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Low-Leakage Current n-GaN/AlGaN/GaN HEMT with TaO_xN_y Gate Dielectric

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1. Introduction

GaN-based high electron mobility transistors (HEMTs) are attractive candidates for use in high power and high frequency applications. One of the problems with conventional Schottky-gate HEMTs is large leakage currents. To make the leakage currents smaller, metal-insulator-semiconductor (MIS)-gate HEMTs have been intensively investigated using various dielectrics. Sometimes the MIS-gate HEMTs suffer from a small transconductance (g_m) and a deep threshold voltage (V_{th}). For these problems, the use of dielectric insulators with high permittivity (high-k), such as HfO_2 [1], La_2O_3 [2], and Ta_2O_5 [3], are desirable. Oxynitride high-k dielectrics have widely been investigated in silicon metal-oxide-semiconductor (Si-MOS) field-effect transistors [4], but they have rarely been studied in MIS-gate GaN-based HEMTs. In this study, we investigated tantalum oxide (TaO_x) and tantalum oxynitride (TaO_xN_y) films as high-k gate insulators for MIS-gate n-GaN/AlGaN/GaN-HEMTs. Results showed that the TaO_xN_y MIS-HEMTs had both a low leakage current and a favorable V_{th} stability.

2. Experimental

A schematic cross section of the fabricated n-GaN/AlGaN/GaN MIS-HEMTs is shown in Fig. 1. The epitaxial layers were grown by metal-organic-chemical vapor deposition and consistsed of a buffer layer, a thick i-GaN layer, an i-AlGaN layer, an n-AlGaN layer, and an n-GaN capping layer [5] on S.I. SiC substrate. Pre-measurements showed a typical sheet resistance of 380 ohm/sq. The processing started with ohmic contact (Ti/Al/Ni/Au) using recessed ohmic technology. A device isolation process was performed by B^+ ion implantation. Prior to gate formation, a 50-nm-thick TaO_x or TaO_xN_y film was deposited as a gate insulator at 350 °C. The TaO_x film was then formed by sputtering in an Ar/O_2 atmosphere (oxygen partial pressure ratio of 57 %) and the TaO_xN_y film was formed by sputtering in an Ar/N_2 atmosphere (nitrogen partial pressure ratio of 15 %). Tantalum pentaoxide (Ta_2O_5 :$\varepsilon \sim 25$) was used as a sputtering target. Following this, a 100-nm Ni gate electrode was fabricated. Finally, a 200-nm silicon nitride (SiN_x) passivation film was deposited by using plasma-enhanced chemical vapor deposition. The gate length and width were 1 μm and 100 μm, respectively.

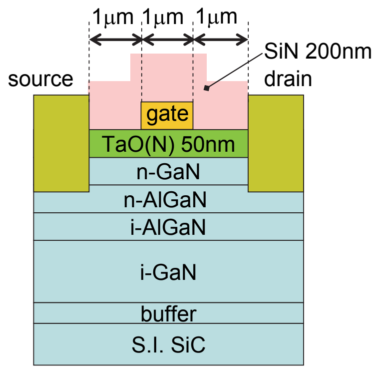

Fig. 1 A schematic cross section of the fabricated n-GaN/AlGaN/GaN MIS-HEMTs.

3. Results and discussions

Material compositions of the insulator films were characterized by using Rutherford backscattering spectrometry (RBS) (Table 1). In the TaO_xN_y film, the N atoms were approximately 14-atomic%, and they occupied not only the O-site and the Ta-site.

Table 1. Film Compositions.

	Ta [at%]	O [at%]	N [at%]	Ar [at%]
TaO_x	27.9	70.5	-	1.6
TaO_xN_y	24.6	59.6	14	1.8
uncertainly	1	4	5	0.3

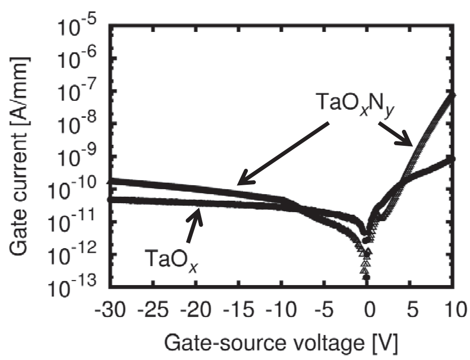

Fig. 2 Drain-opened I_G-V_{GS} characteristics of the MIS-HEMTs.

