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# $SiO_2$ Passivation Effects on the Leakage Current in Dual-Gate AlGaN/GaN High Electron Mobility Transistors

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## 1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) may be promising for microwave applications and high voltage switches due to a wide band gap, high breakdown electric field and high two-dimensional electron gas (2DEG) charge [1-4]. The leakage current of high voltage AlGaN/GaN HEMTs should be decreased in order to suppress a power loss. Recently, various dual-gate AlGaN/GaN HEMTs has been investigated for high-voltage switches [2], broadband power amplifiers [3] and high-power mixers [4] to achieve a high breakdown voltage, high cut-off frequency and high output power.

Various passivation materials such as $Si_3N_4$ and $SiO_2$ have been reported to control surface states and decrease a leakage current of AlGaN/GaN HEMTs [1,5]. However, the leakage current mechanism of dual-gate AlGaN/GaN HEMTs has not been reported. The passivation effects on the leakage current of AlGaN/GaN HEMTs have been scarcely reported.

The purpose of our work is to report the leakage current mechanism of AlGaN/GaN HEMTs employing a dual-gate structure and $SiO_2$ passivation. We have measured the leakage current of all contacts such as the main-gate, additional-gate, drain and source at AlGaN/GaN HEMTs systematically. We have also investigated $SiO_2$ passivation effects of dual-gate AlGaN/GaN HEMTs.

Our experimental results show that the leakage current of dual-gate AlGaN/GaN HEMTs are decreased about 2 orders after $SiO_2$ passivation. The virgin (unpassivated) device has a large leakage current between contacts due to surface trap states. The leakage current is decreased by $SiO_2$ passivation and the leakage current mechanism of AlGaN/GaN HEMTs is verified.

## 2. Fabrications

AlGaN/GaN heterostructure was grown on c-plane sapphire substrate by MOCVD. Undoped 30 nm-thick $Al_{0.26}Ga_{0.74}N$ and Fe-doped 3 μm GaN formed 2DEG channel of AlGaN/GaN HEMTs. A 350 nm-thick mesa was formed for the isolation. The ohmic contact was formed with Ti/Al/Ni/Au by annealing 870 ºC for 30 s. The Schottky contact was formed with Pt/Mo/Ti/Au by the lift-off process. Hall effect measurement on unpassivated sample yielded $6.37\times 10^{12}$ $cm^{-2}$ and 1810 $cm^2/(Vs)$ at room temperature. Finally, a 400 nm-thick $SiO_2$ passivated devices employing ICP-CVD.

The cross-sectional view and fabricated image of dual-gate AlGaN/GaN HEMT is shown in Fig. 1. The main-gate length, additional-gate length and width are 3, 3 and 100 μm, respectively. The distance between an additional-gate and drain is 5 μm.

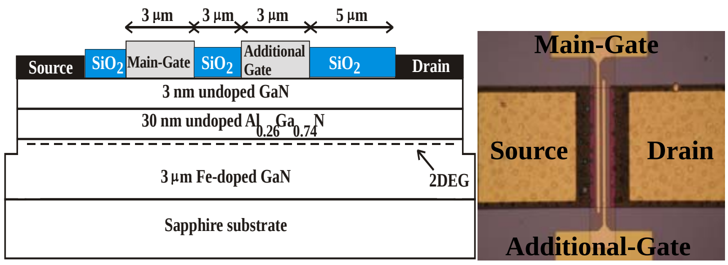



Fig. 1. Cross-sectional view and fabricated image of dual-gate AlGaN/GaN HEMTs.

## 3. Experimental results

The transfer characteristics of AlGaN/GaN HEMT with various additional-gate voltages are measured and that is shown in Fig. 2. When the additional-gate voltage is increased, the drain current and transconductance of the device are increased. When the additional-gate voltage is decreased, 2DEG charge under the additional-gate is depleted and the forward drain current is decreased. The forward drain current of the device at the additional-gate voltage of 0 and 4 V are 270.6 and 365 mA/mm, respectively. When the additional-gate voltage is larger than the drain voltage, the Schottky junction of an additional-gate and drain is forward biased and the forward drain current is decreased.

We have measured the leakage current at all contacts such as the main-gate, additional-gate, drain and source in order to investigate the leakage current mechanism of AlGaN/GaN HEMTs. The measured leakage current of the device before and after $SiO_2$ passivation is shown in Fig. 3. The leakage current of an unpassivated device comes from an additional-gate and source to main-gate. A drain leakage current of an unpassivated device is considerably less than an additional-gate leakage current and source leakage current. In the unpassivated device, the leakage injections from an additional-gate and source to main-gate should not be negligible. The leakage current of an unpassivated device from an additional-gate to main-gate may flow due to surface trap states.

After $SiO_2$ passivation, an additional-gate leakage current and source leakage current are suppressed. The leakage current of a passivated device comes from a drain to main-gate. The $SiO_2$ passivation eliminates the leakage current of an additional-gate and source. The $SiO_2$ passivation also decreases the drain leakage current about 2 orders due to the decreased conduction of surface trap states.

