GaN MOSHEMT using Sputtered-Gate-SiO_2 and Post-Annealing Treatment

Liang Pang[1], Yaguang Lian[1], Dong-Seok Kim[2], Jung-Hee Lee[2], and Kyekyoon Kim[1]

[1]Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, IL 61801
[2]School of Electrical Engineering and Computer Science, Kyungpook National University, Korea, 702-701
E-mail address: kevinkim@ad.uiuc.edu
Tel: (217)-333-7162

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Abstract

By using RF magnetron sputtering with oxygen compensation, high-quality SiO_2-on-GaN with breakdown field of 9.6 MV/cm was achieved. A post-annealing treatment was further developed to remove the sputtering-induced epilayer damage, which not only recovered, but improved the electron concentration and mobility of the 2-D electron gas by 21.7% and 5.5%, respectively. High-performance SiO_2/AlGaN/GaN MOSHEMT was thus fabricated, which exhibited a maximum drain current of 594 mA/mm and a breakdown voltage of 205 V at the gate–drain distance of 2 μm. The breakdown voltage performance is among the best of GaN-based MOSHEMTs reported to date.

INTRODUCTION

Although GaN high-electron-mobility-transistors (HEMTs) have attracted considerable attention for high-power, high-speed and high-temperature application, relatively large gate leakage through the metal/GaN contact remains to be a serious problem [1]. To find a solution, significant progress has been made on metal-oxide-semiconductor (MOS)-HEMTs, where the gate-oxide, like SiO_2, is formed via various techniques like PECVD, E-beam evaporation or ALD [2-4]. RF magnetron sputtering has been proved to be able to deposit SiO_2 on GaN with quality better than the above-mentioned techniques [5], since the energetic particle impingement can make the growing film more condensed, therefore enhancing the oxide breakdown field (V_{br}). However, due to the difficulty to prevent bombardment damage to the epilayer that degrades the 2DEG properties, there are few reports on the successful fabrication of MOSHEMT employing sputtered gate-SiO_2.

In this study, we first optimize the sputtering condition to produce high-quality SiO_2 on GaN, and then propose a post-annealing treatment to remove the sputtering-induce surface damage. As a result, sputtered-SiO_2 MOSHEMTs with high current and breakdown voltage characteristics are demonstrated.

EXPERIMENTAL

Firstly, Al/SiO_2/n^+-GaN MOS-capacitors were fabricated to examine V_{br} of the SiO_2 film under different deposition conditions. The sputtering was carried out at room temperature with a constant power of 160 W. Argon and oxygen (with different ratios) were used as the sputtering gas. Secondly, Hall-effect measurements were conducted to investigate the impact of sputtering damage on the 2DEG properties, and the efficacy of post-annealing treatment for damage recovery was systematically analyzed. Finally, SiO_2/AlGaN/GaN MOSHEMTs were fabricated as follows. After device isolation and recessed source/drain etching, 10-nm SiO_2 was sputtered at the optimized condition on the template. Ti/Al/Ti/Au were then deposited by E-beam evaporation as the Ohmic contacts, followed by post-annealing in N_2 ambient. Deposition of gate metals (Ni/Au) completed the fabrication process.

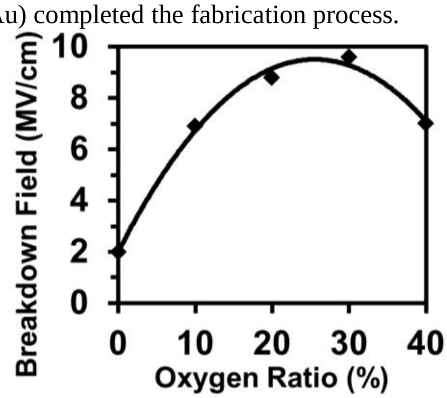

Fig. 1. Breakdown field of the sputtered-SiO_2 films on n^+-GaN as a function of oxygen ratio in the sputtering gas.

RESULTS AND DISCUSSIONS

V_{br} of the SiO_2 film strongly depends on different sputtering conditions, like the oxygen ratio in the sputtering gas. As shown in Fig. 1, continuous improvement in V_{br} was found when increasing the oxygen ratio up to 30%. By introducing oxygen atoms into the film, the oxygen vacancies normally occurred during sputtering were compensated, therefore eliminating the defects and enhancing the film quality. Beyond 30% oxygen ratio, V_{br} started to decrease, which is attributable to the reduction of energy input into the film due to the smaller atomic mass of O than Ar, thus reducing the film density. The largest V_{br} of 9.6 MV/cm is higher than that of

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

	Epilayer	RTA (0 ˚C, 0 s)	RTA (800 ˚C, 20 s)	RTA (900 ˚C, 20 s)	RTA (1000 ˚C, 20 s)	RTA (900 ˚C, 10 s)	RTA (900 ˚C, 30 s)	RTA (900 ˚C, 60 s)
n_s (×10[13] cm[-2])	1.08	0.81	0.98	1.32	1.30	0.99	1.31	1.25
μ (cm²/V·S)	1060	330	644	1118	1077	941	1116	974

the SiO_2 films deposited on GaN by other techniques like PECVD, photo-CVD, and E-beam evaporation [6-8].

