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Effects of High-*k* Passivation Films on AlGaN/GaN HEMT

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1. Introduction

The AlGaN/GaN high electron mobility transistor (HEMT) has been attracting attention for its high voltage and high speed applications and intensive studies have been carried out on them, because GaN has a high breakdown field strength of 2 MV/cm, and AlGaN/GaN HEMTs have a two-dimensional electron gas channel with a low sheet resistance. In order to obtain the good operating characteristics in the HEMTs, a metal-insulator-semiconductor (MIS) gate structure with an insulating film under the gate is useful, because the MIS structure reduces the gate leakage current originating from crystal dislocations in the lattice-mismatched AlGaN/GaN structure.

Recently, several studies have been reported using high-*k* material as insulator in the MIS gate structure [1,2]. The MIS gate structure with the high-*k* insulator film under the gate is effective in reduction of the gate leakage current, and the high breakdown voltage was obtained.

On the other hand, the high-*k* material has generally bandgap energy narrower than the conventional insulator SiO_2. The characteristics of the surface states covered by the passivation films gives the strong influence on the operating characteristics of the HEMT devices. Therefore in this study, we investigated the effect of the high-*k* passivation films on the HEMT structure. TiO_2 was employed as the high-*k* material.

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. TiO_2, SiN and SiO_2 films were employed as the insulator in MIS gate structure. The gate structure with no insulator film, i.e., the metal-electrode-semiconductor (MES) gate structure has also employed for comparing the operating characteristics. All gate insulators were deposited by electron beam evaporation at 200 ˚C. The thickness of TiO_2, SiN and SiO_2 films are 15, 15 and 10 nm, respectively. 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 investigated the effect of the insulator films on the sheet resistance of the AlGaN/GaN heterojunction structure. The sheet resistance was changed after the deposition of the insulator films and found to be 512, 628 and 992 Ω for the SiN, SiO_2 and TiO_2 films, respectively. The sheet resistance with no insulator film was 530 Ω. We considered that the difference of the sheet resistance is due to the electron trap at the AlGaN surface covered by the insulator films.

We also investigated the effect of the insulator films for the operating characteristics of the AlGaN/GaN HEMTs. We measured the typical DC current-voltage characteristic of the fabricated MIS-HEMT. And, all the devices showed good DC device performance and good pinch-off characteristics.

We found the changes in the gate threshold voltage. We show the transconductance g_m characteristics as a function of the gate voltage of the MES, SiN-MIS and TiO_2-MIS gate HEMTs in Fig. 2 (a-c). The drain-source length of the HEMTs was 4.5 μm. The gate threshold voltage was about -4.2, -2.8, and -2.2 V for the SiN, SiO_2 and TiO_2 MIS gate structure, respectively. The gate threshold voltage of MES gate structure was about -2.6 V. We considered that the surface passivation using the high-*k* films reduces the carrier density in the AlGaN/GaN channel, because the high-*k* material has narrow bandgap energy.

For a power-switching device, the trade-off characteristic between the specific on-resistance and the breakdown voltage is important and has been discussed.[3] The trade-off characteristic of fabricated MES and MIS-HEMTs are shown in Fig. 3. The gate length of the HEMTs was 4 μm. 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 specific on-resistance R_{on}▪A was measured at the gate voltage V_g = 2 V, where A is the device area. In the case of MIS-HEMTs, the breakdown voltage is up to 1.7 kV because of the decrease of gate leak current. On the other hand, for MES-HEMT, the breakdown voltage is saturated at about 1 kV. The trade off characteristics of the breakdown voltage and specific on-resistance of the fabricated MIS-HEMT was better than that of the Si-based FET.

4. Conclusions

We fabricated the AlGaN/GaN HEMT with MIS gate structure, and investigated the effect of the high-*k* passivation films on the HEMT structure. The sheet resistance was changed after the deposition of the insulator films. We also found the changes in the gate threshold voltage. The surface passivation using the high-*k* films reduces the carrier density in the AlGaN/GaN channel, because the high-*k* material has narrow bandgap energy.

With the help of the recess gate structure, the normally-off mode operation can be achieved using high-*k* MIS gate structure.

References

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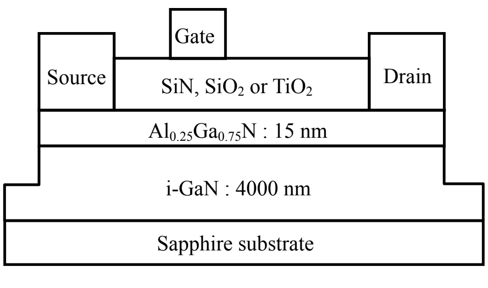

Fig.1. Schematic cross section of AlGaN/GaN HEMT structure.

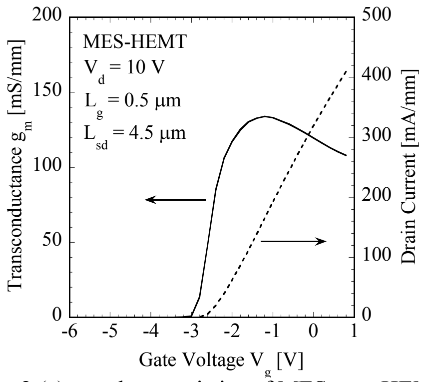

Fig. 2 (a). g_m characteristics of MES-gate HEMT.

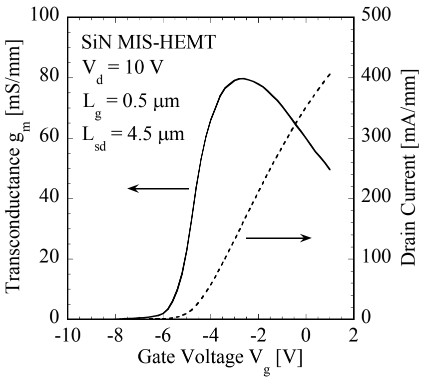

Fig. 2 (b). g_m characteristics of SiN MIS-HEMT.

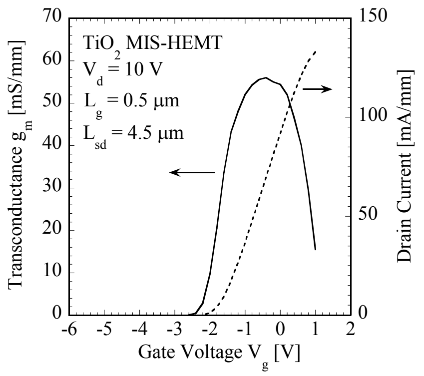

Fig. 2 (c). g_m characteristics of TiO_2 MIS-HEMT.

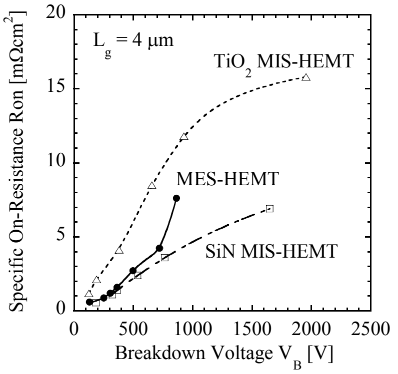

Fig.3. Trade-off characteristic between the specific on-resistance and breakdown voltage.