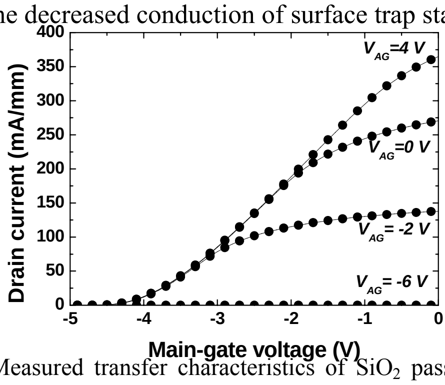
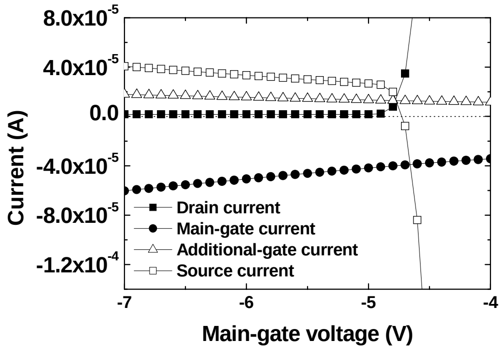
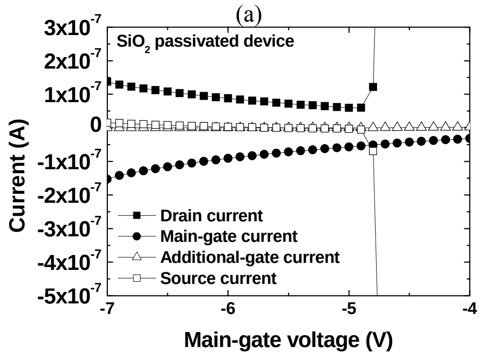



Fig. 2. Measured transfer characteristics of $SiO_2$ passivated AlGaN/GaN HEMT with various additional-gate voltages($V_{DS}$=5 V)




(a)




(b)

Fig. 3. Measured leakage current of AlGaN/GaN HEMT (a) before and (b) after $SiO_2$ passivation ($V_{DS}$=5 V, $V_{M\text{-}Gate}$=-6 V).

The measured drain leakage current of AlGaN/GaN HEMT with various additional-gate voltages is shown in Fig. 4. The drain leakage current of the unpassivated device at the additional-gate voltages of 0 and 4 V are 8.54 and 1.70 μA, respectively. The drain leakage current of an unpassivated device is decreased at the high additional-gate voltage due to the current flow from a drain to additional-gate. When the additional-gate voltage of a passivated device is less than -3 V, the field alleviation-effect of the additional-gate voltage is dominant and the drain leakage current is decreased. When the additional-gate voltage of a passivated device is larger than -3 V, the decrease of a depletion region under an additional-gate is dominant and the drain leakage current is rather increased.

The measured gate leakage current of an unpassivated device and passivated one is shown in Fig. 5. When the additional-gate voltage is 4 V, the additional-gate leakage current of an unpassivated device and passivated one are 15.58 μA and 7.10 pA, respectively. The forward current injection of an additional-gate in an unpassivated device begins even an additional-gate voltage (0 V) is less than a drain voltage (5 V). When the additional-gate voltage of a passivated device is increased to 5 V, the leakage current of an additional-gate is decreased and no leakage current injection is observed. The $SiO_2$ passivation for AlGaN/GaN HEMTs successfully decreases the leakage current between contacts through surface trap states.

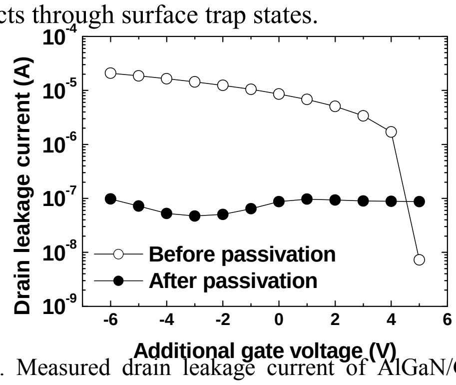



Fig. 4. Measured drain leakage current of AlGaN/GaN HEMT with various additional-gate voltage ($V_{DS}$=5 V, $V_{M\text{-}Gate}$=-6V).

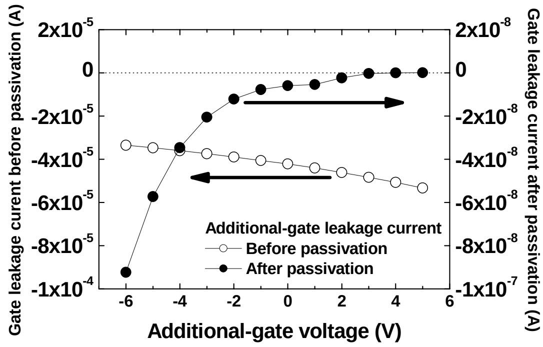



Fig. 5. Measured gate leakage current of AlGaN/GaN HEMT with various additional-gate voltage ($V_{DS}$=5 V, $V_{M\text{-}Gate}$=-6V).

## 4. Conclusions

We have investigated the leakage current mechanism for dual-gate AlGaN/GaN HEMTs by measuring the leakage current of all contacts such as the main-gate, additional-gate, drain and source. We have also measured dual-gate devices before and after $SiO_2$ passivation. The $SiO_2$ passivated device shows only the leakage current flow from a drain to main-gate while the virgin device exhibits a large leakage current flow from a source and additional gate to main-gate. The $SiO_2$ passivation also decreases the drain leakage current of the devices about 2 orders (from 8.54 μA to 87.31 nA) by suppressing electron conduction through surface trap states. The $SiO_2$ passivated dual-gate AlGaN/GaN HEMTs may be promising for high voltage applications by suppressing leakage current through surface trap states.

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