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Total Ionizing Dose (TID) Effects on the 1.2 kV SiC MOSFETs under Proton Irradiation

Jae Hwa Seo[1,a,*], Young Jun Yoon[2,b], Young Jo Kim[1,c], Hyoung Woo Kim[1,d]

[1]Advanced Semiconductor Research Center, Power Semiconductor Research Division, Korea Electrotechnology Research Institute (KERI), Changwon-si 51543, Republic of Korea

[2]Department of Electronic Engineering, Andong National University, Andong 36729, Republic of Korea

[a]jaehwaseo@keri.re.kr, [b]yjyoon@anu.ac.kr, [c]yjkim2@keri.re.kr, [d]hwkim@keri.re.kr

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Abstract. In this paper, the effects of various proton irradiation energies and doses on the electrical characteristics of SiC MOSFETs have been evaluated and characterized using a proton accelerator. The devices under test were designed, fabricated and packaged using 1.2 kV/0.6 µm-tech SiC MOSFET processes. The results demonstrate that the threshold voltage (V_{th}) of the irradiated devices shifted towards negative values due to the radiation-induced positive oxide trapped charges. Moreover, this negative shift in V_{th} and positive trapped charges of field limiting ring (FLR) oxide led to an increase in output currents and a reduction in the breakdown voltage values.

Introduction

In recent times, silicon carbide (SiC) MOSFETs have garnered significant attention owing to their superior material and device properties [1]. Specifically, SiC power MOSFETs have been embraced by the electric vehicle industry due to their high electrical robustness, thermal conductivity, radiation hardness, and wide bandgap. Additionally, the aerospace industry is also exploring the use of SiC power MOSFETs [2-3]. However, the successful integration of SiC MOSFETs in aerospace applications necessitates a thorough examination of the impact of different forms of radiation, including protons, electrons, and heavy ions, in the space environment.

Discussion

In this study, we evaluated the effect of proton irradiation energy and dose on SiC MOSFETs. The devices under test are illustrated in Fig. 1 and were designed, fabricated and packaged using 1.2 kV/0.6 µm-tech SiC MOSFET processes [4].

Table I. Irradiation energy and dose conditions of the SiC MOSFET.

DUT	Irradiation conditions	
	Proton energy	Proton dose
#1 (REF)	-	-
#2	30 MeV	1×10^{12} cm^{-2}
#3	30 MeV	1×10^{13} cm^{-2}
#4	100 MeV	1×10^{12} cm^{-2}
#5	100 MeV	1×10^{13} cm^{-2}

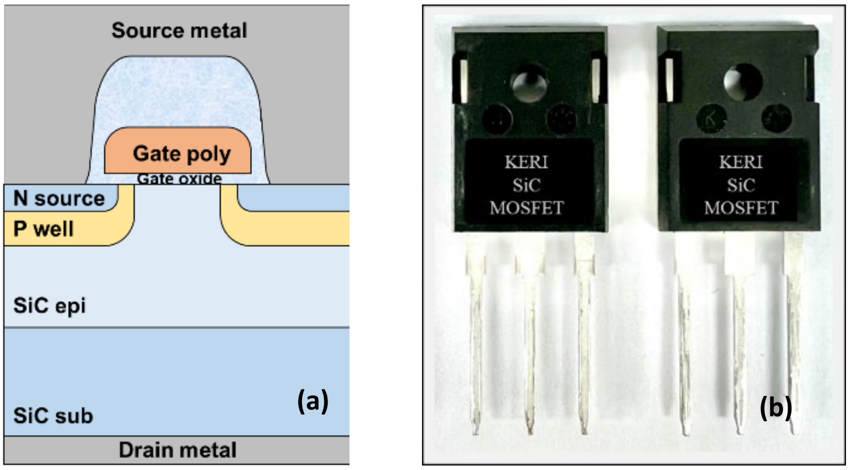

Fig. 1. (a) The cross-sectional diagram and (b) packaged 1.2 kV SiC MOSFET.

The SiC MOSFETs were exposed to various irradiation energies, 30 MeV and 100 MeV, at room temperature, with doses of 1×10^{12} cm^{-2} and 1×10^{13} cm^{-2}, respectively. Table I highlights the irradiation energy and dose conditions of the SiC MOSFET devices.

