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Hot-Carrier Stress Effects on AlGaN/GaN HEMTs Employing 500 °C Oxidized Ni/Au Gate

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1. Introduction

AlGaN/GaN HEMTs (high-electron-mobility transistors) are promising candidate for microwave and high voltage applications due to wide band gap, two-dimensional electron gas, high saturation velocity and low intrinsic carrier density[1-2].

In order to improve AlGaN/GaN HEMTs such as the forward drain current and the leakage current, various passivation and annealing methods have been employed [3-7]. We have already reported that the Ni/Au Schottky gate oxidation successfully suppresses the leakage current and increases the breakdown voltage due to the formation of NiO at the gate edge[6].

The high field stress such as the hot-carrier stress and high-reveres current stress causes the electron trapping and the creation of interface state[7]. So that the reliability on the high field stress of the AlGaN/GaN HEMT employing oxidized Ni/Au Schottky gate is required.

The purpose of our work is to report the effect of hot-carrier stress on AlGaN/GaN HEMTs employing the Ni/Au gate oxidation. We have fabricated AlGaN/GaN HEMTs employing 500 °C oxidized Ni/Au gate and these devices considerably decreased the leakage current by three orders and increased the breakdown voltage from 252 to 384 V. The hot-carrier stress with V_{DS}=30 V and V_{GS}=0 V was applied to AlGaN/GaN HEMTs and the electrical characteristics was measured with various gate bias. After the hot-carrier stress of $1x10^4$ sec, the forward drain current of oxidized AlGaN/GaN HEMT at V_{GS}=-3, -1 and 1 V were decreased by 3.1, 8.9 and 16.8 %, respectively. However, the hot-carrier stress effects such as the positive shift and the decrease of transconductance were not observed remarkably. The degradation of the forward drain current of oxidized device may be due to the scattering induced by the diffused Ni into AlGaN layer.

2. Device Structure and Fabrication

The cross-sectional view of the fabricated AlGaN/GaN HEMTs is shown in Fig. 1. The AlGaN/GaN heterostructure was grown on semi-insulating 4H-SiC substrate by metal organic chemical vapor deposition (MOCVD). The 270 nm mesa structure for isolation was formed by inductively coupled plasma etching. Source and drain, Ti/Al/Ni/Au (20/80/20/100 nm) were formed by using an e-gun evaporator and annealed at 860 °C for 30 s under N_2 ambient. Gate was formed with Ni/Au (50/300 nm) and defined by a lift-off technique. The 500 °C oxidation of Ni/Au gate was performed by furnace. The oxidation time, O_2 flow and pressure were 5 min, 3.5 SLPM and atmosphere, respectively.

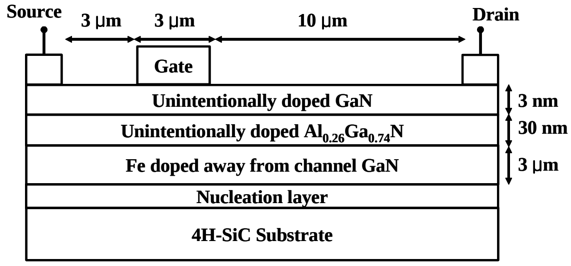

Fig. 1. Cross-sectional view of fabricated AlGaN/GaN HEMT

3. Experimental Result

The oxidized AlGaN/GaN HEMT successfully suppressed the leakage current and increased breakdown voltage as shown in Fig 2. The leakage current at V_{DG} = 100 V of as-fabricated device and oxidized device are 140.0 μA/mm and 1.6 nA/mm, respectively. The breakdown voltage of as-fabricated was 252 V at I_{DS} = 1mA/mm, while that of oxidized device was 384 V at which the device was burned out. The improvement of reverse characteristics is attributed to the formation of NiO at the gate edge and the curing of defect and dislocation[6].

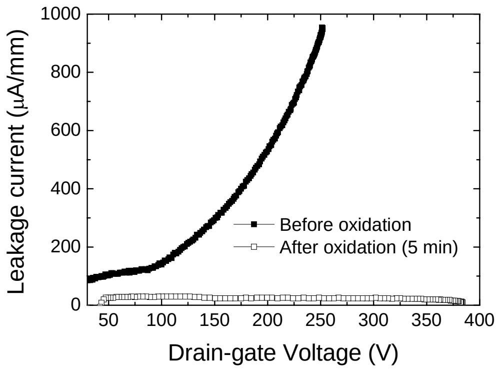

Fig. 2. Measured reverse characteristics of AlGaN/GaN HEMT before and after 5 min oxidation

The transfer characteristics of AlGaN/GaN HEMT before and after oxidation were measured. The threshold voltage of oxidized device was rather increased than that of as-fabricated device. The positive shift of threshold voltage is due to the diffusion of Ni to AlGaN layer. The forward drain current of AlGaN/GaN HEMT at V_{DS}=5 V and V_{GS}=0

V was decreased from 314.9 to 289.0 mA/mm. The maximum transconductance was also decreased from 101.2 to 99.8 mS/mm.

