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High Breakdown Voltage AlGaN/GaN MIS-HEMT with TiO_2/Si_3N_4 Gate Insulator

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1. Introduction

Recently, AlGaN/GaN HEMTs are of great interest as the high power device and the high frequency device, and a lot of researches are done [1-3]. One of the important points for improvement in the breakdown voltage is reduction of the gate leak current. The gate leakage current is due to crystal dislocations in lattice-mismatched AlGaN/GaN structure. The metal-insulator-semiconductor (MIS) structure that has the insulated film under the gate is effective in reduction of the gate leak current.

For MIS structures, SiO_2 have been widely used as the insulator film [3]. However, if the SiO_2 insulator film is thickened in order to improve the characteristics of the breakdown voltage further, the transconductance (g_m) will deteriorate. On the other hand, when the insulator with high dielectric constant is employed in the MIS structure, the insulator film under the gate can be thickened without decreasing the g_m and thereby decreasing the gate leakage current.

In our previous work, we have fabricated the AlGaN/GaN HEMT with MIS gate structure using TiO_2 insulators [4]. Significant reduction in gate leakage current and substantial improvement in breakdown voltage were observed, and the distinct reduction in the transconductance have not been observed with the increase of insulator film thickness. However, there was the problem of current collapse, which may be originated from the oxidization of the AlGaN barrier surface during the deposition of TiO_2.

On the other hand, it is well known that the Si_3N_4 passivation film covering the AlGaN barrier layer reduces the current collapse phenomena. Thus in this study, we employed the TiO_2/Si_3N_4 multilayer insulator structure, and fabricated the MIS gate AlGaN/GaN HEMTs and investigated the operating characteristics.

2. Experiments

The schematic illustration of cross sectional view of the fabricated device is shown in Fig. 1. The AlGaN/GaN heterojunction structure was grown on a 2 inch c-face sapphire substrate by metal organic chemical vapor deposition (MOCVD). The x-ray full width at half maximum of (1 0 -1 2) ω-rocking curve was measured to be 300-400 arcsec, which indicates the good crystalline quality of the MOCVD-grown HEMT structures. The layer structure consists of a 4 μm thick nondoped-GaN layer and a 15 nm thick nondoped $Al_{0.25}Ga_{0.75}N$ barrier layer. The sheet resistance of the nondoped-GaN layer is about 10 MΩ/□. The AlGaN layer was intentionally nondoped in order to obtain the good schottky contact. The sheet resistance of the HEMT structure is 420-510 Ω/□.

Electrical isolation was performed by forming mesa structure with reactive ion beam etching with chlorine gas. In order to form the source and drain ohmic electrodes, Ti/Al/Ni/Au were deposited by electron beam evaporation and annealed by rapid thermal annealing at 780 °C for 30 s in nitrogen gas ambient. The specific contact resistance measured with transmission line model was 3-5 × 10^{-5} Ω·cm^2. The gate insulator of Si_3N_4 and TiO_2 were deposited by electron beam evaporation at 200 °C. The thicknesses of the Si_3N_4 and TiO_2 films used in the MIS-HEMTs were 5 nm and 50 nm, respectively. The relative dielectric constants of the deposited Si_3N_4 and TiO_2 were measured to be 7 and 80, respectively by fabricating the capacitance structures. The gate metal with Ni/Au was formed by electron beam evaporation.

The DC characteristics of the device were measured using Keithley 4200 semiconductor parameter analyzer. The breakdown voltage V_B was measured with Keithley MODEL 248 high voltage supply and Keithley 6514 system electrometer.

3. Results and Discussion

We measured the typical DC current-voltage I_d-V_d characteristic of the fabricated TiO_2/Si_3N_4 MIS-HEMT. And, all the devices showed good DC device performance and good pinch-off characteristics. The maximum drain current density I_d was 430 mA/mm when L_g = 0.5 μm, L_{gsd} = 4.5 μm. The transfer characteristics were measured at the source-drain bias V_d of 10 V. The maximum g_m was 63 mS/mm, even though TiO_2 has the thicknes of 50 nm.

Figure 2 shows the current-voltage characteristics of the gate of the fabricated devices with L_g = 2 μm. The length L_{gs} between the gate and the source is 2 μm. We found the great improvement in the gate leakage characteristic by employing the MIS structure. The gate leakage current of the MIS structure is 1.3 × 10^{-7} A/mm at V_g = 9 V. Moreover, the gate breakdown voltage becomes large by the MIS structure. The gate breakdown voltage of the MIS-HEMT is 10 V on the forward bias. We confirmed the good insulation films were formed under the gate metals.

We measured the current collapse characteristics of the fabricated HEMTs. Figure 3 shows the result of the transition current of the drain. The drain voltage has rapidly changed from 20 V into 1 V while the gate voltage V_g was maintained to 0 V. In the devices structure, L_{sg}, L_g, L_{gd}, and W_g were 2, 4, 18 and 50 μm, respectively. The current collapse in the TiO_2/Si_3N_4 MIS-HEMT was found to be smaller than that in the TiO_2 MIS-HEMT.

