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5-MeV Proton-irradiation characteristics of AlGaN/GaN – on-Si HEMTs with various Schottky metal gates

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Abstract

5 MeV proton-irradiation with total dose of 10^{15} /cm^2 was performed on AlGaN/GaN-on-Si high electron mobility transistors (HEMTs) with various gate metals including Ni, TaN, W, and TiN to investigate the degradation characteristics. The positive shift of pinch-off voltage and the reduction of on-current were observed from irradiated HEMTs regardless of a type of gate materials. Hall and transmission line measurements revealed the reduction of carrier mobility and sheet charge concentration due to displacement damage by proton irradiation. The shift of pinch-off voltage was dependent on Schottky barrier heights of gate metals. Gate leakage and capacitance-voltage characteristics did not show any significant degradation demonstrating the superior radiation hardness of Schottky gate contacts on GaN.

Key words: *AlGaN/GaN-on-Si, high electron mobility transistors, proton irradiation, displacement damage, Schottky contact.*

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I. INTRODUCTION

Field effect transistors (FETs) based on AlGaN/GaN heterostructure have been strong candidates for high-speed and high-power applications owing to excellent material properties such as high saturation velocity and large breakdown voltage [1]. In addition, GaN-based devices have exhibited the potential to endure extreme environments such as an elevated temperature and high radiation [2],[3]. Radiation-abundant environment of the space requires radiation-hardened devices

in space electronics. Majority of satellites and space stations are in low earth orbital to date and protons are major species of radiation effects in this region. Previous works on the radiation response to proton irradiation reported that displacement damage is a main cause of radiation-induced degradation in GaN HEMTs [4],[5].

In this work, we fabricated AlGaN/GaN Schottky HEMTs on Si with various gate metals including Ni, TaN, W and TiN. The fabricated devices were subjected to proton irradiation with a total dose of 10^{15} cm^{-2} at 2 MeV. Moderate dependence on Schottky barrier heights (SBHs) of device degradation was observed after irradiation.

II. EXPERIMENTS

AlGaN/GaN Schottky HEMTs were fabricated on commercially available GaN-on-Si substrate. The schematic cross-sectional view of AlGaN/GaN Schottky HEMTs on Si is presented in Fig. 1. The epitaxial structure consisted of a 4.3 μm GaN buffer layer on Si (111) substrate, a 20 nm AlGaN barrier layer and a 4 nm GaN capping layer. Source/drain ohmic contacts were formed with Ti/Al/Ni/Au (20/120/25/50 nm) layers alloyed by rapid thermal annealing at 830 ℃ for 30 sec in nitrogen ambient. After active area was defined by mesa etching process, a 30 nm SiO_2 was deposited by using plasma enhanced chemical vapor deposition (PECVD). Finally, Schottky metal gates were formed with Ni, TaN, W, and TiN. Ni was deposited by e-beam evaporator and the other metals were by sputtering. The gate length (L_G), gate-to-drain distance (L_{GD}), and gate-to-source distance (L_{GS}) were 2 μm, 15 μm, 3 μm, respectively.

Proton irradiations were performed at the Korea Institute of Radiological and Medical Sciences using an MC-50 cyclotron. The devices were irradiated at a room temperature under low vacuum atmosphere with proton energy of 5 MeV. Total proton dose was 10^{15} cm^{-2}. No electrical connection was made to the devices during irradiation test.

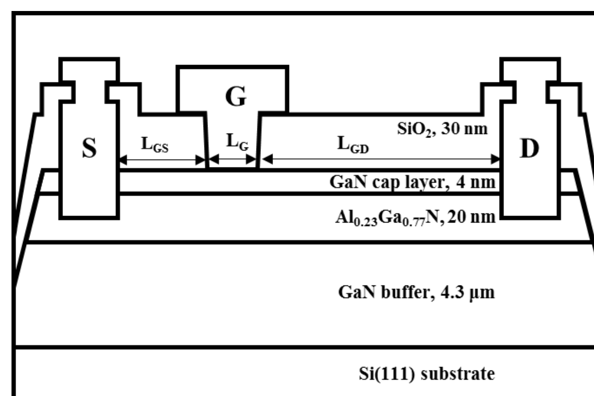

Fig. 1 The cross-sectional view of the fabricated AlGaN/GaN HEMT on Si.

III. RESULTS AND DISCUSSION

DC I-V characteristics were measured before and after the irradiation test to investigate the proton irradiation effect. The output of AlGaN/GaN Schottky HEMTs are shown in Fig. 2 and 3, respectively. After proton irradiation, all types of devices exhibited the increase of on-resistance (R_{ON}) and the reduction of drain current in the output characteristics. The changes in specific R_{ON} of each device were summarized in Table. 1.

