Space radiation effects in GaN-based devices

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***Abstract*— GaN-based devices are attractive as a component of radiation-hardened applications due to higher atomic displacement threshold energy. Because protons are abundant in space, the proton irradiation effects of AlGaN/GaN HEMTs were studied by many research groups, however, most researches were focused on the difference in performance before and after proton irradiation. To accurately evaluate the space radiation effects of electronics operating in space radiation environments, the real-time effects on AlGaN/GaN HEMTs should be studied under operating bias conditions. Therefore, we investigated the synergy effect between biasing and proton fluence, as well as, real-time drain and gate current of devices under different bias conditions during irradiating 100 MeV protons.**

***Keywords*— AlGaN/GaN, HEMT, Proton, Space radiation effects**

I. INTRODUCTION

AlGaN/GaN-based HEMTs(high electron mobility transistors) has a higher radiation hardness compared to Si and GaAs-based devices [1], which can be attractive candidate operating in radiation environments like space.

There are space radiation effects in devices like a TID(total ionizing dose) effect, a DD(displacement damage) effect, and a SEE(single event effect).

Protons are abundant in a space environment, therefore, the proton irradiation effect on the performance of AlGaN/GaN HEMTs was evaluated by many research groups [2-9]. Protons can not only directly cause TID and DD effects but also indirectly cause SEE. However, most researches were focused on the difference in performance before and after irradiation under no bias conditions to assess DD effect. To accurately confirm the proton radiation effects of HEMTs operating in space environments, the devices should be evaluated under operating bias conditions. It is also necessary to confirm the effect of bias conditions on the proton-irradiated HEMTs.

In this study, we investigated the synergy effect between biasing and proton fluence, as well as, real-time drain and gate current of devices under different bias conditions during irradiating 100 MeV protons.

II. EXPERIMENTS

T-gated AlGaN/GaN HEMTs for X-band applications were fabricated by ETRI (Electronics and Telecommunications Research Institute), which showed the good pinch-off characteristic and RF performance as shown in Figure 1.

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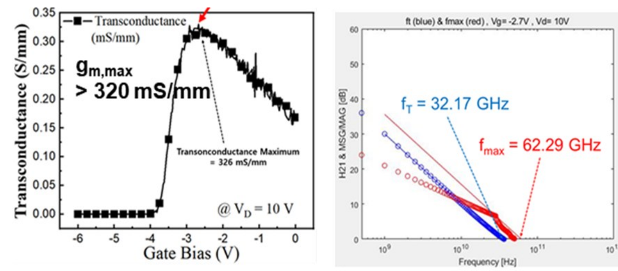

Fig. 1. Transfer and RF characteristics of T-gated AlGaN/GaN HEMT fabricated by ETRI

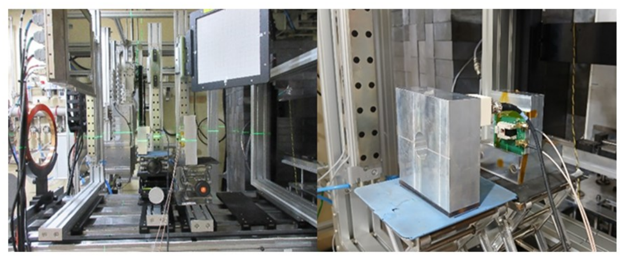

Fig. 2. Photograph of 100-MeV proton irradiation experiments at KOMAC of KAERI

100-MeV proton irradiation to HEMTs was performed at KOMAC (Korea Multi-purpose Accelerator Complex) of KAERI(Korea Atomic Energy Research Institute). To confirm the synergy effect between biasing and proton fluence, three HEMTs were exposed from 10^{11} to 10^{13} p/cm^2, respectively, under V_{GS} of -8 V and V_{DS} of +10 V. For comparison, one device was exposed by 10^{13} p/cm^2 under no biasing. In addition, we measured the real-time drain and gate current of HEMTs under different bias conditions, such as off-state (V_{GS}/V_{DS} = -6/+10 V), semi-on state (V_{GS}/V_{DS} = -3/+10 V), and on-state (V_{GS}/V_{DS} = 0/+10 V), respectively, during irradiating protons up to 5×10^{13} p/cm^2 for evaluating the SEE. Figure 2 showed a photograph of proton radiation experiments.

III. RESULTS & DISCUSSION

Figure 3 showed the transfer I-V characteristics of proton-irradiated HEMTs with different fluence under gate and drain biasing. In case of all grounded HEMT, the characteristics were not almost changed after proton irradiation(not shown) because the proton fluence of 10^{13} p/cm^2 was not enough to cause displacement damage effect [6]. Under biasing, the threshold voltage of all devices was negatively shifted by charge trapping effect, especially gate bias stress. And we found that more proton-irradiated HEMT

