Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp572-573

A-1-6

Sputtered amorphous AlN gate dielectric for AlGaN/GaN metal-insulator-semiconductor heterojunction field-effect transistor

H. A. Shih, M. Kudo, M. Akabori, and T. Suzuki*

Center for Nano Materials and Technology, Japan Advanced Institute of Science and Technology (JAIST)
1-1 Asahidai, Nomi-shi, Ishikawa 923-1292, Japan
*E-mail: tosikazu@jaist.ac.jp, Phone: +81-761-51-1441

1 Introduction

AlGaN/GaN metal-insulator-semiconductor heterojunction field-effect transistors (MIS-HFETs) have attracted considerable attention, because they are effective to reduce gate leakage currents. In particular, high dielectric constant (high-k) oxide materials, such as Al_2O_3 [1] or HfO_2 [2], have been investigated as a gate dielectric insulator of the MIS-HFETs. However, for such oxide insulators, there are difficulties in controlling the interface between the oxide and the nitride [3]. On the other hand, AlN is a non-oxide high-k insulator. Previously, sputter deposition of AlN on AlGaN/GaN, in which we expect a more controllable interface, was applied to passivation of AlGaN/GaN HFETs [4–7]. The AlN-passivated HFETs exhibit good heat release properties due to the high thermal conductivity of AlN ($\sim$ 10 times higher than that of Al_2O_3), and also effective suppression of current collapse. Since AlN has a possible high breakdown field $\gtrsim$ 10 MV/cm and the high dielectric constant ~ 9, which are comparable to those of Al_2O_3, sputtered amorphous AlN can be a favorable gate dielectric of AlGaN/GaN MIS-HFETs, with the merits of more controllable interface and better heat release properties. Although AlGaN/GaN MIS-HFETs with sputtered AlN gate dielectric have been reported [4,8], enough device performance has not been shown, in particular for forward gate leakage properties. In this article, we report on an AlGaN/GaN MIS-HFET with sputtered amorphous AlN gate dielectric, including suppressed forward gate leakage properties.

2 Sputtered amorphous AlN on AlGaN/GaN

AlN thin films on an $Al_{0.29}Ga_{0.71}N$(25 nm)/GaN(3000 nm) heterostructure were deposited by RF magnetron sputtering in N_2-mixed (3 %) Ar ambience using an AlN target. The AlGaN/GaN heterostructure was obtained by metal-organic vapor phase epitaxy on sapphire(0001). The AlN film is amorphous as confirmed by X-ray diffraction measurements. Figure 1 shows an Al2p X-ray photoelectron spectroscopy (XPS) signal for an AlN film of 20 nm thickness deposited at room temperature under a working pressure of 0.2 Pa. The Al2p signal is dominated by Al-N bonding, though the Al-O bonding was detected. Since the Al-O bonding can be attributed to the surface oxidation, we consider that the AlN film is almost stoichiometric. Furthermore, the bandgap of the AlN was estimated by N1s electron energy loss spectroscopy, as shown in Fig. 2. We obtain the bandgap $E_g \sim 6.4$ eV, which is close to the literature value.

3 Device fabrication and characterization

Using the AlN sputter deposition on the $Al_{0.29}Ga_{0.71}N$/GaN heterostructure, we have fabricated MIS-HFET with the amorphous AlN gate dielectric shown in Fig. 3. Hall effect measurements of the heterostructure showed an as-grown electron mobility of 1200 cm^2/V-s and sheet electron concentration of 1.3×10^{13} cm^{-2}. After the Ti/Al Ohmic electrode formation and the device isolation by B^+ implantation, the sputter deposition of AlN gate dielectric insulator of 20 nm thickness was carried out. The formation of Ni/Au gate electrode completed the device fabrication. We obtained the gate length of 150 nm, the source-gate spacing of 2 μm, the gate-drain spacing of 3 μm, and the gate width of 50 μm.

In Fig. 4, we show output characteristics of the fabricated MIS-HFET, which is almost free from current collapse. Although we observed a slightly high on-resistance, a current drivability with a drain current of 600 mA/mm is obtained. Figure 5 shows transfer characteristics, in which there is almost no hysteresis under the gate voltage sweep of -18 V $\rightarrow$ $+6$ V $\rightarrow$ -18 V. According to the insertion of AlN gate dielectric between the gate metal and the AlGaN, the transconductance is not so high; the maximum transconductance is 100 mS/mm. It should be noted that, owing to good insulating properties of the AlN gate dielectric, gate leakage currents are significantly small, 10^{-9} A/mm range or less, for both reverse and forward biases. The small leakage currents lead to the small drain off-currents, which exhibit more than 4 orders reduction in comparison with those of Schottky HFETs fabricated from the same AlGaN/GaN heterostructure. Figure 6 shows gate-source two-terminal (drain open) I-V characteristics; we observed the gate current of 2×10^{-9} A/mm at reverse -18 V, and 3×10^{-10} A/mm even at forward $+6$ V, showing one of the most significant suppression of forward gate leakage currents in AlGaN/GaN MIS-HFETs.

Although we obtained the device operation of the MIS-HFET with the amorphous AlN gate dielectric, it is important to elucidate interface properties between the amorphous AlN and the AlGaN/GaN in detail. For this purpose, we have measured C-V characteristics between a 100 μm $\times$ 100 μm area gate electrode and a grounded Ohmic electrode surrounding the gate. Figure 7 shows measured C-V characteristics for several frequencies, under the gate voltage sweep of -12 V $\rightarrow$ $+3$ V, in which we observe a significant frequency dispersion for forward biases. This is attributed to the interface states between the amorphous AlN and the AlGaN/GaN. Towards practical applications, we need further investigation on the interface states.

