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Total Ionizing Dose effects in SiC MOSFET power devices with different structures

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Abstract. This study investigates the Total Ionizing Dose (TID) effects in commercial 1200 V SiC MOSFET power devices with planar, trench, and double-trench structures. Radiation test results indicate that, with the accumulation of radiation dose, the transfer characteristic curves of all three device structures exhibit a negative shift. However, differences are observed in their breakdown characteristics. The breakdown curve of the planar-structure device shows no degradation with increasing radiation dose, whereas the breakdown characteristic curves of the trench and double-trench structures deteriorate as the radiation dose accumulates.

Keywords: SiC MOSFET, Total Ionizing Dose, transfer characteristics, breakdown characteristics

1. Introduction

SiC power devices offer advantages such as low on-resistance, high operating frequency, and strong high-temperature tolerance. As high-voltage power switches, they serve as core components in high-voltage power supply circuits and therefore exhibit broad application prospects in space power systems. Compared with the conventional terrestrial environment, the space environment contains a large number of radiation particles, including electrons, protons, and heavy ions [1, 2]. These particles can induce various radiation effects in integrated circuits and electronic devices onboard spacecraft, such as total ionizing dose effects, single-event effects, and displacement damage [3-8]. Such radiation effects may cause damage to electronic components, optical equipment, and solar panels on spacecraft, ultimately leading to mission failure [9]. According to statistics from National Aeronautics and Space Administration (NASA), between 1974 and 1994, 35% of 100 recorded spacecraft failures of various types were caused by radiation [10]. Statistics from the European Organization for Nuclear Research (CERN) also indicate that radiation-induced anomalies in space electronic equipment account for approximately 33% of observed cases [11]. SiC MOSFET power devices operating in the space environment are susceptible to Total Ionizing Dose (TID) effects, which can lead to degradation in electrical characteristics such as transfer characteristics and breakdown characteristics. To investigate the extent of radiation-induced degradation in the electrical performance of SiC MOSFET power devices with different structures, this study conducts total ionizing dose experiments on SiC MOSFET devices with planar, trench, and double-trench structures.

2. Device description and experimental procedure

In this study, three types of SiC MOSFET power devices with different structural designs were selected for total ionizing dose testing. The samples included planar-structure SiC MOSFET power devices manufactured by Wolfspeed (formerly CREE), trench-structure SiC MOSFET power devices from Infineon Technologies, and double-trench-structure SiC MOSFET power devices produced by ROHM Semiconductor. All devices were plastic-encapsulated, and the rated breakdown voltage of each device was 1200 V. Figure 1(a) illustrates the structural schematic of the planar SiC MOSFET power device from CREE, Figure 1(b) shows the schematic structure of the trench SiC MOSFET power device from Infineon, and Figure 1(c) presents the structural schematic of the double-trench SiC MOSFET power device from ROHM.

The total ionizing dose irradiation experiment was conducted using a cobalt-60 gamma-ray source at the National Institute of Metrology of China, as shown in Figure 2. The dose rate employed in the experiment was 50 rad(Si)/s. During irradiation, the SiC MOSFET devices were tested under an on-state bias condition in the cobalt-60 radiation environment. The applied bias consisted of a gate-to-source voltage of 15 V and a drain-to-source voltage of 0 V. The devices were first irradiated in the cobalt-60 radiation field. After reaching specified accumulated dose levels under the on-state irradiation bias condition, the devices were removed from the cobalt-60 source and their electrical characteristics were measured at room temperature in a designated testing area.

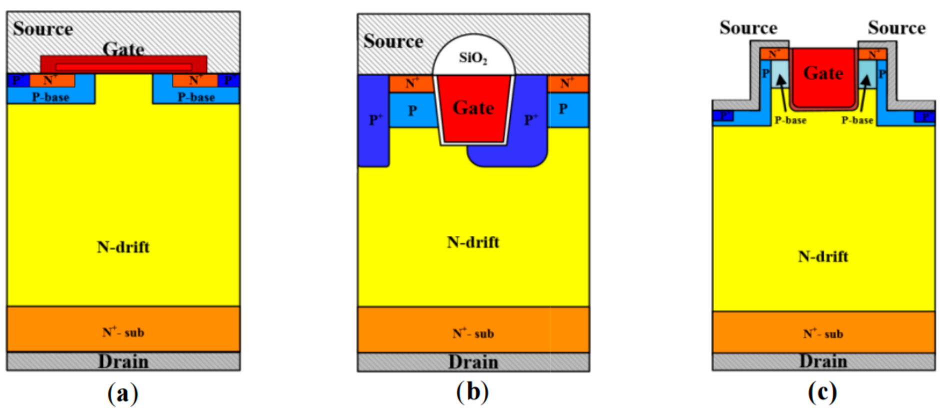

Figure 1. Schematic cross-sectional view of (a) planar structure, (b) trench structure and (c) double trench structure of SiC MOSFET power devices