The off-state breakdown voltage at the gate voltage V_g of –15 V was measured with Fluorinert^{TM} (FC-40: 3M) covering the device surface. Almost all the devices measured were biased to destruction. The breakdown voltage behavior for TiO_2/Si_3N_4 MIS-HEMT is shown in Fig. 4, where L_g = 4 μm, L_{gd} = 28 μm. The drain breakdown voltage of this device was 1.1 kV. On resistance R_{on} of this device was measured at the gate voltage V_g = 4 V, and the specific on-resistance R_{on}▪A was found to be 15 mΩ·cm^2, where A is the device area. The trade off characteristics of the breakdown voltage and specific on-resistance of the fabricated TiO_2/Si_3N_4 MIS-HEMT was better than that of the Si-based FET.

4. Conclusions

We fabricated the AlGaN/GaN HEMT with MIS gate structure using TiO_2/Si_3N_4 insulators, and found that the current collapse was significantly reduced in comparison with TiO_2 MIS-HEMT. Significant reduction in gate leakage current and substantial improvement in breakdown voltage were observed. The breakdown voltage and on-resistance for fabricated TiO_2/Si_3N_4 MIS-HEMT were found to be 1.1 kV and 15 mΩ·cm^2, respectively. The AlGaN/GaN HEMT is a promising candidate for high voltage switching device applications such as economic electrical automobiles.

References

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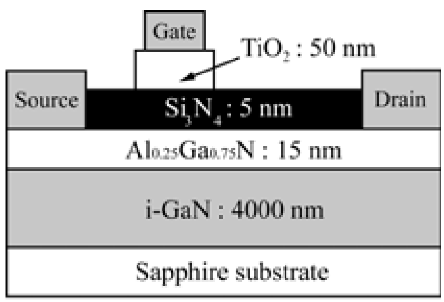

Fig.1. Schematic cross section of AlGaN/GaN HEMT structure.

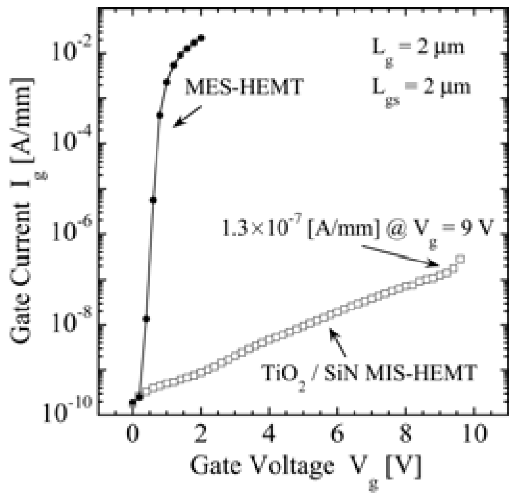

Fig. 2. I_g-V_g characteristics of gate.

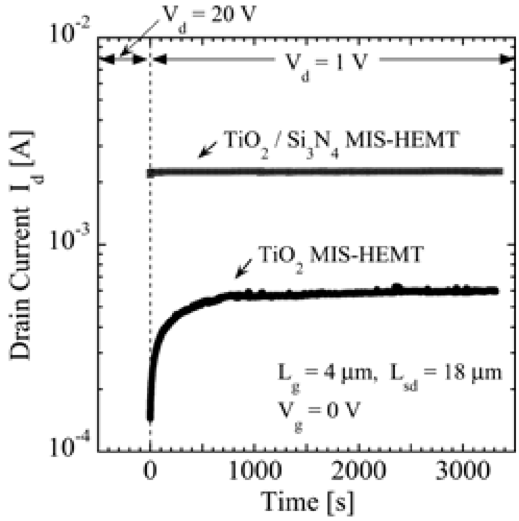

Fig. 3. Drain current transient

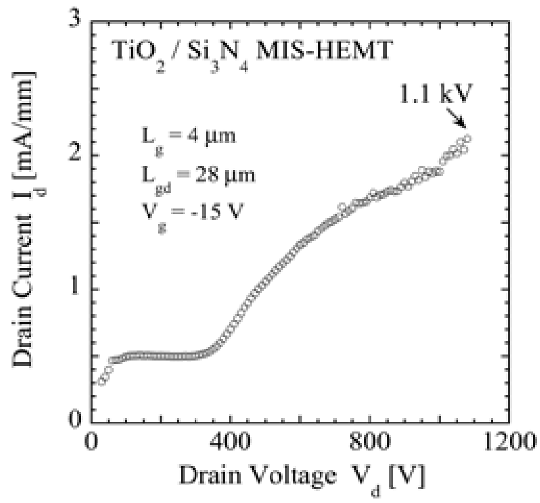

Fig.4. Off-state breakdown voltage behavior.