Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp504-505

Effect of Two-Step E-Beam SiO_2 Passivation on AlGaN/GaN HEMT Performance

Hsiang-Lin Yu, Heng-Kuang Lin*, and Yi-Jen Chan

*Department of Electrical Engineering, National Central University, Chungli, Taiwan 32054, R.O.C
Phone: +886-3-4227151 ext 34526 Fax: +886-3-4255830, E-mail: hklin@ee.ncu.edu.tw

1. Introduction

There has been intense development of AlGaN/GaN high-electron-mobility transistors (HEMTs) as candidates for high power and high temperature applications at microwave frequencies. However, the performance of these devices is limited by trapping effects through drain current collapse. Much attention has been focused on the reduction of surface states using different passivation dielectrics such as Si_3N_4, SiO_2, SiO, benzocyclobutene (BCB)…etc [1][2]. Plus, MIS devices fabricated on the AlGaN/GaN material system [3] and capping an in-situ Si_3N_4 layer during epitaxy growth [4] are reported and exhibit current collapse-free performance. In this work, we propose a two-step passivation process using e-beam evaporation, which imitates the in-situ concept and targets minimization of processing effect on the dielectric-AlGaN interface state density. Device performance will be compared to an unpassivated AlGaN/GaN HEMT with identical layer structure.

2. Experiment

The AlGaN/GaN heterostructure epitaxy materials were grown by MOCVD on a sapphire substrate and consist of 5nm n^+-GaN ($1x10^{19}$ cm^{-3}), 30nm undoped AlGaN, and 3μm undoped GaN from surface to substrate. Hall measurements showed electron mobility of 1190 cm^2/Vs and the sheet charge density of 1.27×10^{13} cm^{-2}. Device fabrication started with mesa definition, which was made by dry etch in BCl_3/Cl_2-based plasma atmosphere, and was followed by formation of Ti/Al/Ni/Au ohmic contacts. After removing n^+-GaN cap, a first-step 10nm e-beam evaporated SiO_2 passivates the device immediately. The processes of the cap removal and the oxide deposition are developed for creating a fresh epitaxy surface and forming a low-trap-density interface with the following deposited SiO_2. Plus, additional benefits of the above process flow includes removal of anti-polarization generated by the n^+-GaN cap in the device access region, which results in reduction of the access resistance, and improvement of contact resistance assisted by the highly doped cap layer under ohmic metals. After removing the SiO_2 cap layer, Ni/Au gates were fabricated on the AlGaN top barrier. We then passivated a second-step e-beam SiO_2 dielectric with 280nm thickness. Finally, Ti/Au interconnect metals were made. TLM measurement shows contact resistance of 0.6 Ω-mm. Gate length and width are 2 and 100×2 μm respectively, and source-to- and gate-to- drain spacing are 6 and 2μm respectively. Device cross-sectional schematic is shown in Fig. 1.

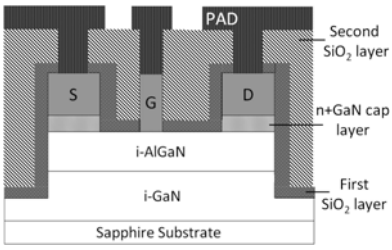

Fig. 1 Cross-sectional schematic of the AlGaN/GaN HEMT with two-step SiO_2 passvation.

3. Result

Comparing the unpassivated device to the one with two-step passivation, I_{DSS} arises from 550 mA/mm to 590 mA/mm and transconductacne from 120 to 135 mS/mm as shown in Fig. 2. Threshold voltages in both devices differ by only 0.1V. Measured peak f_T and f_{MAX} values increase from 4.35GHz and 12.55GHz to 5.85GHz and 18.25GHz respectively.

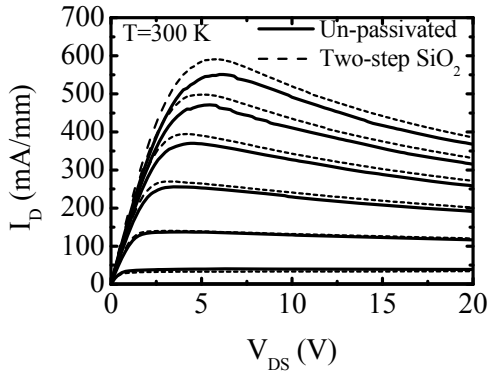

Fig. 2. I-V characteristics comparison at 300 K.

Fig 3 and Fig. 4 are the measured DC and pulsed I-V characteristics of the two AlGaN/GaN HEMTs respectively. Chosen pulse width varies from 1ms to 1μs. It is observed that the AlGaN/GaN HEMT without passivation suffers from current collapse at high frequencies but the two-step passivated HEMT does not. Fig. 5 shows the comparison of microwave power performances evaluated by a load-pull system to the two devices but with larger 100×6 μm gate widths. Comparing the unpassivated device to the one with two-step passivation, maximum output power (P_{out}) is increased from 0.68 to 1.44 W/mm, power added efficiency (PAE) from 22 to 37 % and power gain from 9 to 15 dB at V_{DS}= 25V and 2.4GHz.

