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High Speed AlGaN/GaN MIS-HEMT with High Drain and Gate Breakdown Voltages

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1. Introduction

Recently, AlGaN/GaN HEMT’s are of great interest as the high power device and the high frequency device, and a lot of researches are done [1]. One of the problems of these devices is the leakage current through gate schottky contacts that results from crystal dislocations in AlGaN/GaN structure, and the breakdown voltage worsens due to the gate leakage current. This problem is solved by applying the insulation film under the gate, i.e., the metal-insulator-semiconductor (MIS) structure. Higashiwaki, et. al. employed MBE-grown AlGaN/GaN wafers, and demonstrated the high-speed HEMT with the MIS gate of 2 nm thick SiN insulator [2]. However, drain breakdown voltage is low, and the characteristics of gate and drain breakdown voltage are not investigated.

In this study, we employed the MOCVD-grown wafer, and fabricated AlGaN/GaN HEMT of the MIS structure with relatively thick insulator. Three kinds of films, SiO_2, SiN and TiO_2 with different thicknesses were formed under the gate, and we investigated the operating characteristics, such as the breakdown voltage characteristics.

2. Experiments

Schematic illustration of cross sectional view of the fabricated device is shown in Fig. 1. AlGaN/GaN heterojunction structure was grown on sapphire substrates by metal organic chemical vapor deposition. XRD measurements were performed for MOCVD-grown wafer, and FWHM of the peak in the (1 0 –1 2) ω-rocking curve was 300-400 arcsec, which indicates the good crystal quality of the MOCVD-grown HEMT structure. The layer structure consists of a 4 μm i-GaN layer, and a 15 nm nondoped $Al_{0.25}GaN_{0.75}$ barrier layer. 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. Source and drain ohmic metal, Ti/Al/Ni/Au were deposited by electron beam evaporation and annealed by RTA at 780˚C for 30 s in nitrogen gas ambient. The specific contact resistance measured with transmission line model was 3-5 x 10^{-5} $\Omega\cdot cm^2$. The insulating films, SiO_2, SiN, and TiO_2 were deposited by electron beam evaporation at 200˚C. Films with 5 nm, 10 nm, and 15 nm were deposited for all insulators. The gate metal with Ni/Au was formed by electron beam evaporation. The gate width of the device is 50 μm, and the gate length (L_G) is 0.4-4 μm. The distance between the source and drain is 3-30 μm.

The DC characteristics of the device were measured using an HP4142B modular source and monitor. The breakdown voltage (V_B) was measured with the 371A curve tracer. RF performance was characterized by on wafer S-parameter measurements using an HP8510C network analyzer in the 1-40 GHz range.

3. Results and Discussion

Fig. 2 shows the current-voltage characteristic between the gate and the source of the fabricated HEMT with L_G=4 μm. The thickness of the insulation film is 5 nm. The current doesn’t flow through the gate electrode of the MIS-HEMT on the forward bias, and we confirmed the good insulation films were formed under the gate metals. We also found the great improvement in the gate leakage characteristic by employing the MIS structure. The gate leakage current of the MIS structure is 10-100 times smaller than that of the normal structure. Moreover, the gate breakdown voltage becomes large by the MIS structure. The gate breakdown voltage of the HEMT with TiO_2, SiO_2 and SiN insulators are 138 V, 188 V and 189 V, respectively. These values are much higher than that of the normal device, which indicates the advantage of the MIS–HEMT for the actual device applications.

Fig. 3 shows the drain breakdown voltage characteristic as a function of the distance between the source and drain when the gate voltage is –5 V. The breakdown voltage increases when the source drain distance lengthens, and the maximum breakdown voltage is over 500 V. However we did not find the significant difference between each MIS structures.

The RF characteristics f_T and f_{max} of each device structure were measured. The f_T and f_{max} of the SiN-MIS-HEMT as a function of the gate length is shown in Fig. 4 where L_{SD} is 7.6 μm. Explicit dependence of the high frequency characteristic on the thickness of SiN could not be found. In our experiments, high-speed characteristics are thought to be mainly determined by the electrical property of 2DEG channel. Shorter the L_G becomes, higher f_T and f_{max} gradually become higher. No saturation of f_T and f_{max} is found at the short gate length. When the L_G is 0.4 μm, f_T and f_{max} are about 13 GHz and 43GHz, respectively. The drain breakdown voltage of this device was about 250 V. This high-speed HEMT device with high drain and gate breakdown voltages is an attractive device in actual applications. Farther improvement in RF characteristics can be expected by shortening the gate length.

