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A New ICP-CVD SiO_2 Passivation for High Voltage Switching AlGaN/GaN HFETs

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1. Introduction

AlGaN/GaN HFETs may be promising for microwave applications and high voltage switches due to a large band gap of GaN, a high breakdown electric field, and a high two-dimensional electron gas (2DEG) concentration [1]. The surface states have critical effects on leakage current, forward DC current and RF dispersion of GaN-based devices. The electrons of the AlGaN/GaN heterostructure are injected to the surface states by a high electric field and those induce 2DEG channel depletion and the trapping effects. High quality passivation layer should be required to solve those problems. Si_3N_4 passivation of the AlGaN/GaN HFETs [2] is currently studied to increase an output power and to suppress RF dispersion due to increased positive charge of Si_3N_4/AlGaN interface and decreased electron injection to the surface states.

Compared Si_3N_4 passivation, few SiO_2 passivated AlGaN/GaN HFETs by plasma enhanced chemical vapor deposition (PECVD) have been reported to decrease a leakage current [3]. Inductively coupled plasma-chemical vapor deposition (ICP-CVD) method is known to have a high remote plasma density with reduced ion damages on semiconductors compared with PECVD [4]. High ion damages during a passivation process can degrade 2DEG formation of AlGaN/GaN heterostructure.

The purpose of our work is to report a new ICP-CVD SiO_2 passivation method for high voltage switching AlGaN/GaN HFETs in order to decrease leakage currents and to increase DC characteristics with breakdown voltages. After ICP-CVD SiO_2 passivation, the drain current of the AlGaN/GaN HFETs is increased by 20 % ~ 35 % and the leakage current of those is decreased about 2 orders. The ICP-CVD SiO_2 passivation mechanisms are discussed with experimental results.

2. Fabrications

The AlGaN/GaN heterostructure was grown on a C-plane sapphire substrate by MOCVD. The epitaxial layers of the AlGaN/GaN heterostructure are shown in Fig. 1. The mesa was formed for the isolation. Source and drain ohmic contacts were formed with Ti/Al/Ni/Au by annealing 880 ºC for 30 s. The Schottky gate was formed with Pt/Mo/Ti/Au by the lift-off process. Room-temperature hall effect measurement on unpassivated sample yielded 4.39×10^{12} /cm^2 and 1070 cm^2/Vs. The ICP-CVD SiO_2 with a 300 nm thickness passivated AlGaN/GaN HFETs after the Schottky gate formation. The SiO_2 deposition was done at 300 ^{o}C and 35 mtorr pressure using nitrous oxide, silane and helium.

3. Experimental results

The AlGaN/GaN HFETs are successfully fabricated and those electric characteristics are measured. The measured transfer characteristics of the AlGaN/GaN HFET before/after SiO_2 passivation are shown in Fig. 2. A threshold voltage (-3.4 V at 1 mA/mm) is identical between the unpassivated device and the passivated one. The extrinsic transconductance ($g_{m.max}$) and the drain current at Vg=0 V of the unpassivated device are 71.3 mS/mm and 185.7 mA/mm. After SiO_2 passivation, those are increased to 87.4 mS/mm and 242.1 mA/mm. The SiO_2 passivation layer suppresses the electron injections to the surface states and 2DEG depletion. On current of the devices are increased due to ICP-CVD SiO_2 passivation with a good quality.

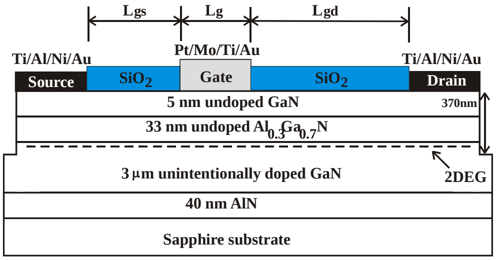

Fig. 1. Cross-sectional view of ICP-CVD SiO_2 passivated AlGaN/GaN HFET.

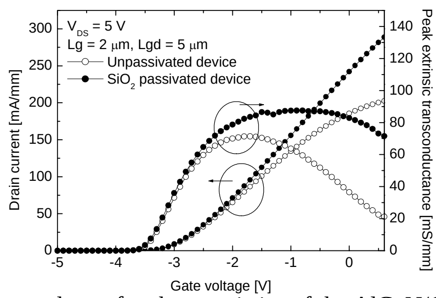

Fig. 2. Measured transfer characteristics of the AlGaN/GaN HFET

The measured current-voltage characteristics of devices are shown in Fig. 3. The saturation current of the devices is measured with a gate voltage sweep, -4 V to 2 V with 1 V/step. When Vg is higher than -1 V, the drain current of the unpassivated device is degraded than that of the passivated one. The ICP-CVD SiO_2 passivation layer suppresses a negative virtual gate in the gate-drain surface region and a current collapse. Maximum drain current of the passivated device is increased by 67 % compared with that of the unpassivated one. Our results exhibit a lower maximum drain current than state of the art performance (1000 mA/mm) because the undoped GaN cap layer and the large gate-drain space are designed for a low leakage current and a high off-state breakdown voltage.

