Study on radiation resistance of GaN power devices†

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

Single event effects in power devices such as single event burnout (SEB) and single event gate rupture (SEGR) cause permanent damage to devices. Since SEB and SEGR in spacecraft power supply components directly lead to spacecraft loss, it is important to improve the radiation hardness of power devices for space applications by optimizing the device structure or process. Gallium nitride (GaN) power devices are expected to be applicable to spacecrafts as replacements for conventional silicon power devices because of their excellent performance. However, their susceptibility to heavy ions under significantly lower voltage than the rated voltage has been reported,[1–3] and the damage mechanisms are still unclear. In this paper, we report radiation test results of normal-off lateral GaN power field effect transistors.

Figure 1 shows a cross sectional image of the test device and irradiation directions for the test. Test devices were irradiated with ^{84}Kr ions in air using RIKEN AVF in combination with the RIKEN ring cyclotron. The energy of the ion at the incident edge of the device is 1713 MeV and the range is 123 μm in GaN. The gate-source voltage (V_{GS}) was set to 0 V to maintain the device off-state. The drain-source voltage (V_{DS}) was applied and increased in a given voltage step after the total fluence at each V_{DS} reached 3.0×10^5 in the perpendicular condition or 3.5×10^5 in the angled condition. Note that the rated V_{DS} of this device is 800 V. However, since the device does not immediately break down when it is biased above its rated voltage, part of this evaluation was performed by applying a voltage higher than the rated voltage. The drain and gate leakage current (I_D, I_G) was continuously monitored during irradiation.

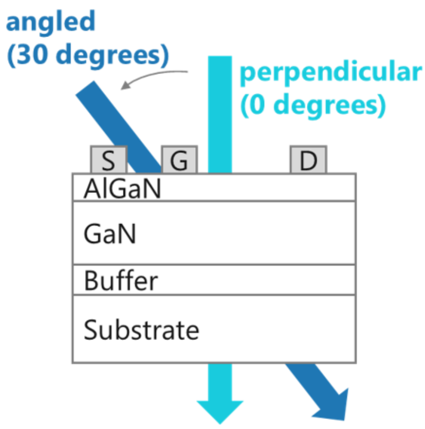

Fig. 1. Cross sectional image of the device and irradiation angle.

Figure 2 shows the leakage current transition at the end of irradiation at each V_{DS}. No increase in leakage current was observed under the perpendicular condition, whereas I_D and I_G rapidly increased at $V_{DS} = 850$ V under angled irradiation. This result indicates that angled irradiation is worse in this device than perpendicular condition, which is known as the worst irradiation condition in most power devices.[4] Additional experiments at another facility showed that larger ion incidence angles resulted in lower breakdown V_{DS}, and the worst irradiation condition was along horizontal direction to the device surface and orthogonal to the electrode stripes of the device. In addition, the simultaneous surge in I_D and I_G during irradiation was confirmed in all broken devices, suggesting the formation of a leakage path between the gate and drain. Since the worst-case direction corresponds to the path of the current flow, it is assumed that the breakdown is caused by the localized high current flow due to the multiplication of charge induced by an ion.

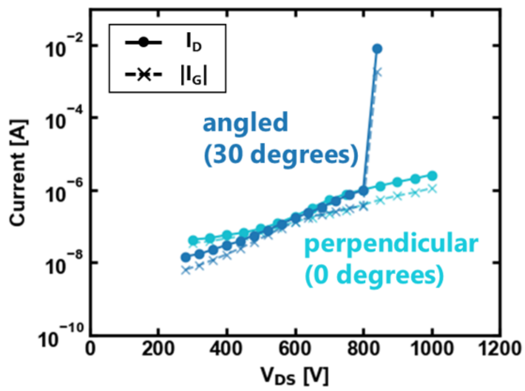

Fig. 2. Transition of the leakage current of the test device.

Horizontal irradiation, which is the worst-case condition of this device, is difficult to conduct as it requires significantly high energy beams with long range in GaN. The result of this test indicates that the failure modes were the same regardless of the irradiation angle and direction, and thus, angle irradiation can be used to evaluate radiation hardness of the improved device. In the future, we will evaluate improved prototype devices by angle irradiation and analyze the failure mechanisms by a combination of failure analysis and TCAD simulation.

† Condensed from the article in Proc. 67th Space Sci. Technol. Conf., JSASS-2023-40949 (2023).
*1 Research and Development Directorate, Japan Aerospace Exploration Agency

References
1) S. Kuboyama *et al.*, IEEE Trans. Nucl. Sci. **53**, 3343 (2006).
2) S. Kuboyama *et al.*, IEEE Trans. Nucl. Sci. **58**, 2734 (2011).
3) E. Mizuta *et al.*, IEEE Trans. Nucl. Sci. **65**, 1956 (2018).
4) J. L. Titus, IEEE Trans. Nucl. Sci. **60**, 1912 (2013).

DOI:10.34448/RIKEN.APR.57-076