The hot-carrier stress with V_{DS}=30 V and V_{GS}=0 V was applied to AlGaN/GaN HEMT before and after the oxidation. After hot carrier stress of 1×10^4 sec, the transconductace of AlGaN/GaN HEMT before the oxidation showed slight shift to the positive direction and the maximum transconductance decreased from 101.2 to 94.4 mS/mm as shown in Fig 3. The positive shift of the transconductance is due to the electron trapping or the creation of interface state in the gate-drain region and the degradation of the transconductance is due to the decrease of mobility or channel carrier concentration[7].

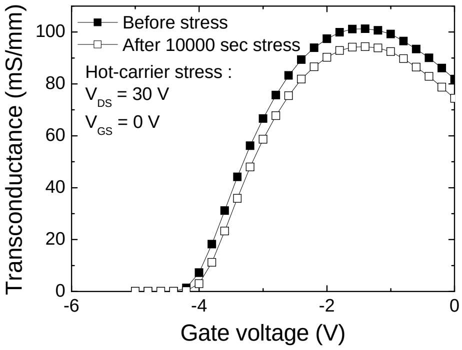

Fig. 3. Measured transconductance of AlGaN/GaN HEMT before oxidation after the hot-carrier stress of 1×10^4 sec.

Fig 4 shows the transconductance of 5 min oxidized AlGaN/GaN HEMT after the hot-carrier stress time of 1×10^4 sec. The transconductance of oxidized device hardly shifted to the positive direction and its maximum value decreased from 99.8 and 96.8 mS/mm. These results imply that the Ni/Au oxidation of AlGaN/GaN HEMTs suppresses the electron trapping or the creation of interface state induced by the hot-carrier stress.

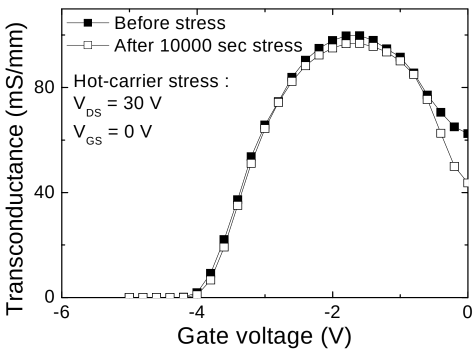

Fig. 4. Measured transconductance of 5 min oxidized AlGaN/GaN HEMT after the hot-carrier stress of 1×10^4 sec.

After the hot-carrier stress of 1×10^4 sec was applied, the forward drain current of AlGaN/GaN HEMT before and after oxidation with various gate biases were measured. The degradation of forward drain current with various gate bias after the hot-carrier stress are summarized in Table. I. The forward drain current was measured at V_{DS}=5 V. When the gate bias is 1 V, the forward drain current of AlGaN/GaN HEMT before oxidation was decreased by 7.9 %, while that of AlGaN/GaN HEMT after oxidation was decreased by 16.8 %. As shown in Fig 3 and Fig 4, the Ni/Au gate oxidation suppresses the hot-carrier effect, so that another effect results in the degradation of the forward drain current of oxidized AlGaN/GaN HEMT.

Table. I. the degradation of the forward drain current with various gate bias after the hot-carrier stress of 1×10^4 sec.

	V_{GS}=-3 V	V_{GS}=-1 V	V_{GS}=1 V
Before oxidation	17.9 %	8.6 %	7.9 %
After 5 min oxidation	8.9 %	3.1 %	16.8 %

As the gate bias increases, the degradation of the forward drain current of oxidized device is increased. Our experimental results show that the diffused Ni into AlGaN layer may behave the scattering center. The Ni/Au Schottky gate is annealed in high temperature, Ni is diffused into AlGaN layer[8]. When the gate voltage increases, the scattering induced by the diffused Ni into AlGaN layer is increased and the forward drain current is decreased.

4. Conclusion

We have fabricated AlGaN/GaN HEMT employing 500 ^{o}C oxidized Ni/Au gate and measured the electric characteristics and reliability on hot-carrier stress. The oxidized device decreased the leakage current at V_{DG} = 100 V from 140.0 μA/mm to 1.6 nA/mm and increased the breakdown voltage from 252 V to 384 V. The Ni/Au oxidation AlGaN/GaN HEMT suppresses the electron trapping of the creation of interface state induced by the hot-carrier stress. After the hot-carrier stress with V_{DS}=30 V and V_{GS}=0 V of 1×10^4 sec, the degradation of the forward drain current of oxidized AlGaN/GaN HEMT was increased as the gate bias increased. The degradation of the forward drain current of oxidized AlGaN/GaN HEMT after hot-carrier stress may be due to the scattering induced by the diffused Ni into AlGaN layer.

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