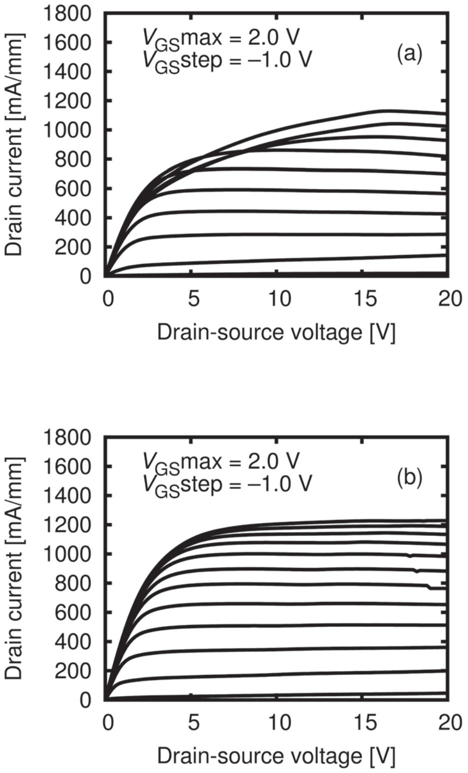

Fig. 3 I_D-V_{DS} characteristics of TaO_x sample (a) and TaO_xN_y sample (b).

Table 2 History of sheet resistance.

	Initial [ohm/sq.]	After deposition [ohm/sq.]
TaO_x sample	384	601
TaO_xN_y sample	370	360

Fig. 2 shows the drain-opened I_G-V_{GS} characteristics of the TaO_x MIS-gate device (TaO_x sample) and the TaO_xN_y MIS-gate device (TaO_xN_y sample). In both samples, low reverse leakage currents were obtained, which indicates that these materials could be excellent insulators for the GaN-based semiconductors. In our experience, to achieve these ultra-low leakage currents, a reactive gas element (O_2 or N_2) must be added to the sputtering atmosphere. Fig. 3 (a) and (b) show the I_D-V_{DS} characteristics of the TaO_x sample and the TaO_xN_y sample, respectively. In the TaO_xN_y sample, a large drain current modulation was observed. In contrast, in the TaO_x sample, a current degradation was observed, probably due to a bombardment of negative ionized oxygen (O^-) atoms that originated from the introduction of O_2 as a reactive gas in the sputtering atmosphere. In fact, the sheet resistance of the TaO_x sample significantly increased after the sputtering deposition (Table 2). Fig. 4 (a) and (b) show the double-sweep transfer characteristics of the TaO_x sample and the TaO_xN_y sample, respectively. Superior pinch-off characteristics and the rather large maximum transconductances were obtained. The TaO_x sample had a large positive V_{th} shift of 2.3 V, which was caused by high density negative-charge trap at the TaO_x/n-GaN interface and/or in the TaO_x layer. In contrast, the TaO_xN_y sample had a relatively-small positive V_{th} shift of 0.7 V, which indicates that the TaO_xN_y sample had a comparatively small density of negative-charge trap. We conclude that the TaO_xN_y film is a favorable candidate for a gate insulator with low-leakage current to be used in n-GaN/AlGaN/GaN HEMTs.

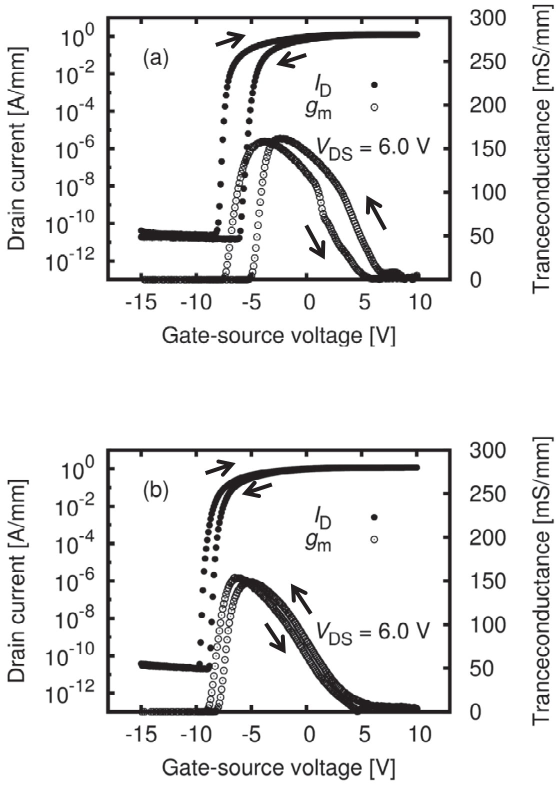

Fig. 4 Transfer characteristics of TaO_x sample (a) and TaO_xN_y sample (b). V_{GS} start = −15 V and V_{GS} return = + 10 V.

4. Conclusions

We investigated a TaO_x and a TaO_xN_y MIS-gate n-GaN/AlGaN/GaN HEMTs. Results demonstrated that TaO_xN_y MIS-HEMTs was able to achieve both an ultra-low leakage current and a favorable V_{th} stability.

References

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