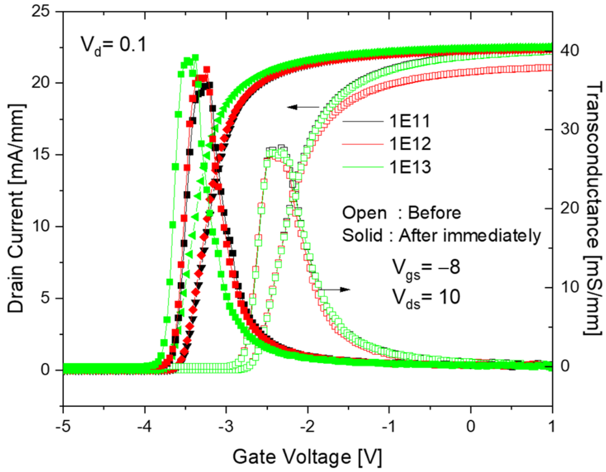

Fig. 3. Linear transfer *I-V* characteristics of proton-irradiated HEMTs with different fluence under V_{GS}/V_{DS} = -8/+10 V.

is more shifted. It is indicated that degree of change in threshold voltage depends on the proton fluence, which means that radiation-induced defects act as additional sites for charge trapping after proton irradiation.

The real-time drain and gate currents of HEMTs were measured before/on/after proton irradiation under different operating states, as shown in Figure 4.

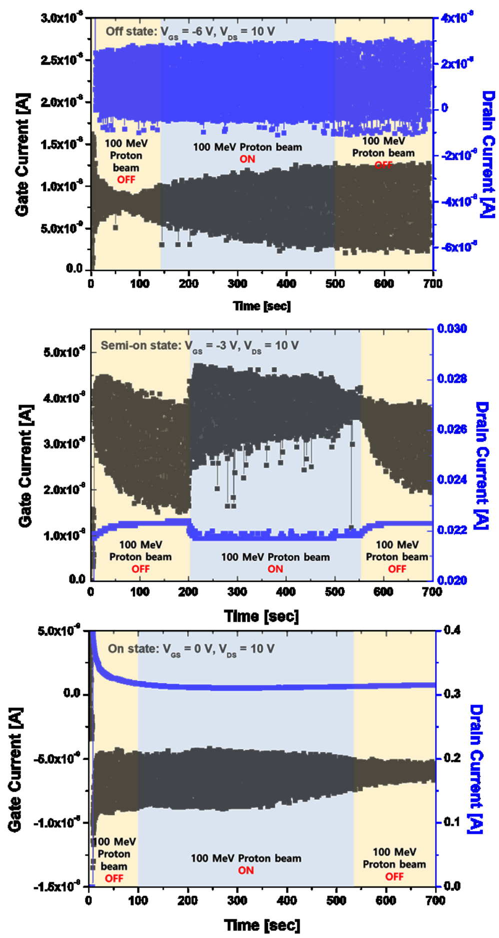

Fig. 4. Real-time measured drain and gate currents of HEMTs before/on/after 100-MeV proton irradiation under different operating states.

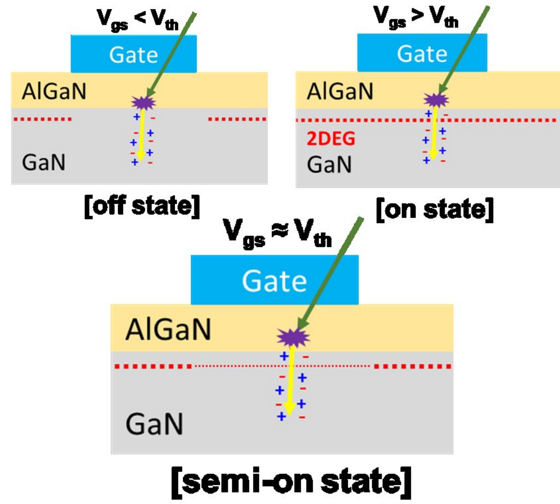

Fig. 5. Schematic of proton-induced SEE phenomenon under various operating states.

Under off- & on-states, the real-time current characteristics of HEMTs were not almost changed with and without proton irradiation. However, under semi-on state, the temporary leakages in drain and gate currents were occurred during proton irradiation into HEMT, which means that proton-induced SEE was confirmed. Figure 5 illustrated the schematic of proton-induced SEE phenomenon under various operating states. SEE-induced electrons around 2-dimensional electron gas(2DEG) can be additional electrons in channel by drain electric field induced drift. Under off-state, these electrons cannot supply in 2DEG due to channel depletion. Under semi-on state, these electrons can occasionally supply in 2DEG due to existence of weak channel, which caused the temporary increase in drain current. Under on-state, these electrons are significantly smaller than electrons in 2DEG. If 100-MeV protons are irradiated into HEMT applied drain biasing close to breakdown voltage, the device will be burn-out(destructive) due to SEE.

IV. Summary

The proton irradiation effects of AlGaN/GaN HEMTs on electrical properties under various bias conditions were investigated. We confirmed that proton irradiation can induce defects acting as additional sites for charge trapping, which can influence the shift of threshold voltage. Through real-time current measurement, the proton-induced SEE was observed in semi-on state of HEMT. This temporary current is related to the proton irradiation energy, flux, fluence and drain bias condition because all parameters can affect the probability of occurrence in SEE.

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