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Improved High-Temperture Characteristics of AlGaN/GaN MISHEMTs with ZrO_2/Al_2O_3 Dual Dielectric Films

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Abstract

AlGaN/GaN MISHEMTs with ALD ZrO_2/Al_2O_3 dual dielectric films have been fabricated. The device exhibited a gate leakage current of $9x10^{-11}$A/mm at room temperature, which was about 3 orders of magnitude lower than that for the Schottky-gated AlGaN/GaN HEMT. The amount of increse in the gate leakage current from RT to 300 ºC for the dual-film MIS device was the lowest among devices fabricated in this work. These results indicate that the proposed ZrO_2/Al_2O_3 dual dielectric film MISHEMT is promising for stable device operation at high temperatures.

1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) have attracted great interest for applications in high-temperature, high-voltage, and high-frequency devices. However, conventional Schottky-barrier gate AlGaN/GaN HEMTs suffer from high gate leakage current, resulting in degraded power-switching efficiency and breakdown characteristics. In order to suppress gate leakage during off-state period, metal-insulator-semiconductor (MIS) HEMTs have been studied using various dielectric materials, such as SiN, Al_2O_3, HfO_2, and ZrO_2.

To further improve overall performance, dual dielectric film MISHEMTs have been recently reported [1-3]. Suppression in current collapse and gate leakage current has been presented by using dual dielectric film MISHEMTs. Tian et al. [3] reported that the degradation in gate leakage current for the dual dielectric MISHEMT was less than that for the single dielectric MISHEMT. However, the reported gate leakage current at RT was rather high (10^{-7} A/mm). In this paper, we propose s dual ZrO_2/Al_2O_3 dielectric film AlGaN/GaN MISHEMT and demonstrate its improved gate leakage characteristics estimated at temperature from RT to 300 ºC.

2. Experiment

Figure 1 shows the schematic cross-sectional view of the fabricated device. AlGaN/GaN heterostructures were grown by MOCVD on a sapphire substrate. The thickness and Al composition for AlGaN were 20nm and 0.24, respectively. Our HEMT fabrication started with mesa isolation, followed by evaporating Ti/Al/Mo/Au metal stack as ohmic contacts. Ohmic metals were then annealed by RTA at 850 ºC for 30s in an N_2 ambient. After cleaning the AlGaN surface by BHF solution, dielectric films, i.e., ZrO_2/Al_2O_3 (2/2 nm), Al_2O_3 (4 nm), and ZrO_2 (4 nm), were deposited at 250 ºC using ALD. Ni/Au was used as a gate metal with a gate length of 2 μm and a width of 100 μm. Post annealing was performed at 300 ºC for 10 min.

3. Results and discussion

Figure 2 shows I-V characteristics measured at RT for the dual-dielectric MISHEMT with ZrO_2/Al_2O_3. Excellent pinch-off and saturation characteristics were measured with a maximum drain current of 480 mA/mm and a threshold voltage of -3.3 V. Figure 3 compares two-terminal gate leakage current for dual-MIS and Schottky-gated HEMTs. The leakage current measured at V_{gd}=-100 V for the ZrO_2/Al_2O_3 MISHEMT was about 3 orders of magnitude smaller than that for the standard HEMT. Table 1 summarizes device characteristics. The MISHEMTs with dual ZrO_2/Al_2O_3 and single Al_2O_3 showed higher maximum drain currents than those for ZrO_2-MIS and Schottky-gated HEMTs. No significant differences were observed in the maximum transconductance between devices. A gate leakage current of as low as $1x10^{-10}$ A/mm was measured for the MISHEMTs with dual ZrO_2/Al_2O_3 and single ZrO_2, whereas an order of magnitude larger gate leakage was measured for the MISHEMT with single Al_2O_3. The subthreshold slope was also the lowest (71mV/dec) for ZrO_2/Al_2O_3 and ZrO_2 MISHEMTs. The interface trap density (D_{it}) estimated by C-V measurements was the lowest for Al_2O_3 MISHEMTs and was lower for the dual MISHEMT than that for the ZrO_2 MISHEMT, indicating that the better MIS interface quality was obtained by using Al_2O_3 as an interface film. Figure 4 shows the temperature dependence of two-terminal leakage current for ZrO_2/Al_2O_3-MIS and Schottky-gated HEMTs. The leakage current for the ZrO_2/Al_2O_3 MISHEMT remained as low as $4x10^{-8}$ A/mm at 300 ºC, which was even lower than that for the Schottky-gated HEMT measured at RT. This trend is more clearly shown in Fig. 5, where the lowest leakage characteristics at RT and 300 ºC are shown for the dual ZrO_2/Al_2O_3 MISHEMT.

4. Conclusions

We have successfully fabricated AlGaN/GaN MISHEMTs with ZrO_2/Al_2O_3 as a dual dielectric film gate insulator. The excellent interface property of Al_2O_3 and the reduced gate leakage of ZrO_2 resulted in the superior MIS device characteristics with a lowest gate leakage current at 300 ºC. The developed dual-dielectric MIS technology is promising for statble switching operation at high temperatures.