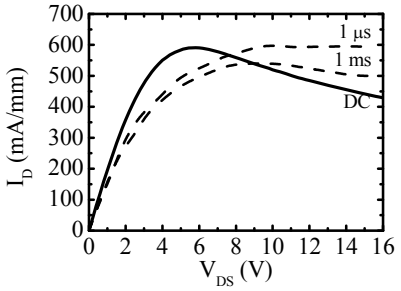

Fig. 3 DC and pulse I –V curves of the two-step passivated HEMT. Chosen pulse width varies from 1ms to 1μs.

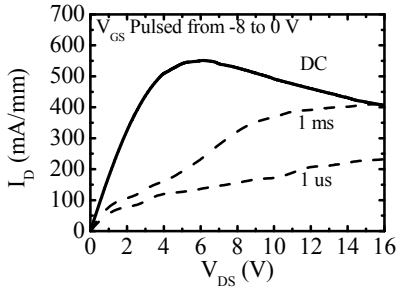

Fig. 4 DC and pulse I-V curves of the unpassivated HEMT. Chosen pulse width varies from 1ms to 1μs.

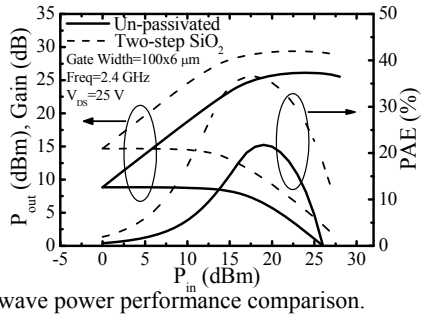

Fig. 5 Microwave power performance comparison.

It is well known that the drain current collapse and the power performance degradation at high frequency are generally explained as the existence of electrical traps localized at the device surface. To confirm the effect of the surface trap states on the device performance, low-temperature (100K) I-V measurement was made to the two devices as shown in Fig. 6. Earlier threshold of the kink current (as specified approximately by drain voltage) in the two-step passivated HEMT is observed and is given as an indirect evidence of surface trap density change at the surface, which results in enhanced electric field and thus carrier speed and saturation current. Earlier frequency results in the two devices demonstrate what is expected in the low-temperature I-V measurement.

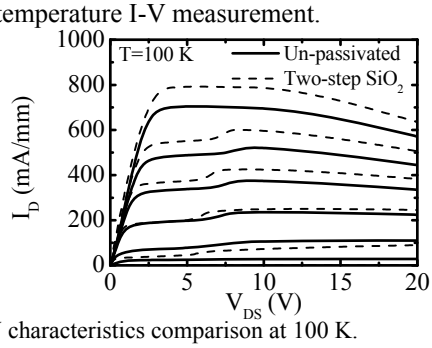

Fig. 6 I-V characteristics comparison at 100 K.

Fig. 7 (a) and (b) are Schottky and off-state gate leakages respectively. Though the Schottky gate leakage is lowered by about one order at V_{GS}=20V, the off-state gate leakage inversely becomes one-order higher in the two-step passivated HEMT. Traps states existing at the interface of the SiO_2 and the AlGaN is suspected for this additional leakage contribution. Off-state breakdown voltage of the two-step passivated HEMT is determined as 105V higher than 90V in the unpassivated HEMT (Fig. 8). The traps at the interface do not result in abrupt breakdown behavior of the device.

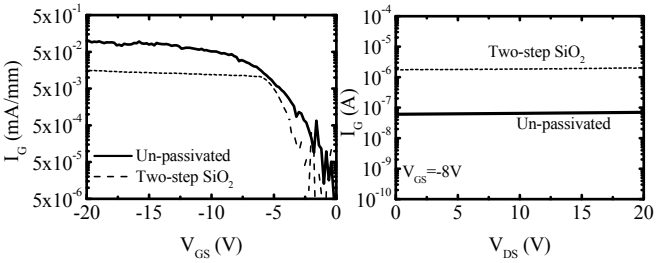

Fig. 7 (a) Schottky gate characteristics comparison.
(b) I_G-V_{DS} characteristics comparison at off state.

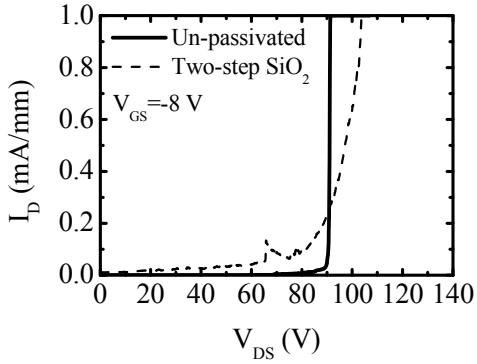

Fig. 8 Off-state breakdown characteristics comparison.

4. Conclusion

We successfully improve the issues of the drain current collapse and the power degradation induced by the surface traps using the proposed two-step e-beam SiO_2 passivation process. Plus, DC and high-frequency performance are also enhanced. Though higher off-state leakage is observed at low biases but breakdown voltage is increased.

References

[1] S. Arulkumaran et al., *Appl.Phys. Lett.*, vol. 84, p.613 (2004)
[2] W.K Wang et al., *IEEE Electron Device Lett.*, vol. 25, p.763 (2004)
[3] M. Higashiwaki et al., *IEEE Electron Device Lett.*, vol. 27, p.16 (2006)
[4] K. Cheng et al., *Journal of Crystal Growth*, vol. 298 p.822 (2007)