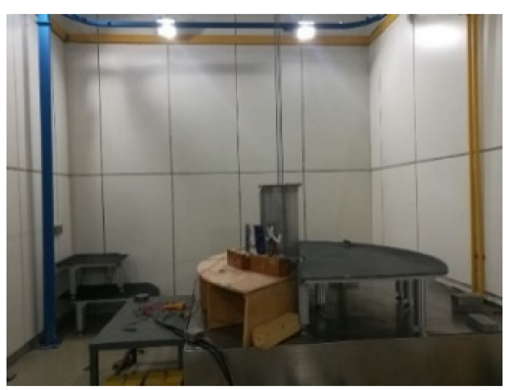

Figure 2. Cobalt-60 radiation test environment

3. Radiation test results

3.1. Transfer characteristics measured after irradiation

Figure 3 shows the relationship between the transfer characteristic curves and the accumulated total ionizing dose for 1200 V SiC MOSFET devices with three different structures. Specifically, Figure 3(a) presents the relationship between the transfer characteristics of the planar-structure device and the radiation dose; Figure 3(b) shows the relationship for the trench-structure device; and Figure 3(c) illustrates the relationship for the double-trench-structure device. By comparing the transfer characteristic curves of the three device structures, it can be observed that the negative shift of the transfer characteristics in the planar-structure device is smaller than that of the trench-structure device, while the negative shift of the trench-structure device is smaller than that of the double-trench-structure device.

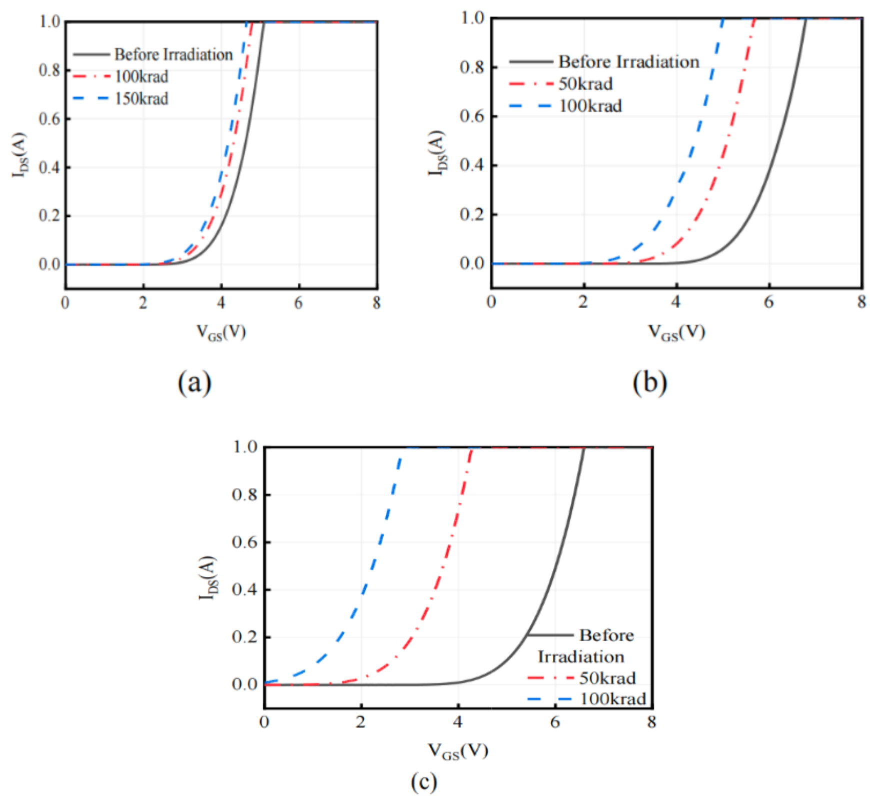

Figure 3. Measured transfer characteristic curves of SiC MOSFET power devices before and after irradiation with TID. (a) Planar structure, (b) trench structure and (c) double trench structure

