AlGaN/GaN MOS-HEMTs using RF magnetron Sputtered SiO_2 Gate Insulator and Post-Annealing Treatment

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Summary

We propose high-quality RF magnetron sputtered SiO_2 gate insulator for high-voltage AlGaN/GaN MOS-HEMTs. A very high dielectric breakdown field over 9.6 MV/cm of SiO_2 insulator was achieved by adding an additional oxygen flow. A post-annealing treatment was further developed to recover the sputtering-induced surface damage. After post-annealing, carrier concentration and mobility in 2DEG channel were improved by 21.7 and 5.5 %, respectively. As a result of optimized sputtering and post treatment conditions, we achieved a very high breakdown voltage of 205 V at relatively short gate-drain distance of 2 μm (**breakdown field of 102.5 V/μm**).

Motivation

Although, AlGaN/GaN HEMTs have attracted considerable attention for high-power and high-speed applications, relatively large leakage through the Schottky-gate contact remains a serious problem [1]. A SiO_2/AlGaN/GaN MOS-HEMT is a suitable structure for suppression of leakage current due to wide bandgap of SiO_2 and high conduction band offset at SiO_2/GaN interface [2]. However, further investigation into SiO_2 gate insulator is required to increase the breakdown voltage and gate sweeping rating. In this paper, we propose RF magnetron sputtered SiO_2 and optimize its deposition and post-treatment conditions for high breakdown voltage.

Fabrication Procedure and Experimental Results

Al/SiO_2/n^+ GaN (n= 1.4×10^{19} cm^{-3}) MOS-capacitor was fabricated to examine V_{br} of the SiO_2 insulator under different deposition conditions. The sputtering was carried out at room temperature with a constant power of 160 W and an argon/oxygen gas mixture. The oxygen rate per total gas flow was varied from 0 to 40 % to find the optimum conditions for high V_{br}. The V_{br} of the SiO_2 film strongly depends on different oxygen flow as shown in Fig. 1. The V_{br} was improved with increase of the oxygen ratio up to 30 % so that the highest value of 9.6 MV/cm was achieved. The oxygen flow introduces oxygen atoms into the film and densifies SiO_2 insulator. Beyond 30 % oxygen ratio, V_{br} started to decrease, which is attributed to the reduction of energy input into the film due to the smaller atomic mass of O than Ar, reducing the film density. The sheet carrier concentration and the electron mobility in SiO_2/AlGaN/GaN sample using 30 % oxygen condition were decreased by 25 and 69 %, respectively, due to sputtering damage to AlGaN surface. This damage was recovered after post-annealing treatment as shown in Table 1. It is seen that the post-annealing at 900 ˚C for 20 s is able to fully restore the epilayer crystallinity and interface quality.

Based on the optimized sputtering and post-annealing conditions, sputtered-SiO_2/AlGaN/GaN MOS-HEMT was fabricated as follows: 220 nm-deep mesa isolation, 10 nm-thick SiO_2 sputtering, Ti/Al/Ti/Au source/drain formation and Ni/Au gate formation. Cross-sectional view of the fabricated devices is shown in Fig. 2. As for the device dimensions, the gate length, width, source-to-drain and gate-to-drain distances were 2, 100, 6, and 2 μm, respectively. For the characterization, the gate leakage current of the MOS-HEMT was first compared with that of the conventional HEMT of the same dimensions. It was found that at a reversed gate bias of –30 V, more than four orders of magnitude lower leakage current was achieved by using the MOS-HEMT. The I_d-V_d and transfer characteristics were then investigated (Fig. 3 and 4). The peak drain current and the maximum transconductance were 594 mA/mm and 74.5 mS/mm, respectively. The three-terminal off-state breakdown voltage was measured by a curve tracer and was 205 V. A comprehensive comparison of the breakdown voltages per unit gate-drain distance, obtained from various publications, is presented in Fig. 5. The dielectric thickness is also taken into consideration since a direct comparison using MOS-HEMTs with the same dielectric thickness is difficult. The breakdown voltage performance of our device is, if not better, at least on-par with other GaN-based MOS-HEMTs reported to date.

References

[1] I. Daumiller, et al., IEEE Electron Device Lett. 20, 448 (1999).
[2] K. Matocha, T. P. Chow and R. J. Gutmann, IEEE T. Electron Device 52, 6 (2005).

