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High Quality SiO_2/Al_2O_3 Gate Stack for GaN MOSFET

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1. Introduction

GaN MOSFET with normally-off operation is an excellent candidate for high power devices. To realize high performance GaN MOSFET, a high quality gate insulator is required. We have shown a high integrity SiO_2 gate insulator on GaN, which has a low interface state density (D_{it}) of SiO_2/GaN, a high breakdown electric field, and a high charge-to-breakdown (Q_{bd}), respectively, formed by Microwave (2.45 GHz: MW) Plasma Enhanced Chemical Vapor Deposition (PECVD) so far [1]. Furthermore, we have also demonstrated an AlGaN/GaN hybrid MOS-HFET [2-4] with a high field-effect mobility of 161 cm^2/Vs by applying the SiO_2 gate insulator deposited by MW-PECVD. However, the D_{it} of SiO_2/GaN is higher compared with Si devices and it should be reduced. Recently, GaN MOSFET with Al_2O_3 gate insulator has been demonstrated [5, 6]. Al_2O_3 is one of the good candidates as a gate insulator of GaN MOSFET like SiO_2 since Al_2O_3 has a larger direct wide bandgap, a larger conduction band offset and a larger valence band offset on GaN, respectively [7]. In this paper, we report on the experimental demonstration of applying Al_2O_3 to GaN MOSFET.

2. Experiments

In order to investigate the interface properties of gate insulator/GaN and the electrical characteristics of insulators, n-type GaN on Si (111) substrates were applied for fabrication of GaN MOS capacitors. Al_2O_3 and SiO_2 were formed by Atomic Layer Deposition (ALD) and MW-PECVD, respectively. We also applied some gate insulators to AlGaN/GaN hybrid MOS-HFET, the structure of which is shown in Fig. 1. After mesa etching and recessed region etching to define the channel region by RIE, gate insulators were formed. Then gate, source and drain electrodes were fabricated.

3. Results and Discussions

Fig. 2 shows the energy distribution of the interface state density (D_{it}) of Al_2O_3/GaN and SiO_2/GaN. The thicknesses of Al_2O_3 and SiO_2 films were 50-60 nm. Al_2O_3 and SiO_2 films were annealed at 700^{o}C and 800^{o}C after deposition, respectively. D_{it} is estimated by applying the Terman method to the Capacitance-Voltage (*C-V*) characteristics at 150^{o}C [8]. The D_{it} of the GaN MOS capacitor with Al_2O_3 is lower than that with SiO_2. Fig. 3 shows the Current density-Electric field (*J-E*) characteristics of those GaN MOS capacitors at room temperature. The breakdown field of Al_2O_3 is much lower and the leakage current is much higher compared with SiO_2. From these results, SiO_2/Al_2O_3 stacked layer structure is employed for good interface property and high insulating in GaN MOSFET. In this experiment, 3 nm Al_2O_3 formed on GaN and 60 nm SiO_2 was deposited on Al_2O_3. After SiO_2/Al_2O_3 deposition, 700^{o}C annealing was performed. Fig. 4 shows the D_{it} of SiO_2/Al_2O_3/GaN, Al_2O_3/GaN and SiO_2/GaN, respectively. The D_{it} of SiO_2/Al_2O_3/GaN is almost the same as Al_2O_3/GaN. Fig.5 and Fig. 6 are the *J-E* characteristics and Q_{bd} of these GaN MOS capacitors, respectively. The breakdown field and Q_{bd} of the GaN MOS capacitor with SiO_2/Al_2O_3 are almost the same as SiO_2. These results indicate the SiO_2/Al_2O_3 gate stack has a low-interface state density between the structure and GaN, a high-breakdown field, and a high Q_{bd}.

Fig. 7 shows the transfer characteristics of AlGaN/GaN hybrid MOS-HFETs with SiO_2/Al_2O_3 gate stack and SiO_2 and Fig. 8 shows the field-effect mobility evaluated from the transfer characteristics of these MOS-HFETs. Both MOS-HFETs show good normally-off operations with the threshold voltage of about 4.2 V. The on-state characteristic of MOS-HFET with SiO_2/Al_2O_3 is superior to that with SiO_2. The field-effect mobility of MOS-HFET with SiO_2/Al_2O_3 is higher in all channel length and the MOS-HFET has the maximum field-effect mobility with 192 cm^2/Vs at the channel length of 50 μm.

4. Conclusion

We have demonstrated a high quality gate insulator for GaN MOSFET by applying SiO_2/Al_2O_3 gate stuck. We also demonstrated an AlGaN/GaN hybrid MOS-HFET with a high field-effect mobility by applying this dielectric stuck.

References

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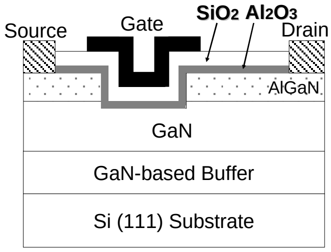

Fig. 1. A schematic cross section of AlGaN/GaN hybrid MOS-HFET. SiO_2/Al_2O_3 stack structure gate insulator was applied.

