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High Integrity SiO_2 Gate Insulator Formed by Microwave-Excited PECVD for AlGaN/GaN Hybrid MOS-HFET on Si Substrate

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1. Introduction

GaN has superior physical properties for power devices. For power transistors, normally-off operation is strongly required from the fail-safe point of view and several structures of normally-off GaN-based transistors have been proposed. In these structures, a new type of GaN-based transistor with a high-threshold voltage, a low on-state resistance, and a high-breakdown voltage, so-called AlGaN/GaN Hybrid MOS-HFET, has been demonstrated [1-3]. To realize high performance GaN MOSFET, a high quality gate insulator is required. SiO_2 is a good candidate as a gate insulator of GaN MOSFET since SiO_2 has a larger direct wide bandgap, a larger conduction band offset and a larger valence band offset on GaN, respectively [4]. In this paper, a high quality SiO_2 on GaN formed by Microwave (2.45 GHz: MW) Plasma Enhanced Chemical Vapor Deposition (PECVD) is demonstrated. Then an AlGaN/GaN Hybrid MOS-HFET with a high field-effect mobility to which MW-PECVD SiO_2 is applied is also demonstrated.

2. Experiments

MW plasma is capable of exiting a low-electron temperature (<1 eV) and a high-electron density (>10^{12} cm^{-3}) at the substrate surface position [5, 6]. In order to investigate the interface properties of SiO_2/GaN and the electrical characteristics of SiO_2, n-type GaN on Si (111) substrates were applied for fabrication of GaN MOS capacitors. SiO_2 films were formed by MW-PECVD and Capasitive Coupled Plasma (CCP) CVD. We also applied these SiO_2 films to AlGaN/GaN Hybrid MOS-HFET. The structure of AlGaN/GaN Hybrid MOS-HFET is shown in Fig. 1. After mesa etching and recessed region etching to define the channel region by RIE, SiO_2 films were formed by MW-PECVD and CCP-CVD as the gate insulator. Then gate, source and drain electrodes were fabricated by sputtering.

3. Results and Discussions

Fig. 2 shows the energy distribution of the interface state density (D_{it}) of SiO_2/GaN. D_{it} is estimated by applying the Terman method to the Capacitor-Voltage (*C-V*) characteristics at 150°C [7]. The D_{it} of the GaN MOS capacitor with MW-PECVD SiO_2 is lower than that with CCP-CVD SiO_2. Fig. 3 shows the Current density-Electric field (*J-E*) characteristics of these GaN MOS capacitors at 200°C. The MW-PECVD SiO_2 has a high-breakdown field with over 11 MV/cm. Fig. 4 shows the charge-to-breakdown Q_{bd} of these GaN MOS capacitors. The Q_{bd} with MW-PECVD SiO_2 is over one order of magnitude higher than that with CCP-CVD SiO_2. It is suggested that their results are caused by plasma damage such as ion bombardment and charge-up by CCP-CVD SiO_2 deposition on GaN since CCP excites electrons to very high temperature.

An annealing after SiO_2 deposition on GaN is well known to be effective to decrease D_{it} of SiO_2/GaN [8, 9]. Fig. 5 shows the energy distribution of the D_{it} of GaN MOS capacitor with and without annealing after MW-PECVD SiO_2 deposition. The D_{it} is also decreased by annealing. Moreover, the Q_{bd} of GaN MOS capacitors with and without annealing after MW-PECVD SiO_2 deposition are evaluated. As shown in Fig. 6, the Q_{bd} of GaN MOS capacitor with annealing is about one order of magnitude higher than that without annealing. These results indicate that the annealing after SiO_2 deposition on GaN is effective not only for decreasing D_{it} of SiO_2/GaN but also for improving Q_{bd} of SiO_2.

Fig. 7 shows the transfer characteristics of AlGaN/GaN Hybrid MOS-HFETs with MW-PECVD SiO_2 and CCP-CVD SiO_2 and Fig. 8 shows the field-effect mobility evaluated from the transfer characteristics of these MOS-HFETs. These SiO_2 films were annealed after the deposition. The on-state characteristic of MOS-HFET with MW-PECVD SiO_2 is superior to that with CCP-CVD SiO_2. The field-effect mobility of MOS-HFET with MW-PECVD SiO_2 is higher in all channel length and the MOS-HFET has the maximum field-effect mobility with 161 cm^2/Vs at the channel length of 50 μm.

4. Conclusion

We have shown the formation of a high quality gate insulator for GaN MOSFET by depositing SiO_2 by MW-PECVD and annealing after deposition. We also demonstrated an AlGaN/GaN Hybrid MOS-HFET with a high field-effect mobility by applying this gate insulator.

References

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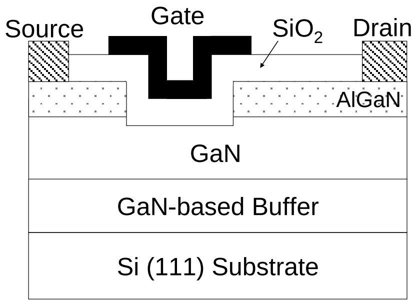

Fig. 1. A schematic cross section of AlGaN/GaN Hybrid MOS-HFET.

