Investigation of non-catastrophic failure mode observed in SiC diodes

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Power devices are widely used for the power handling portion of the electronic devices for space systems as well as ground-based commercial devices. In our previous study, we investigated the fatal destruction mode called single-event effects (SEEs) in the SiC schottky barrier diode (SiC-SBD) and SiC metal-oxide-semiconductor field-effect transistor (SiC-MOSFET). SiC is expected to be a candidate material the next-generation semiconductor devices. It is applicable to high-voltage and high-temperature applications because of its inherent wide energy band gap. In addition, SiC is suitable for use in ultra-high frequency applications.

However, experimental date on SiC properties for radiation are rare. If we elucidate the mechanism of SEEs, it will be an innovative achievement.

In our previous study, 3 regions were revealed in the failure mode of SiC diodes as shown in Fig. 1. Region 1 is a non-destructive region, and collected charge is reproducibly measured with no damage. In region 2, there is a permanent increase in leakage current. We define the permanent damage region, region 2 in Fig. 1, as a non-catastrophic failure region. Further, region 3 in Fig. 1 is defined as a catastrophic failure region in which a single event burnout (SEB) occures. SEB is a failure mechanism caused by a large current arising from the irradiation of heavy ion. In a previous study, it was reported that the failure mode of SiC diodes is due to local heating.[1)] By irradiating heavy ions, high density electron-hole pairs and many defects (traps) are generated along its track. The resulting current flow contributes to local heating, and carriers are generated by trap-assisted tunneling. However, little is known about which factors the mechanism is depends on, its structure, applied voltage, and energy and fluences of ions.

Thus, in this experiment, to evaluate the difference of structures of SiC diodes and the effect of fluence, 4 types of commercial SiC-SBDs were prepared. Table 1 lists the electrical characteristic of the samples. The test sample was irradiated with a Kr-ion beam with an energy of 2304 MeV using the RIKEN RILAC+RRC. The total fluence was set to 2.5×10^4 or 3×10^5 ions/cm^2 at the chip surface. The reverse voltage, V_R, was increased with an interval of 20 V.

The result of this experiment is presented Fig. 2. It shows the leakage current of all test samples. Solid lines show that the total fluence at each V_R is 2.5×10^4 ions/cm^2 and dashed lines show that it is 3×10^5 ions/cm^2 at each V_R. We defined the device as broken when the leakage current deviated from the rated current. It can be seen that the leakage current increases permanently with increasing reverse voltage. Finally, for example, the leakage current of SiC-SBD C deviated from its rated current at 400 V. The leakage current of SiC-SBD D deviated at 460 V.

Moreover, Fig. 2 shows that there are some effects of difference of radiation fluence. The leakage current increases with increasing fluence. These results correspond with the previous experimental results. Generated electron-hole pairs tended to increase with increasing radiation fluence. A greater number of electron-hole pairs causes greater damage to devices. Finally, the leakage current at 3×10^5 ions/cm^2 is greater than that at 2.5×10^4 ions/cm^2.

In this experiment, non-catastrophic failure is observed in all samples. However, for use in space, it is important to clarify the long-term reliability of SiC diodes in region 2, and additional careful experiments are required in the future.

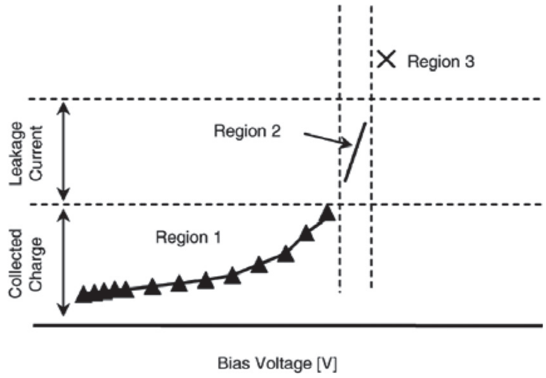

Fig. 1. Characteristic regions observed by heavy ion irradiations on SiC Schottky diodes.

Table 1. Test sample

	SiC-SBD A	SiC-SBD B	SiC-SBD C	SiC-SBD D
V_{BR}	1200 V	600 V	1200 V	1200 V
I_R	200 uA	100 uA	400 uA	200 uA
Diode Type	Schottky Barier			

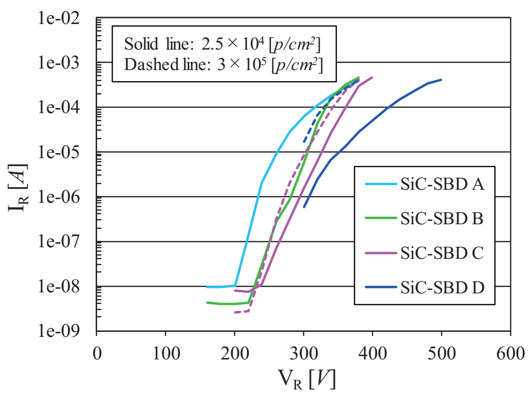

Fig. 2. Leakage current of SiC diodes.

Reference
1) S. Kuboyama et al., IEEE Trans., vol. 53, No. 6, 2006.

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