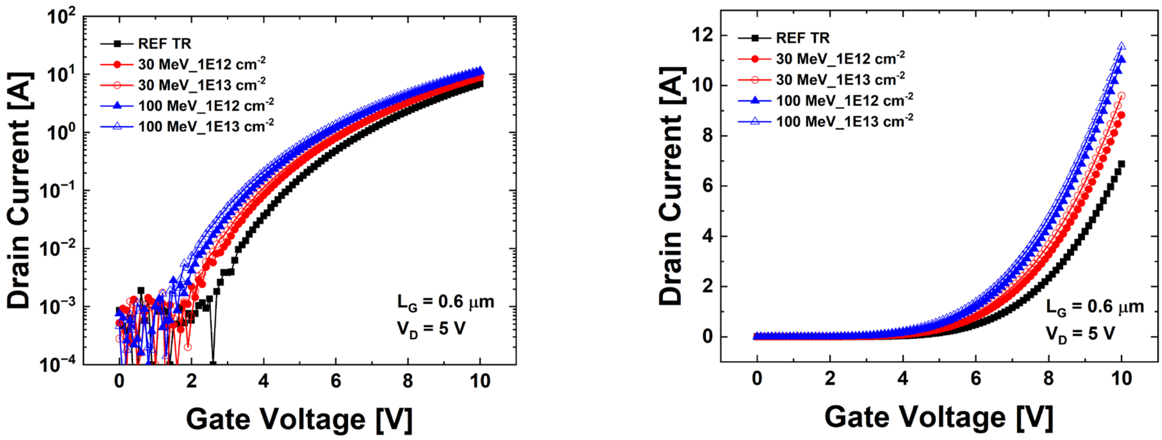

Fig. 2. The logarithmic and linear scale I_{DS}-V_{GS} transfer characteristics of DUT.

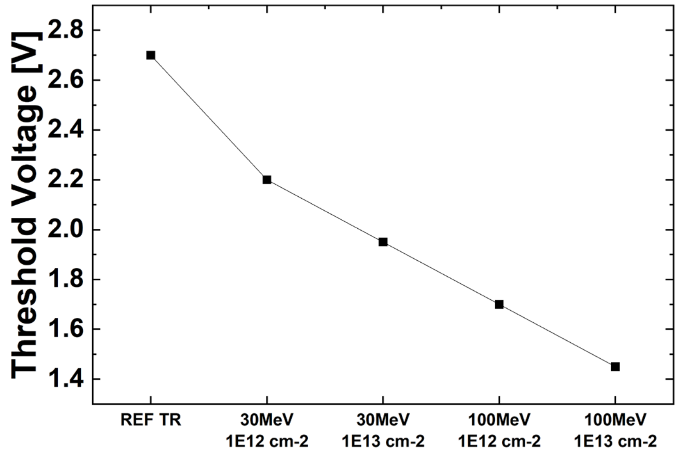

Fig. 3. The threshold voltage characteristics of DUT.

The I_{DS}-V_{GS} transfer characteristics of the SiC MOSFETs are shown in Fig. 2. The threshold voltage (V_{th}) of the irradiated devices shifted towards negative values due to the radiation-induced positive oxide trapped charges [5]. Irradiated protons can form electron-hole pairs within a 60 nm gate oxide, and these holes remain as a positive charge within the gate oxide, creating an effect as if the gate controllability has become worse. As demonstrated in Fig. 3, the use of 60 nm thick gate oxide and FLR oxide in the devices resulted in a considerable decrease in V_{th}, about 45%.