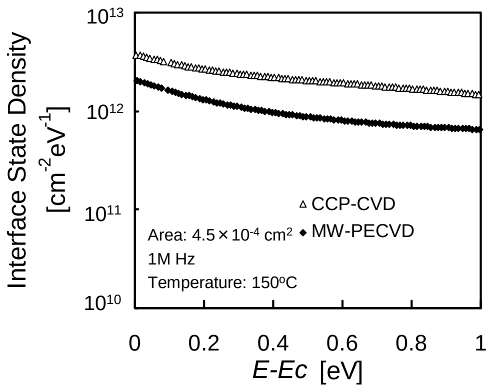

Fig. 2. D_{it} of GaN MOS capacitors with MW-PECVD SiO_2 and CCP-CVD SiO_2 calculated from the *C-V* characteristics at 150°C. SiO_2 films were not annealed after deposition.

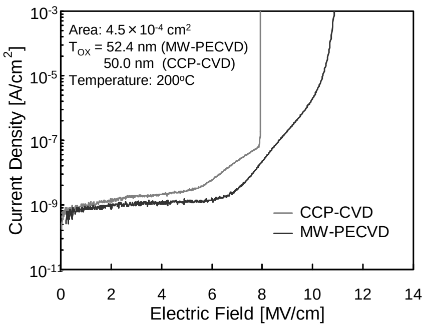

Fig. 3. *J-E* characteristics of GaN MOS capacitors with MW-PECVD SiO_2 and CCP-CVD SiO_2 at 200°C. SiO_2 films were not annealed after deposition. Electric field is defined (V_g-V_{FB})/EOT (V_g: gate voltage, V_{FB}: flatband voltage shift, EOT: equivalent oxide thickness)

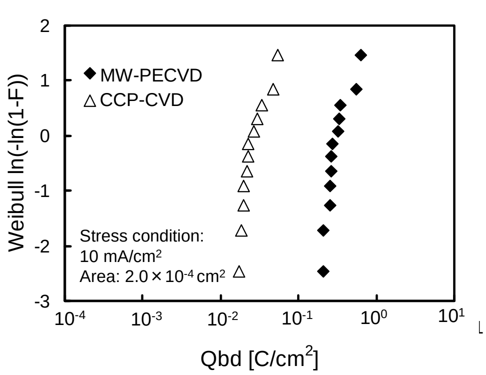

Fig. 4. Charge-to-breakdown Q_{bd} of GaN MOS capacitors with MW-PECVD SiO_2 and CCP-CVD SiO_2. SiO_2 films were not annealed after deposition.

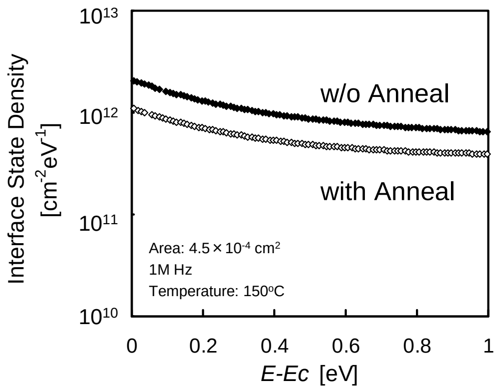

Fig. 5. D_{it} of GaN MOS capacitors with and without annealing after MW-PECVD SiO_2 deposition calculated from the *C-V* characteristics at 150°C. (Annealing: 800°C, 30 min)

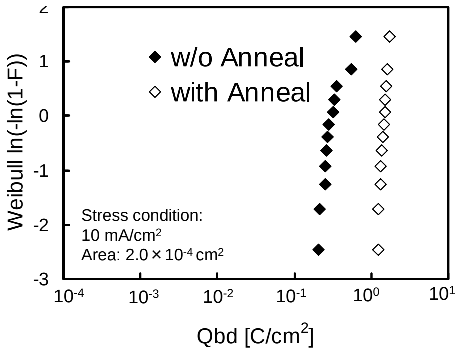

Fig. 6. Charge-to-breakdown Q_{bd} of GaN MOS capacitors with and without annealing after MW-PECVD SiO_2 deposition calculated from the *C-V* characteristics at 150°C. (Annealing: 800°C, 30 min)

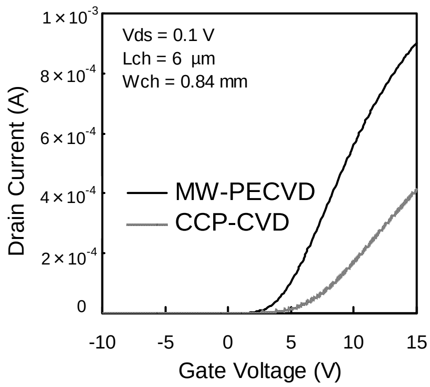

Fig. 7. Transfer characteristics of AlGaN/GaN Hybrid MOS-HFETs with MW-PECVD SiO_2 and CCP-CVD SiO_2. SiO_2 films were annealed at 800°C for 30 min after deposition.

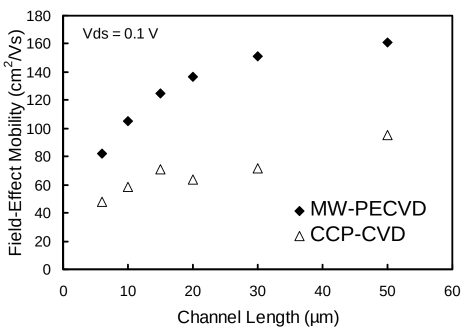

Fig. 8. Field-effect mobility versus channel length of AlGaN/GaN Hybrid MOS-HFETs with MW-PECVD SiO_2 and CCP-CVD SiO_2. SiO_2 films were annealed at 800°C for 30 min after deposition.