The Effects of SF_6 Plasma and *in-situ* N_2 Plasma Treatment on Gate Leakage, Subthreshold Slope, and Current Collapse in AlGaN/GaN HEMTs

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We achieved substantial improvements in gate leakage currents, subthreshold characteristics, and current collapse phenomena for AlGaN/GaN high electron mobility transistors (HEMTs). We investigated the removal of SiN_x pre-passivation layer and the SiN_x re-deposition process for great performance.

The conditions of the sensitive GaN surface and the SiN_x pre-passivation layer which was deposited with the intention of protecting the cleaned GaN surface might have been changed when we carried out the ohmic annealing at high temperature. Therefore, we employed SF_6 plasma for the removal of the high temperature annealed 100 Å SiN_x pre-passivation layer and the GaN surface treatment. So far the effects of SF_6 treatment were investigated with hard plasma conditions [1]. However, we employed low damage soft SF_6 plasma treatment with various exposure times such as 1 min, 2 min, 3 min, and 5 min, which would reduce the possible plasma damage. By using soft plasma treatment with only SF_6 gas and optimized short time, we could prevent carbon or oxygen contamination and defects on the surface which might introduce traps on GaN.

To recover nitrogen-vacancy and suppress current collapse phenomena, N_2 plasma treatment prior to SiN_x passivation has been widely used [2]. However, since long-time N_2 plasma treatment also would induce excess plasma damage, we experimented by varying exposure time such as 1 min, 2 min, and 4 min. A small amount of fluorine ions might have occurred by SF_6 plasma treatment, although we employed soft plasma condition for SF_6. Therefore, we carried out *in-situ* N_2 plsma treatment to reduce the fluorine residues before 1200 Å SiN_x re-deposition. Fabrication flow was described in Fig. 1.

By optimizing SF_6 plasma and in-situ N_2 plasma treatment prior to SiN_x passivation (re-deposition), we reduced the reverse biased gate leakage currents to 67 nA/mm at the gate voltage of -100 V, which belongs to the lowest ever reported as shown in Fig. 2. It is thought that the quality of the SiN_x/GaN interface and Ni/GaN Schottky interface was improved due to the enhanced GaN surface [3]. We also reduced subthreshold slope to 71 mV/dec as shown in Fig. 3. XPS measurement results showed that the amount of fluorine ions was reduced after *in-situ* N_2 plasma treatment in Fig. 4, therefore we could improve pulsed I-V characteristics with proper *in-situ* N_2 plasma treatment as shown in Fig. 5. Breakdown voltage was 220 V at I_D = 1 μA/mm and specific on-resistance was 0.52 $m\Omega\cdot cm^2$ with SF_6 plasma and *in-situ* N_2 plasma treatment for each 2 min as shown in Fig 6.

[1] G. Vanko et al., Vacuum, vol. 84, pp. 235-237, 2009.

[2] H. Hasegawa et al., J. Vac. Sci. Technol. B, vol. 21, pp. 1844-1855, 2003.

[3] T. Hashizume et al., Appl. Phys. Lett., vol. 84, pp. 4884-4886, 2004.

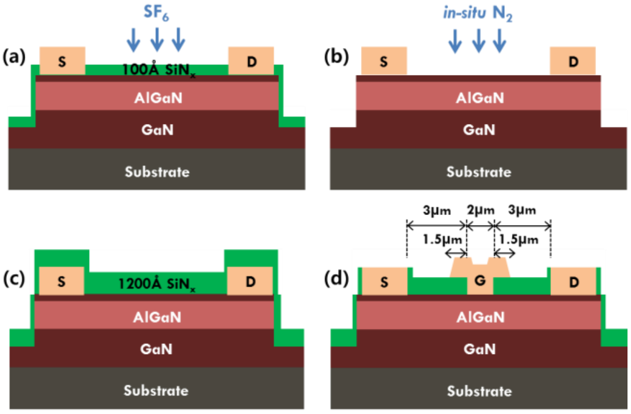

Fig. 1. Cross-sectional schematic of AlGaN/GaN HEMT fabrication flow after ohmic formation. 100 Å SiN_x was removed and then surface treatments were carried out simultaneously by using SF_6 plasma before 1200 Å SiN_x re-deposition with *in-situ* N_2 plasma treatment.