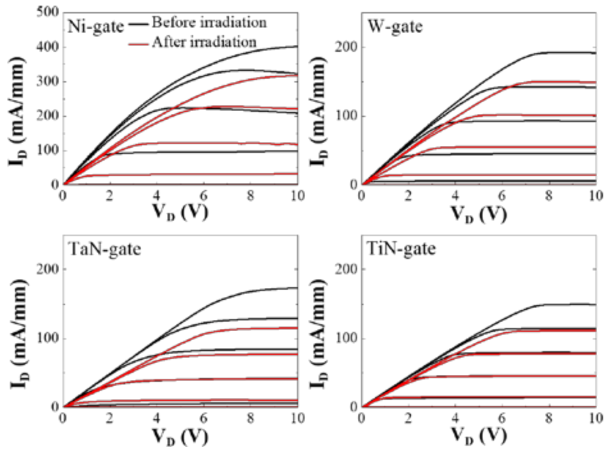

Fig. 2 The output characteristics measured from V_G = 1 to −5 V (−1 V step) before and after proton irradiation.

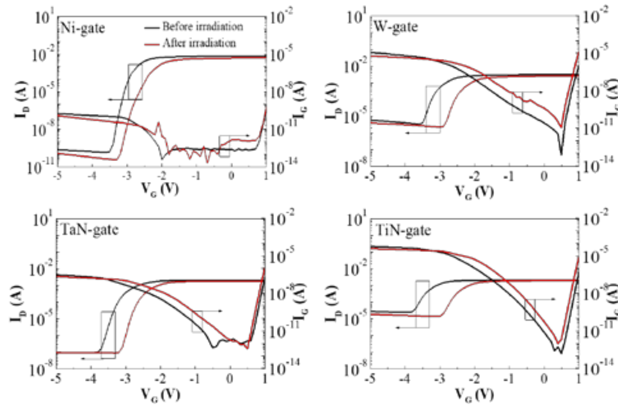

Fig. 3. The transfer characteristics measured at V_D = 1 V before and after proton irradiation.

As shown in Fig. 3, the reduction of on-current and off-state leakage were also observed in the transfer characteristics of all types of devices.

Hall measurements were carried out to investigate the radiation effects on the transport properties of the electron channel at heterojunction. We measured Hall measurement patterns fabricated on the same wafer to extract Hall-mobility, sheet carrier concentration, and sheet resistance. The results are summarized in table. 2.

Table 1 The change of R_{ON} by proton irradiation.

R_{ON} ($m\Omega*cm^2$)	Ni	TaN	W	TiN
Before irradiation	2.59	7.41	5.43	7.1
After irradiation	3.65	9.30	6.51	8.06

Table 2 The change of the transport parameters by proton irradiation from Hall measurements.

	μ (cm^2/Vs)	n_{sh} (cm^{-2})	R_{sh} (Ω/□)
Before irradiation	1700	$7.7x10^{12}$	472
After irradiation	1170	$6.5x10^{12}$	816

Each parameter was degraded by proton irradiation regardless of a type of Schottky metal. Hall measurement clearly indicated that the degradation of R_{ON} and on-current should be to the degradation of the channel properties. The degradation of electrical properties was related to proton bombardment effects in GaN-based heterostructures [6],[7].

The Schottky barrier height (SBH) was extracted from the forward I-V characteristics of Schottky gate diodes. The SBH of each type of the device was reduced after proton irradiation. The SBH reduction was inversely proportional to the magnitude of SBH. In fig. 3, a positive shift of the pinch-off voltage (V_{th}) was

observed after proton irradiation. The magnitude of the V_{th} shift became larger as the SBH decreases. The changes of device parameters were summarized in table 3. It suggests that radiation-hardness can be improved by employing the gate metal with a large SBH.

Table 3 The change of the SBH and V_{th} by proton irradiation.

metal	SBH (eV)	△SBH (eV)	△V_{th} (V)
Ni	1.09	-0.04	0.41
TaN	0.91	-0.045	0.57
W	0.85	-0.05	0.67
TiN	0.79	-0.07	0.79

IV. CONCLUSIONS

We investigated the effect of proton irradiation on AlGaN/GaN-on-Si HEMTs with Ni, TaN, W, and TiN Schottky contacts. The positive shift of V_{th} and the reduction of on-current were observed due to displacement damage. Hall measurements revealed that the transport properties of the electron channel were degraded by proton irradiation. The devices with the gate metal having the larger SBH demonstrated the stronger radiation resistance.

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