References

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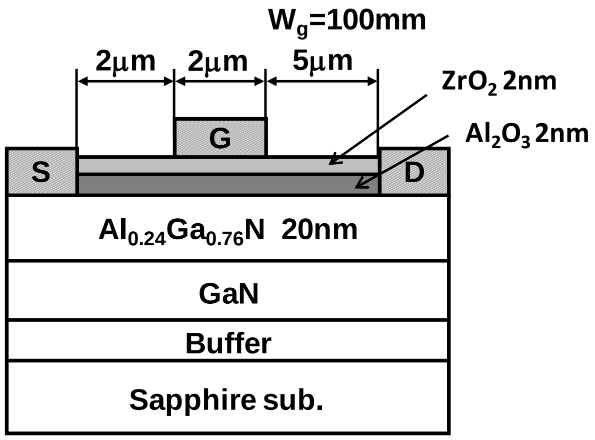

Fig. 1 Schematic cross-sectional structure of ZrO_2/Al_2O_3 MISHEMT.

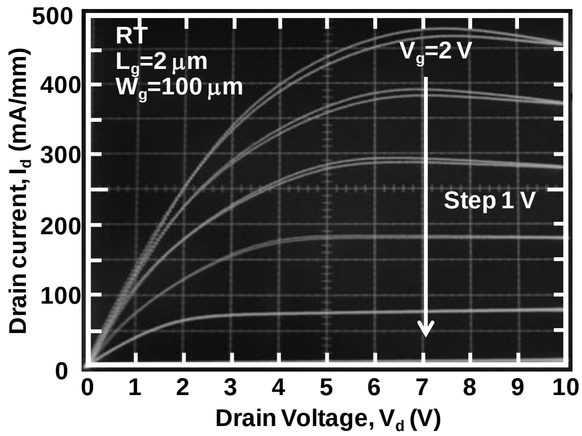

Fig. 2 Id-Vd characteristics for ZrO_2/Al_2O_3 MISHEMT measured at RT.

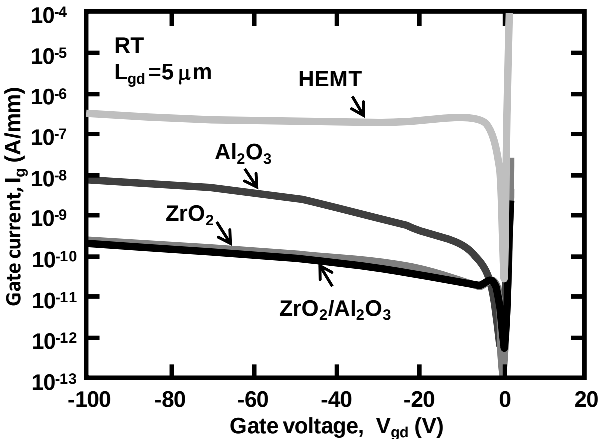

Fig. 3 Two-terminal gate-drain leakage current.

Table 1 DC parameter and interface trap density

structure	Id_max (mA/mm)	Gm_max (mS/mm)	Vth (V)	BVds (V)	Ig_leak (A/mm)	SS (mV/dec)	Dit (cm^{-2})
ZrO_2/Al_2O_3 (2nm/2nm)	480	94	-3.3	275	$9x10^{-11}$	71	$2x10^{12}$
Al_2O_3 (4nm)	489	96	-3.7	330	$2x10^{-9}$	78	$9x10^{11}$
ZrO_2 (4nm)	425	93	-2.9	275	$1x10^{-10}$	71	$4x10^{12}$
HEMT	340	98	-2.6	275	$2x10^{-7}$	92	---

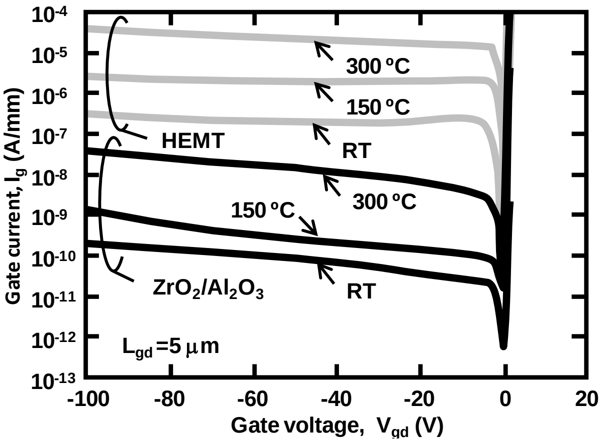

Fig. 4 Gate leakage current for ZrO_2/Al_2O_3 MISHEMT and Schottky-gated HEMT.

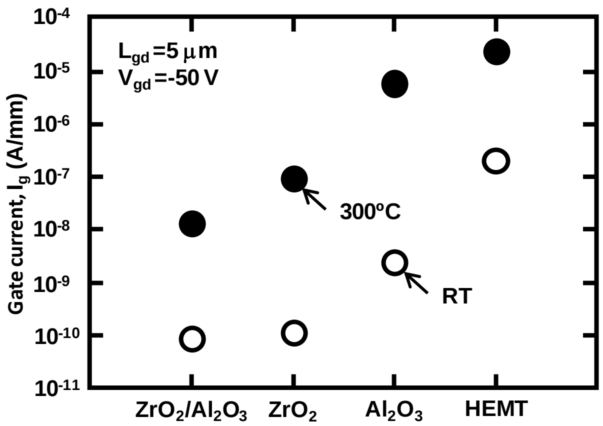

Fig. 5 Gate leakage current for all devices at RT and 300 ºC.