Figure 4 illustrates the relationship between the negative drift of the threshold voltage and its variation rate with the accumulated radiation dose for the three device structures. As shown in Figure 4(a), when the accumulated radiation dose reaches 100 krad(Si), the threshold voltage of the planar-structure device exhibits a negative drift of 0.35 V, corresponding to a variation rate of 8.2%. When the accumulated dose reaches 150 krad(Si), the threshold voltage shows a negative drift of 0.39 V, with a variation rate of 9.2%. From Figure 4(b), it can be seen that for the trench-structure device, when the accumulated radiation dose reaches 50 krad(Si), the threshold voltage exhibits a negative drift of 1.27 V, corresponding to a variation rate of 21.4%. When the accumulated dose increases to 100 krad(Si), the threshold voltage shows a negative drift of 2.15 V, with a variation rate of 36.2%. Figure 4(c) presents the relationship between the threshold voltage of the double-trench-structure device and the radiation dose. The results indicate that when the accumulated radiation dose reaches 50 krad(Si), the threshold voltage exhibits a negative drift of 2.42 V, corresponding to a variation rate of 43%. When the accumulated dose reaches 100 krad(Si), the threshold voltage shows a negative drift of 3.45 V, with a variation rate of 64.3%.

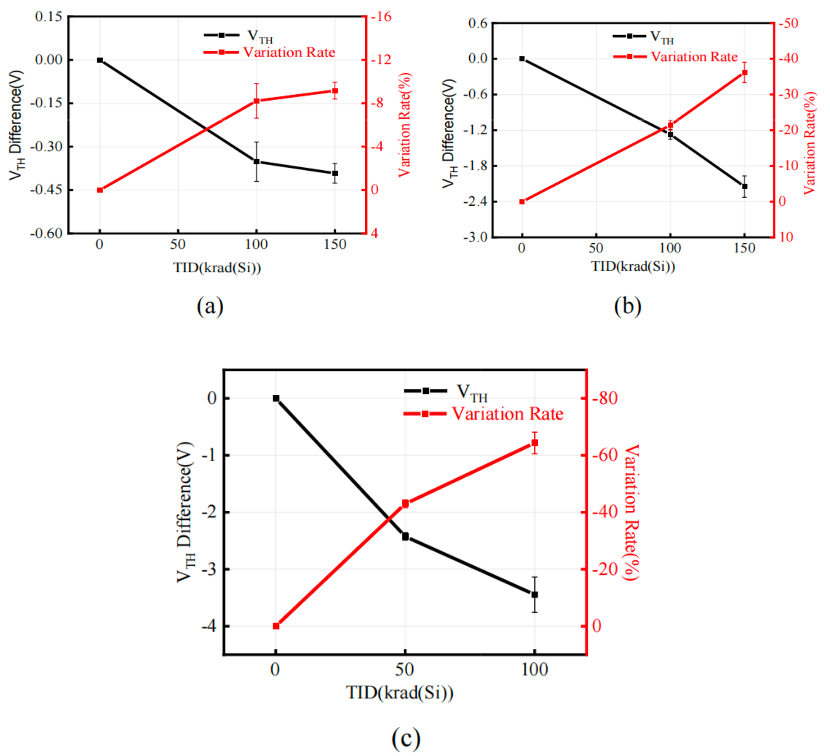

Figure 4. Calculated threshold voltage difference of SiC MOSFET power devices before and after irradiation with TID. (a) Planar structure, (b) trench structure and (c) double trench structure

3.2. Breakdown characteristics measured after irradiation

Figure 5 shows the relationship between the breakdown characteristic curves and the accumulated total ionizing dose for 1200 V SiC MOSFET devices. Specifically, Figure 5(a) presents the relationship between the breakdown characteristics of the planar-structure device and the radiation dose; Figure 5(b) shows the relationship for the trench-structure device; and Figure 5(c) illustrates the relationship for the double-trench-structure device.