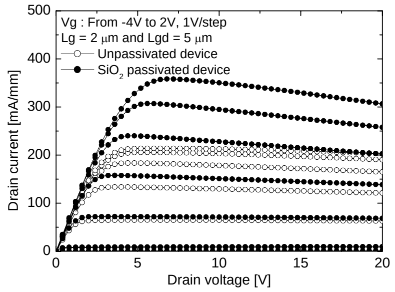

Fig. 3. Measured current-voltage characteristics of the AlGaN/GaN HFET

The leakage current and the breakdown voltage of the high voltage switching device are critical. The leakage current and the off-state breakdown voltage of the devices are measured by HP4156 and curve tracer 371A. The measured leakage current of the devices is shown in Fig. 4. The leakage current of the SiO_2 passivated device is decreased about 2 orders compared with that of the unpassivated device. The SiO_2 passivation layer suppresses electron injections to surface states. The surface leakage paths of the passivated devices are decreased compared with unpassivated one. The measured breakdown characteristics of the devices are shown in Fig. 5. When the unpassivated device is reverse gate-drain biased, the leakage current is increased as the reverse gate-drain bias increases (soft breakdown occurs). On the other hand, the SiO_2 passivated device achieves the low leakage current and the hard breakdown characteristics due to decreased surface leakage paths. The measured off-state breakdown voltages of the unpassivated and the SiO_2 passivated AlGaN/GaN HFET are 282 V and 455 V. The measured on-state breakdown voltages of the SiO_2 passivated devices are in the ranges of 80 V ~ 110 V.

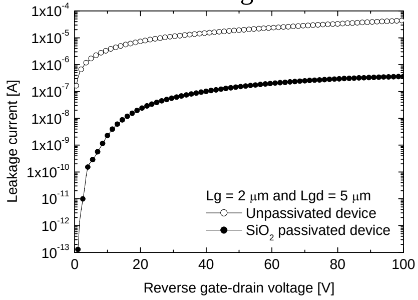

Fig. 4. Measured leakage current of the AlGaN/GaN HFET

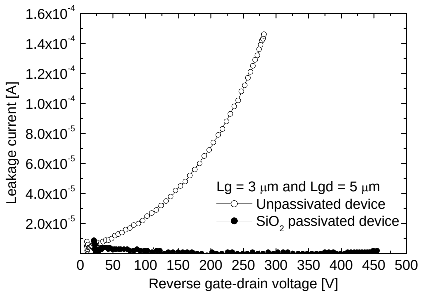

Fig. 5. Measured breakdown voltage of the AlGaN/GaN HFET

The ICP-CVD SiO_2 passivation effects are investigated for several AlGaN/GaN HFETs. Fig 6 shows the measured drain current changes and leakage current changes of the devices after SiO_2 passivation. The drain current of the passivated devices is increased by 20 % ~ 35 % compared with that of unpassivated devices. The leakage current of the passivated devices is less than 1.3 % of unpassivated device's leakage current. The 2DEG channel concentration (n_s) is extracted by C-V measurements and the measured n_s is shown in Fig. 7. The n_s can be calculated by [5]

$$Q_s = \int_{Vg'}^{0} C_{dg} dV_g [C]$$

$$n_s = \frac{Q_s}{L \times W \times 1.6 \times 10^{-19}} [/cm^2]$$

After ICP-CVD SiO_2 passivation, n_s is increased about 3.6 % ~ 13.8 %. The ICP-CVD SiO_2 passivation process does not damage the strained AlGaN. The suppressed electron injections to surface states increase 2DEG. The another possible reason of 2DEG increase may be that the surface donor-like state level (E_D) moves to Fermi level (E_F) due to SiO_2 passivation.

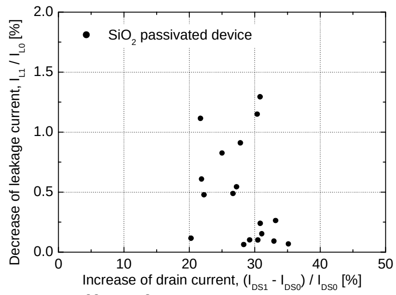

Fig. 6. Passivation effects for several AlGaN/GaN HFETs. I_{DS1} and I_{L1} are drain current and leakage current of the passivated device. I_{DS0} and I_{L0} are those of the unpassivated one.

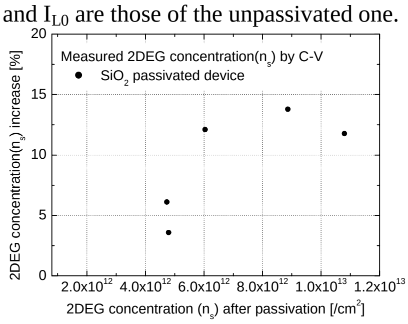

Fig. 7. 2DEG changes of the several AlGaN/GaN HFETs after passivation

4. Conclusions

The new ICP-CVD SiO_2 passivation method is proposed for high voltage switching AlGaN/GaN HFETs. The electrical characteristics of the devices are measured before/after passivation. After ICP-CVD SiO_2 passivation, the drain current of the devices is increased by 20 % ~ 35 % and the leakage current of those is decreased about 2 orders. The SiO_2 passivation layer sucessfully suppresses the electron injections to surface states, 2DEG depletion and the surface leakage current.

References

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