4. Conclusions

We fabricated the high-speed AlGaN/GaN MIS-HEMT with high drain and gate breakdown voltages. When the L_{DS} and L_G are 7.6 μm and 0.4 μm, f_T and f_{max} are 13 GHz and 43 GHz, respectively. The drain breakdown voltage was about 250 V, and the gate breakdown voltage was over 180 V. These operating characteristics are significantly attractive for the high-power and the high-speed applications.

References

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[2] M. Higashiwaki and T. Matsui, Jpn. J. Appl. Phys. **44** (2005) L475.

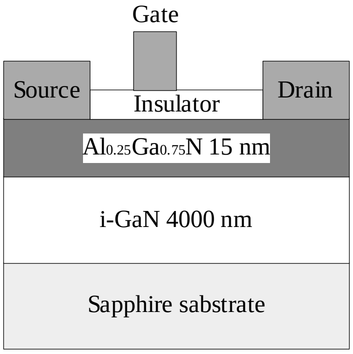

Fig.1. Schematic cross section of AlGaN/GaN HEMT structure.

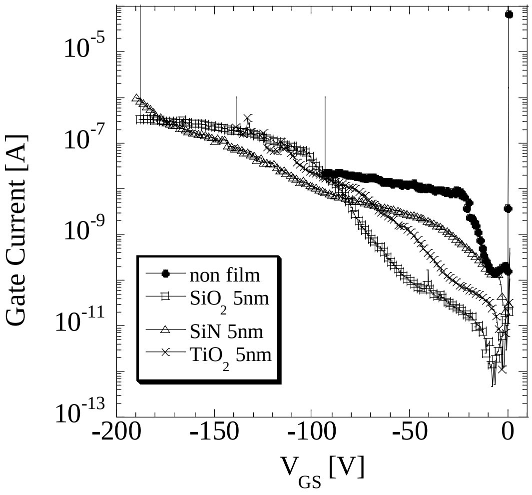

Fig.2. I-V characteristics of gate leak current.

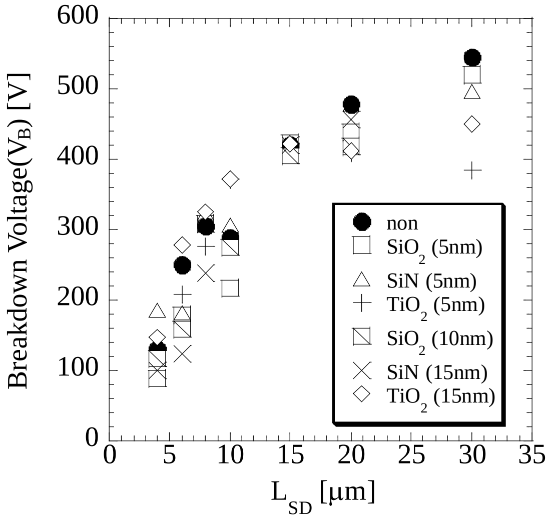

Fig. 3. Breakdown voltage versus L_{SD} length.

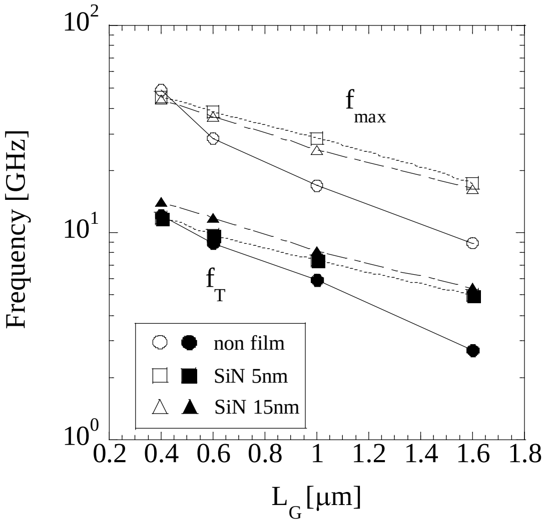

Fig.4. f_T and f_{max} versus gate length.