Evaluation of horizontal irradiation for SiC vertical diodes

M. Iwata,*[1] M. Takahashi,*[1] N. Ohtani,*[1] N. Nemoto,*[1] and H. Shindou*[1]

Silicon carbide (SiC) devices are the candidates for next generation power device for space applications because of their excellent electric property. To clarify the destruction mechanism of SiC devices caused by heavy ions, which is a critical issue for usage in harsh radiation environments, we have conducted experiments under various irradiation conditions.

The test was conducted on the 650 V commercial SiC vertical diodes with a junction barrier Schottky (JBS) structure, which is the same as in the previous report.[1)] Test devices were decapped and irradiated with ^{84}Kr ions at room temperature in air using RIKEN AVF coupled with the RIKEN Ring Cyclotron (RRC). The energy of ion at incident edge of the device was 3040 MeV. Irradiations were performed from different sides: one was from the upper side, the other was from the left side, horizontal to the device surface, as shown in Fig. 1. A reverse voltage (V_R) was applied to the device and the leakage current (I_R) was continuously monitored during irradiation. Further, V_R was initialized at 240 V and increased in 40 V steps after the total fluence at each V_R reached 1.0×10^6 ions/cm^2. The maximum V_R in this test was 640 V, which was close to the rated voltage of the test device.

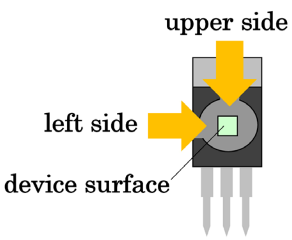

Fig. 1. Irradiation direction to the device.

Figure 2(a) shows the transition of I_R at the end of irradiation at each V_R. The device irradiated from the left side was broken at $V_R = 600$ V, whereas that irradiated from the upper side was not broken until the maximum V_R. Figure 2(b) shows the transition of I_R with increasing fluence at $V_R = 600$ V irradiated from the left side; I_R abruptly increased and reached approximately 6 mA.

The same test was conducted for different samples to confirm the effects of crystal direction relative to ion tracks. The samples were 650 V SiC diodes created by the same company; however its structure was planar type, which does not have p+ regions at the Schottky contact. No increase in I_R was observed when irradiated from both sides, which implies that interaction between the p+ regions and charges generated by a heavy ion affected the device breakdown more than crystal direction.

*1 Research and Development Directorate, Japan Aerospace Exploration Agency

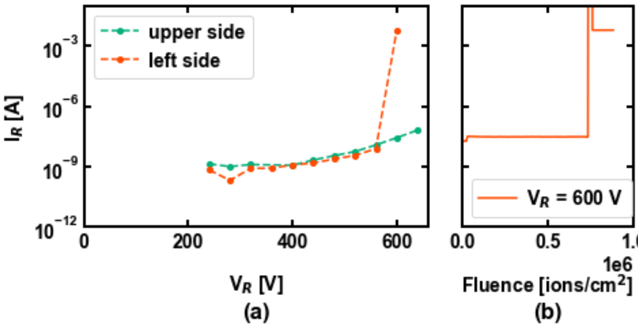

Fig. 2. (a) Transition of I_R during irradiation and (b) Transition of I_R at $V_R = 600$ V irradiated from left side.

Follwing the test, a surface damage considered evidence of single-event burnout (SEB) was observed on the device irradiated from the left side. It was located approximately 320–450 μm from the left edge of the device. Focusing on linear energy transfer (LET) transition in the device, the highest LET with a Bragg peak was 43.8 MeV/(mg/cm^2) at 383 μm, which is approximately the center of the damage site. Note that incidence position in device thickness direction remained unclear in this test; however, for triggering SEB, an ion was introduced into the depletion layer because deposited charges must be accelerated by the electric field.

The electric field lines within depletion layer are perpendicular to the surface under certain V_R; thus, charges generated by an ion move vertically in vertical diodes. These charges are amplified in the collection process, which can cause device degradation or destruction. Although less amplification can be expected for horizontal irradiation because reduction in charge multiplication with increasing tilt angle has been reported,[2)] a rapid increase in I_R and surface damage were observed in the device irradiated from the left side. The same behavior could not be observed at normal incidence (*i.e.*, perpendicular to the device surface) with the same ion and device; gradual increase of I_R at lower V_R was observed instead. Focusing on a small vertical region in the device, charges generated by horizontal irradiation are considered to exist as a point, and all charges including amplified charges might be collected in an extremely short period of time. However, the time for all charges to be collected at normal incidence might be longer than horizontal irradiation because charges are generated in a vertical line along an ion track. This difference in collecting time period might affect the difference in destruction mode.

References
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2) A. Javanainen *et al.*, IEEE Trans. Nucl. Sci. **64**, 2031 (2017).