After optimizing the sputtered-SiO_2 quality, the impact of sputtering damage on the 2DEG properties was investigated. Hall-effect measurements showed that after 10-nm SiO_2 was sputtered on the AlGaN surface with 30% oxygen mixing, the electron concentration (n_s) and mobility (μ) decreased by 25% and 69% respectively, which was resulted from the sputtered-induced interface states. In order to improve the interface quality, a post-annealing treatment was developed. Table 1 shows the values of n_s and μ under different annealing temperatures or durations. It can be seen that performing the post-annealing at 900 ˚C for 20 s is able to fully restore the epilayer crystallinity and interface quality. The additional improvement in both n_s (21.7%) and μ (5.5%) is due to the chemical passivation of the exposed epilayer surface dangling bonds by the SiO_2 film. Further increasing the annealing temperature or time resulted in reduction of n_s and μ again, owing to the defect generation by AlGaN/GaN film dissociation at the elevated temperature, which degraded the epilayer crystallinity and channel interface morphology. Furthermore, it was found that the optimized post-annealing condition coincides with the metal annealing for source/drain Ohmic contact formation. Therefore, these two steps can be combined to save the thermal cost and simplify the fabrication process.

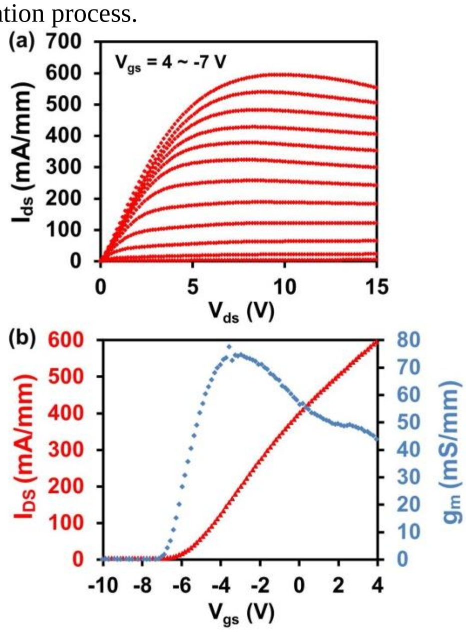

Fig. 2. (a) I_d-V_d and (b) transfer characteristics of 10-nm sputtered-SiO_2/AlGaN/GaN MOSHEMT.

Based on the optimized sputtering and post-annealing conditions, sputtered-SiO_2/AlGaN/GaN MOSHEMT was fabricated, whose I_d-V_d and transfer characteristics are shown in Fig. 2. 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 205 V. A comprehensive comparison of the breakdown voltages per unit gate-drain distance, obtained from various publications [8-15], is presented in Fig. 3. The dielectric thickness is also taking into consideration. The breakdown voltage performance of our device is, if not better, on-par with other GaN-based MOSHEMTs reported to date.

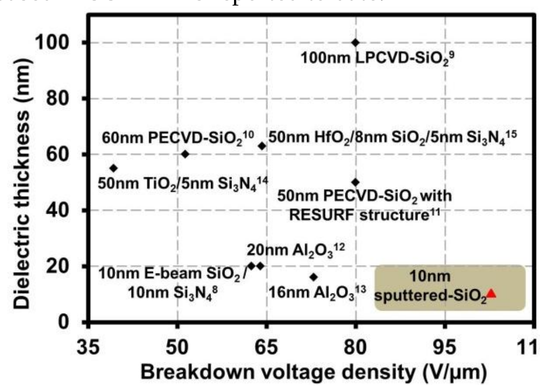

Fig. 3. Comparison of breakdown voltages density of MOSHEMTs achieved by different groups.

CONCLUSIONS

Using room temperature RF magnetron sputtering with 30% oxygen mixing, highly condensed SiO_2 has been demonstrated to be a suitable gate insulator for GaN-based MOSHEMTs. Further adopting the post-annealing treatment during Ohmic contact formation effectively removed the sputtering-induced epilayer damage, resulting in the MOSHEMT with high saturation current and breakdown voltage.

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