Figures and Table

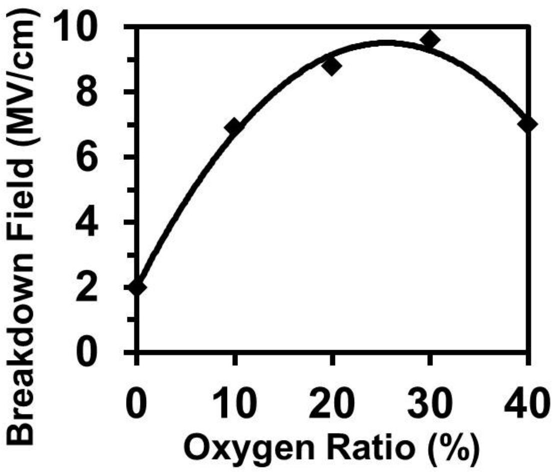

Fig. 1: Breakdown field of the sputtered-SiO_2 films on n^+ GaN as a function of oxygen ratio

Table 1. Values of the electron concentration (ns) and mobility (μ) under different annealing temperatures and durations.

Experimental conditions	Electron mobility ($cm^2/V\cdot S$)	Sheet concentration ($\times 10^{13}$ cm^{-2})
Epilayer	1060	1.08
RTA (0 ˚C, 0 s)	330	0.81
RTA (800 ˚C, 20 s)	644	0.98
RTA (900 ˚C, 20 s)	1118	1.32
RTA (1000 ˚C, 20 s)	1077	1.30
RTA (900 ˚C, 10 s)	941	0.99
RTA (900 ˚C, 30 s)	1116	1.31
RTA (900 ˚C, 60 s)	974	1.25

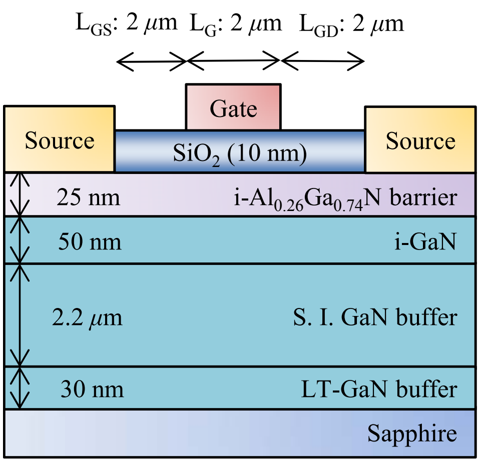

Fig. 2: Cross-sectional view of the fabricated AlGaN/GaN MOS-HEMT

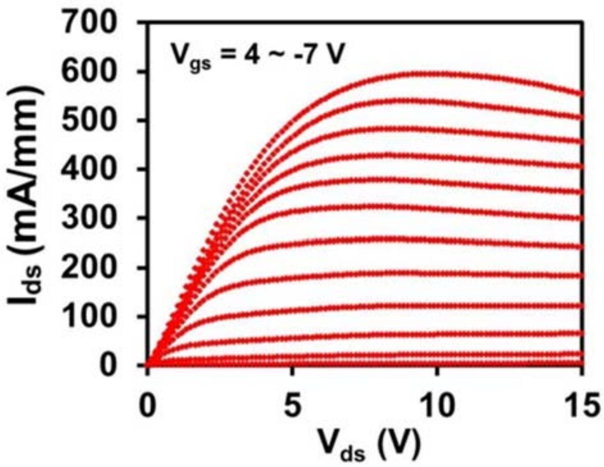

Fig. 3: Output *I-V* of the AlGaN/GaN MOS-HEMT

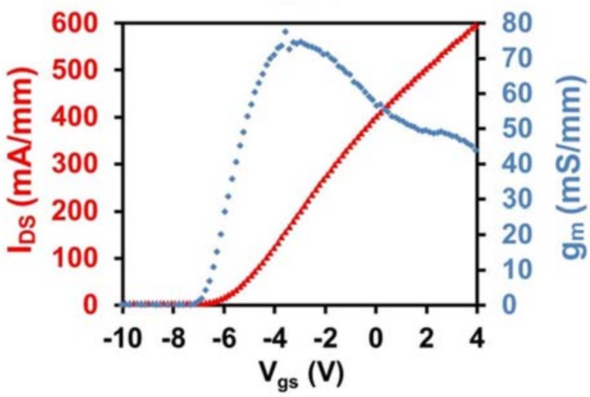

Fig. 4: Transfer characteristics of the AlGaN/GaN MOS-HEMT

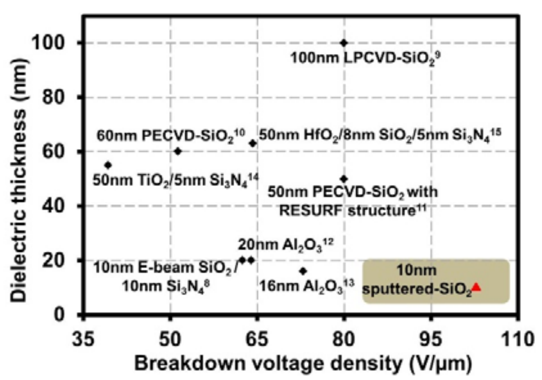

Fig. 5: Comparison of breakdown voltage density of MOS-HEMTs achieved by different groups