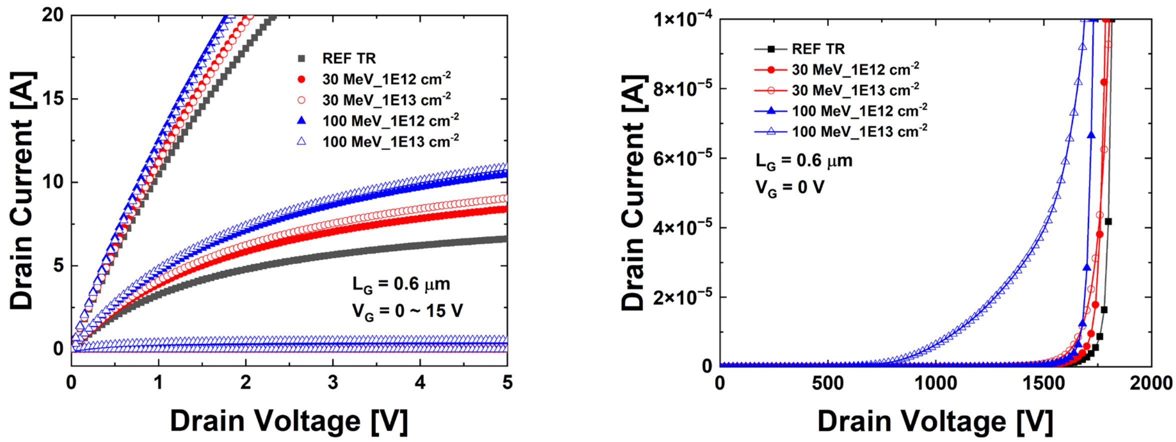

Fig. 4. The output characteristic and breakdown voltage characteristics of DUT.

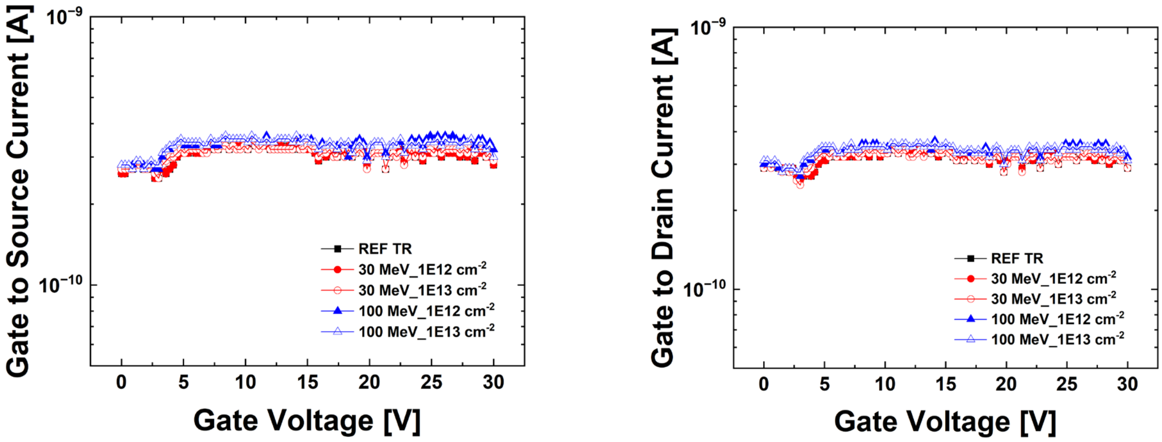

Fig. 5. The gate to source and drain leakage current characteristics of DUT.

This negative shift in V_{th} and positive trapped charges of FLR oxide led to an increase in output currents and a reduction in the breakdown voltage values, as depicted in Fig. 4. Furthermore, there were no changes in the gate leakage current, as shown in Fig. 5.

Positive trapped charges generated by protons are formed not only in the gate oxide but also in the SiO_2 located in the FLR area. These effect change the electric field distribution in the FLR area and promote a field crowding, leading to earlier breakdown. Also, the negative V_{th} shift can degrade breakdown voltage by accelerating drain-induced barrier lowering that increases the drain leakage current at $V_{GS} = 0$.

Summary

In general, the exposure of transistors to proton irradiation leads to the occurrence of both total ionizing dose (TID) and displacement damage (DD) effects. However, in this experiment, only the TID effect influenced the change in transistor characteristics. It is important to note that the DD effect of the device results in an increase in on-resistance and a decrease in on-state current characteristics. Nevertheless, these effects were not observed in our devices under test.

However, we anticipate that the degradation of the transfer characteristics will manifest with further increases in irradiation dose, and we are presently investigating this in our ongoing experiment.

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