4 Summary

We fabricated and investigated an AlGaN/GaN MIS-HFET with sputtered amorphous AlN gate dielectric. Owing to good insulating properties of the AlN, gate leakage currents are significantly reduced. We realized one of the most significant suppression of forward gate leakage currents in AlGaN/GaN MIS-HFETs.

References

[1] T. Hashizume, S. Ootomo, and H. Hasegawa, Appl. Phys. Lett. **83**, 2952 (2003).

[2] C. Liu, E. F. Chor, and L. S. Tan, Appl. Phys. Lett. **88**, 173504 (2006).

[3] N. Maeda, T. Makimura, T. Maruyama, C. Wang, M. Hiroki, H. Yokoyama, T. Makimoto, T. Kobayashi, and T. Enoki, Jpn. J. Appl. Phys. **44**, L646 (2005).

[4] Y. Liu, J. A. Bardwell, S. P. McAlister, S. Rolfe, H. Tang, and J. B. Webb, Phys. Status Solidi C **0**, 69 (2002).

[5] D. Ueda, 65th Annual Device Research Conference, 2007, p. 27.

[6] N. Tanaka, H. Takita, Y. Sumida, and T. Suzuki, Phys. Status Solidi C **5**, 2972 (2008).

[7] N. Tanaka, Y. Sumida, H. Kawai, and T. Suzuki, Jpn. J. Appl. Phys. **48**, 04C099 (2009).

[8] R. Stoklas, D. Gregušová, Š. Gaži, J. Novák, and P. Kordoš, J. Vac. Sci. Tech. B **29**, 01A809 (2011).

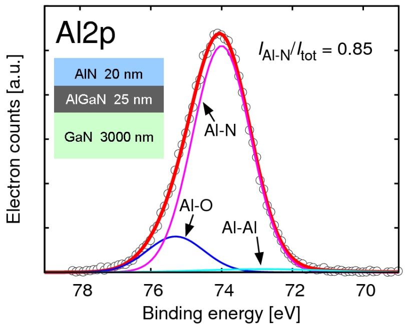

Fig. 1: Al2p XPS signal for the AlN film of 20 nm thickness. The ratio of the Al-N intensity to the total intensity $I_{\mathrm{Al-N}}/I_{\mathrm{tot}}$ is 0.85.

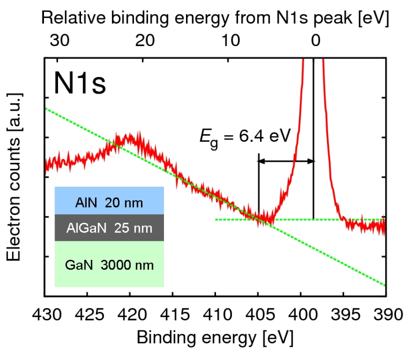

Fig. 2: AlN bandgap $E_{\mathrm{g}} \sim 6.4$ eV estimated by N1s electron energy loss spectroscopy.

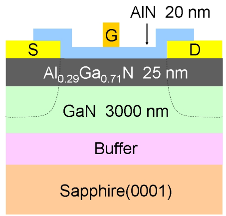

Fig. 3: Schematic cross section of the fabricated MIS-HFET.

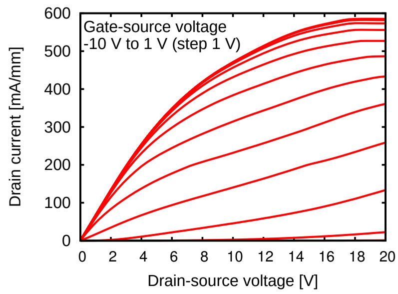

Fig. 4: Output characteristics of the MIS-HFET with the gate length of 150 nm.

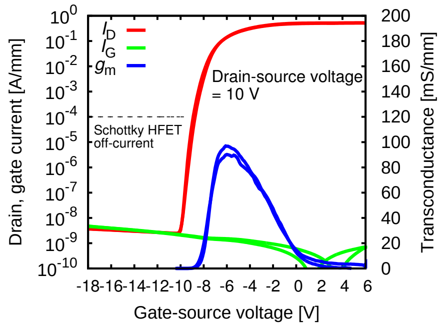

Fig. 5: Transfer characteristics of the MIS-HFET with the gate length of 150 nm. Drain current I_{D}, gate current I_{G}, and transconductance g_{m} were obtained under the gate voltage sweep of -18 V $\rightarrow +6$ V $\rightarrow -18$ V.

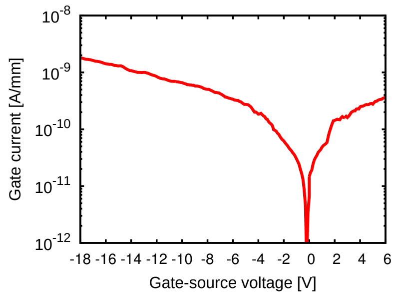

Fig. 6: Gate-source two-terminal (drain open) I-V characteristics of the MIS-HFET with the gate length of 150 nm.

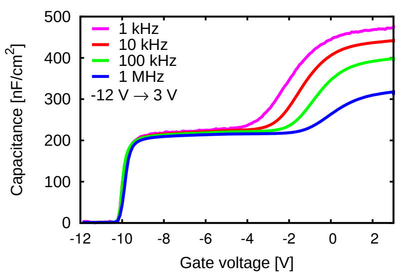

Fig. 7: C-V characteristics between a 100 μm × 100 μm area gate electrode and a grounded Ohmic electrode surrounding the gate for several frequencies.