field in the device is the superposition of internal (built-in) electric field and external electric field determined by the bias voltage. At the beginning of irradiation, the induced charge carriers lead to the increase of the internal field, and hence to the increase of the overall electric field. This causes the sudden increase of the induced current until the equilibrium is reached allowing the current to stabilize. The current overshoot decreases with the increasing of dose rates, so that for a value of 26.312 Gy/h there are no more overshoots as can be seen in the Figure 9.

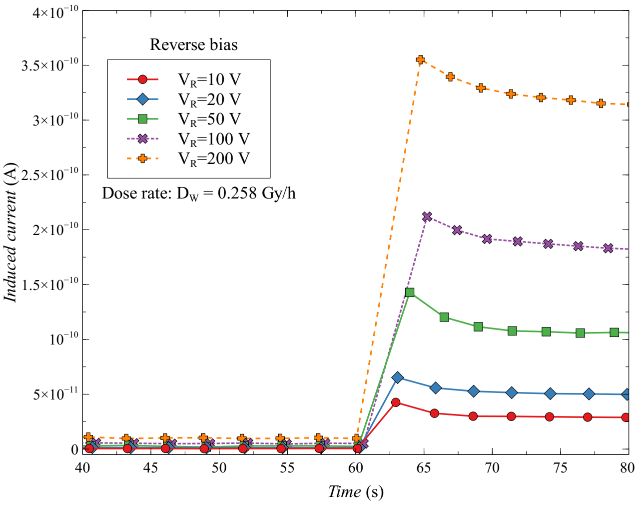

Fig. 8. Radiation-induced current as a function of bias voltage for the lowest dose rate (0.258 Gy/h) for Diode 1.

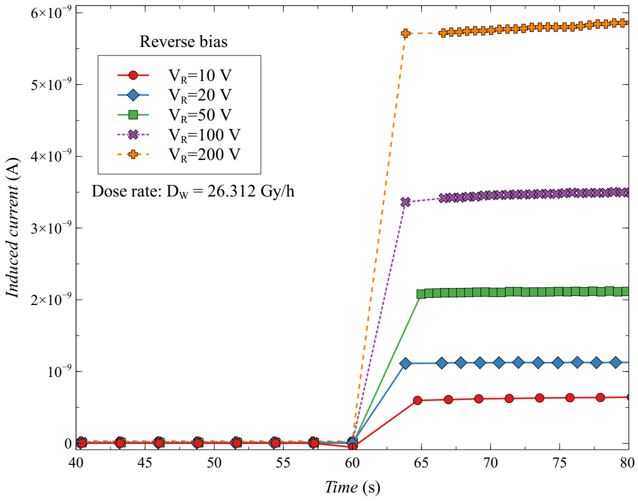

Fig. 9. Radiation-induced current as a function of bias voltage for the highest dose rate (26.312 Gy/h) for Diode 1.

IV. CONCLUSION

The selected low-cost commercial power Silicon Carbide (SiC) Schottky diodes were irradiated by gamma radiation from a Co-60 source, and the radiation-induced current was measured for various dose rates and reverse bias voltages. It was shown that the induced current is stable during exposure, and the mean value of the induced current is related to the dose rate according to the simple power-law equation. The results show that the dosimetric characteristics of these diodes have excellent match, although their manufacturers are different. These results confirm that the investigated commercial diodes have a potential to be used for dosimetric purposes, as a cheap alternative to more expensive custom-designed SiC dosimeters.

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