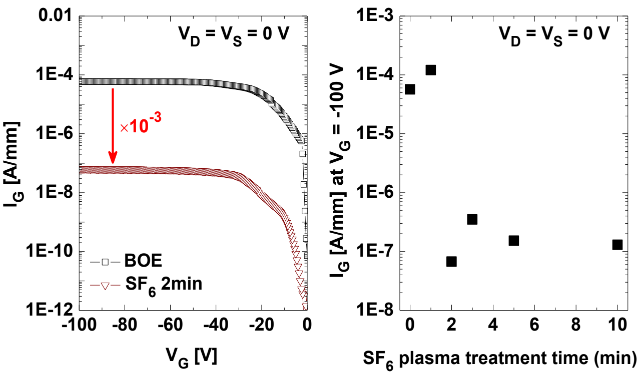

Fig. 2. Reverse biased gate leakage currents of AlGaN/GaN HEMTs with and without SF_6 plasma treatment. The reduction of reverse biased leakage current with SF_6 plasma treatment for 2 min is about three orders of magnitude.

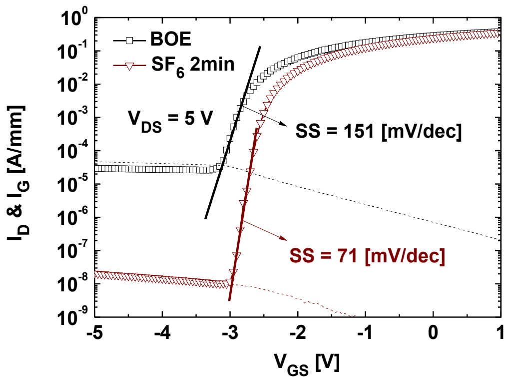

Fig. 3. Subthreshold characteristics (symbol line) and gate leakage currents (dashed line) of AlGaN/GaN HEMTs with and without SF_6 plasma treatment at V_{DS} = 5 V.

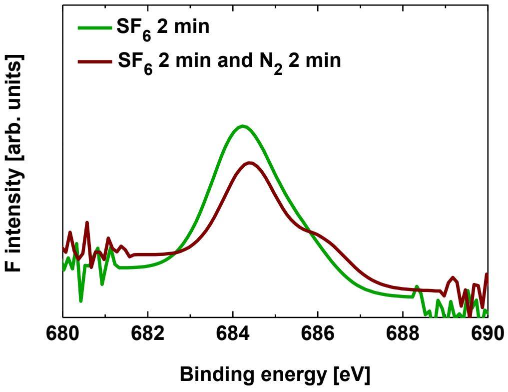

Fig. 4. XPS measurements of F1s peak after SF_6 plasma treatment and *in-situ* N_2 plasma treatment.

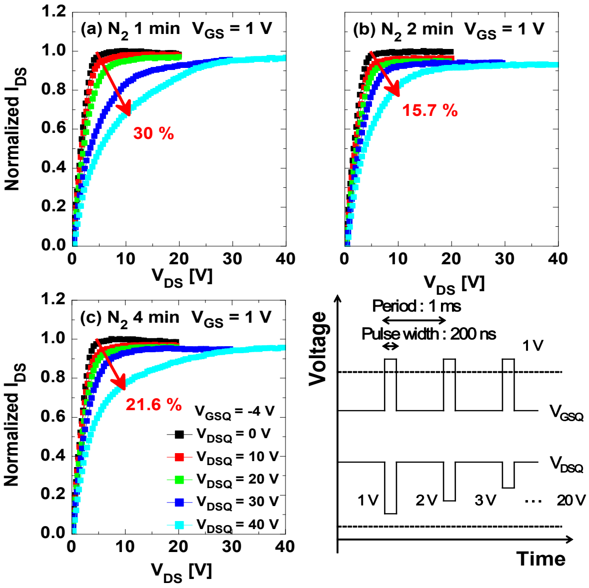

Fig. 5. Pulsed I-V characteristics of AlGaN/GaN HEMTs (W_G = 2×50 μm) with SF_6 treatment for 2 min and *in-situ* N_2 plasma treatment for (a) 1 min, (b) 2 min, and (c) 4 min.

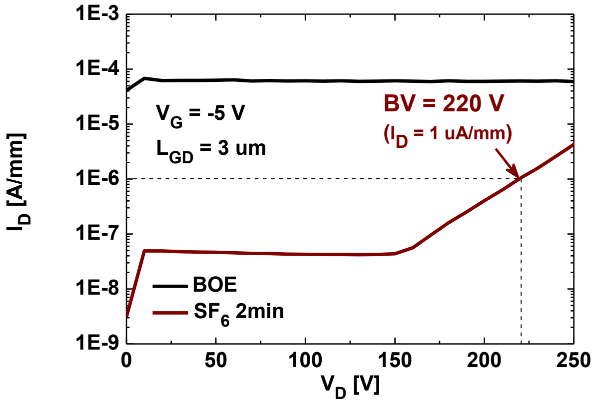

Fig. 6. Breakdown voltage measurements with and without SF_6 plasma treatment.