Investigation of single-event effect observed in GaN-HEMT

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Wide bandgap semiconductor devices, such as GaN and SiC, are attractive for next-generation satellites to reduce the energy losses in high-power and high-frequency systems. Although Si is still the dominant material used in space systems, there is a strong demand for new more efficient new devices. For GaN-HEMTs, the single event effects (SEEs) for tele-communication or radar components have already been evaluated. However, there are few reports for power-handling applications. For use in satellite power applications, it is necessary to resolve SEE mechanisms and take some appropriate steps.

In this study, we report the results of evaluating SEE on GaN-HEMT for power-handling applications. Table 1 lists the details of ions that were used for the evaluation in this study. Figure 1 shows device structures. The GaN-HEMT in this study is a commercial off-the-shelf 600 V device.

Typical experiment results are shown in Fig. 2. Figure 2(a) shows the change of I_{DS} during irradiation as a function of Xe fluence at V_{GS}=0 V. Devices were irradiated sequentially in steps of 20 V. Figure 2(b) shows I_{DS} and IGS at the end of each irradiation run as a function VDS. Therefore, the curves indicate the increase of leakage current induced by the heavy ions. For Xe ions, the leakage current increased continuously as the fluence increased in the range of 300–360 V, and finally the device was destroyed at 380 V because of excessive current. The continuous behavior suggests that the damages occur at localized damage sites introduced by each ion strike. For tests with Kr ions that at V_{GS}=0 V, the leakage current does not increase up to 500 V, and the device was suddenly destroyed at 520 V because of excessive current. On the other hand, for a test at V_{GS}=+0.95 V, device destruction did not occur until the rated voltage of the device. It is assumed that the reason why the device was not broken at V_{GS}=+0.95 V was the voltage drop between the drain and source due to the current flowing between the drain and source. The difference of behaviors between Xe and Kr ions might be attributable to the difference of LETs to create the damage sites. From Fig. 2, it can be seen that a large current flow between the drain and source. However, because the source pad of this device was connected to the substrate, to distinguish the current pass, a detailed electrical measurement was performed after cutting the connection between the source and substrate. Figure 3 shows the leak current between the drain and substrate after irradiation. Clearly, a conduction pass was observed between the drain and substrate.

To confirm the electrical pass between the drain and substrate, charge collection measurements with Kr ions

Table 1. Characteristics of the ion species.

Ion	^{86}Kr	^{136}Xe
Energy [MeV]	1600	2567
Range [um]	0.951	98.3
LET (GaN surface) [MeV · cm^2/mg]	18.0	36.2

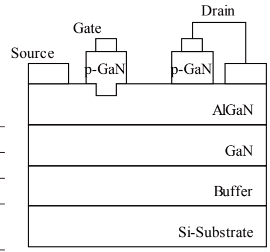

Fig. 1. Device structure.

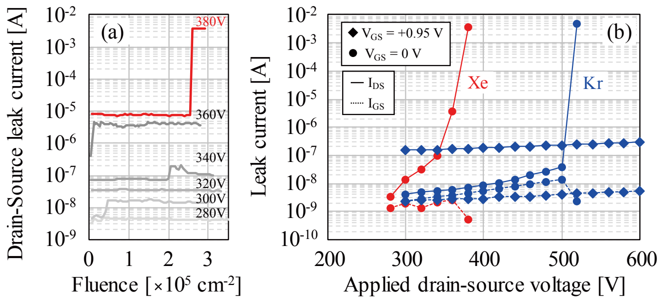

Fig. 2. Irradiation experiment results of GaN-HEMT.

were performed before breakdown. In the measurements, the sample device works as a solid-state detector (SSD) for the particle-energy analyzing system, and the collected charge spectra are shown in Fig. 4. The figure also shows that charges flow between the drain and substrate. Moreover, the peak corresponds to the charge collected in the entire geometric active area on the Si substrate. Additionally, the collected charge is enhanced at a higher bias voltage. However, the maximum collected charge is approximately 1.0 pC, which is much less than the charge deposited in the Si substrate, approximately 70 pC. The active layer and Si substrate are electrically connected by a charge column generated by an ion, but the conductivity disappears while a small portion of the charge deposited in the Si substrate is collected.

In this experiment, the SEE in GaN-HEMT was observed. It is assumed that one failure mode of this GaN-HEMT is the electrical connection between the active layer and Si substrate due to ion incidence. On the other hand, this phenomenon might depend on the angle of ion incidence or portions on which ions are incident. In future work, it is necessary to change these parameters and to investigate another failure mode.

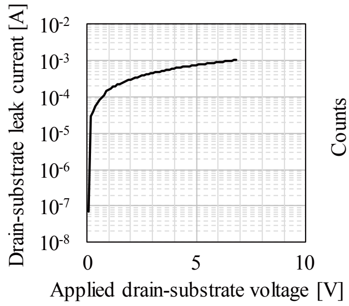

Fig. 3. Drain-substrate leak current after irradiation.

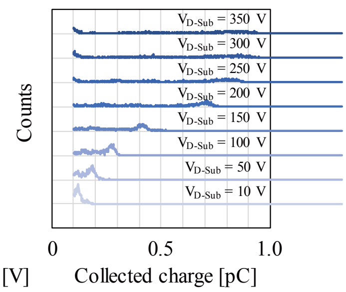

Fig. 4. Collected charge spectra.

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