A comparison of the breakdown behavior of the three device structures in Figure 5 indicates that the breakdown characteristics of the planar-structure device remain essentially unchanged with increasing radiation dose. In contrast, the breakdown characteristics of the trench-structure device exhibit a negative shift as the radiation dose accumulates, accompanied by an increase in leakage current. Although the double-trench-structure device does not show a clear negative shift in its breakdown characteristics, a substantial increase in leakage current is observed, which is significantly larger than that of the trench-structure device. According to the datasheets provided by Wolfspeed (formerly CREE), Infineon Technologies, and ROHM Semiconductor, the voltage corresponding to a leakage current of 100 μA is defined as the breakdown voltage of the device. When the accumulated radiation dose reaches 150 krad(Si), the planar-structure device shows no change in breakdown voltage (ΔV= 0 V). For the trench-structure device, when the accumulated radiation dose reaches

100 krad(Si), the change in breakdown voltage is 607 V, corresponding to a degradation rate of 41.9%. For the double-trench-structure device, when the accumulated radiation dose reaches 100 krad(Si), the change in breakdown voltage reaches 1679 V, corresponding to a degradation rate of 91.7%.

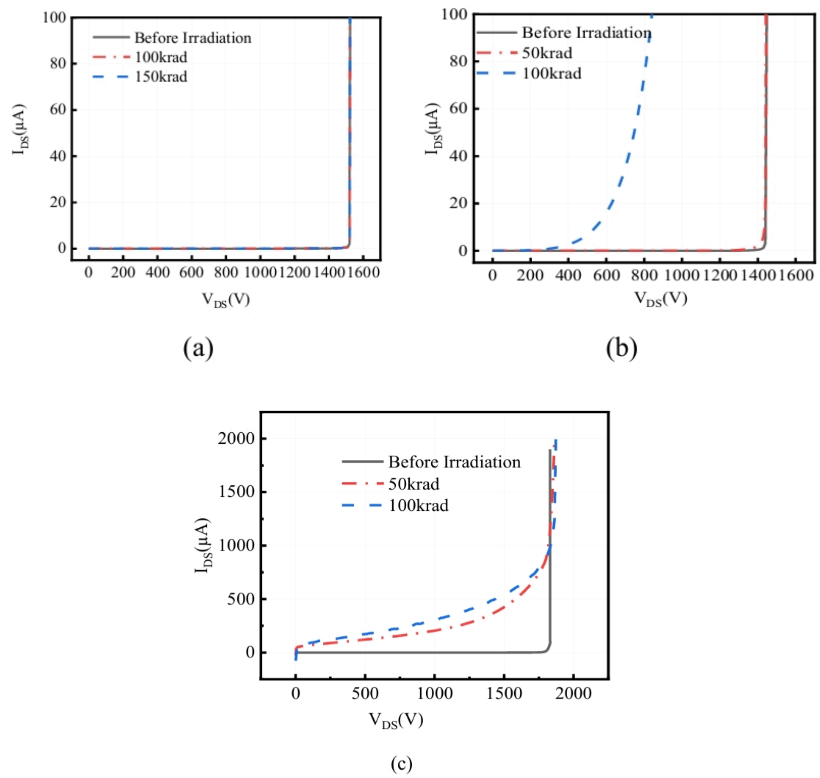

Figure 5. Measured breakdown characteristic curves of SiC MOSFET power devices before and after irradiation with TID. (a) Planar structure, (b) trench structure and (c) double trench structure

4. Conclusion

This study investigated the Total Ionizing Dose (TID) effects in 1200 V SiC MOSFET high-voltage power devices with planar, trench, and double-trench structures manufactured by Wolfspeed (formerly CREE), Infineon Technologies, and ROHM Semiconductor, respectively. The devices were exposed to a cobalt-60 gamma radiation source at a dose rate of 50 rad(Si)/s to evaluate their radiation tolerance. The TID test results show that the planar-structure SiC MOSFET power device exhibits only slight degradation in threshold voltage under relatively low radiation dose conditions. When the accumulated radiation dose reaches 150 krad(Si), the threshold voltage degradation rate is merely 9.2%, and the breakdown voltage shows no degradation. In contrast, the trench-structure and double-trench-structure SiC MOSFET power devices exhibit significant degradation under radiation exposure. When the accumulated radiation dose reaches 100 krad(Si), the threshold voltage degradation rates reach 36.2% and 64.3%, respectively, while the corresponding degradation rates of the breakdown voltage are 41.9% and 91.7%.

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