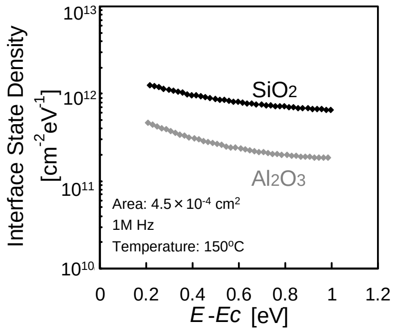

Fig. 2. D_{it} of GaN MOS capacitors with SiO_2 and Al_2O_3 calculated from the *C-V* characteristics at 150ºC. D_{it} of Al_2O_3 is lower than that of SiO_2.

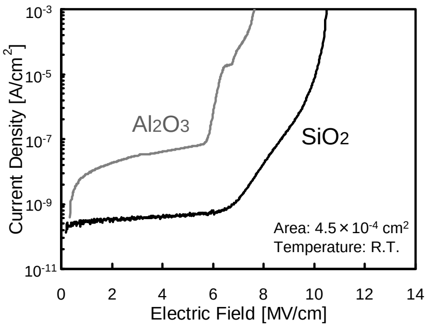

Fig. 3. *J-E* characteristics of GaN MOS capacitors with SiO_2 and Al_2O_3. Electric field is defined. $(V_g - V_{FB})$/EOT (V_g: gate voltage, V_{FB}: flatband voltage shift, EOT: equivalent oxide thickness) The breakdown field of Al_2O_3 single layer is much lower and the leakage current is much higher than SiO_2.

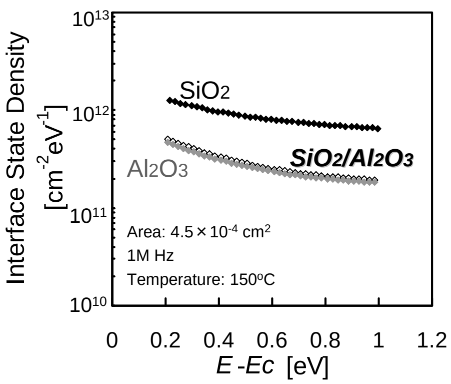

Fig. 4. D_{it} of GaN MOS capacitors with SiO_2, Al_2O_3 and SiO_2/Al_2O_3 calculated from the *C-V* characteristics at 150ºC. D_{it} of the stack structure of SiO_2/Al_2O_3 is the same as that of Al_2O_3 single layer and is also lower than that of SiO_2.

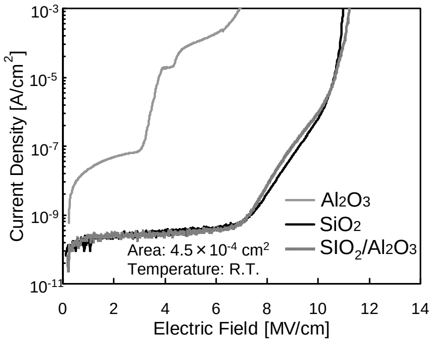

Fig. 5. *J-E* characteristics of GaN MOS capacitors with SiO_2, Al_2O_3 and SiO_2/Al_2O_3. The breakdown field of the stack structure of SiO_2/Al_2O_3 is the same as that of SiO_2.

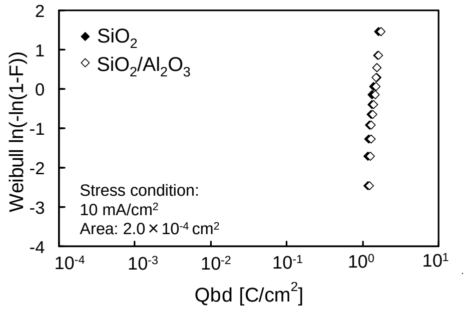

Fig. 6. Charge-to-breakdown Q_{bd} of GaN MOS capacitors with SiO_2 and SiO_2/Al_2O_3. The Q_{bd} of of the stack structure of SiO_2/Al_2O_3 is the same as that of SiO_2.

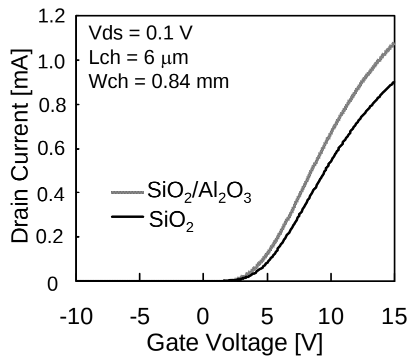

Fig. 7. Transfer characteristics of AlGaN/GaN hybrid MOS-HFETs with SiO_2 and SiO_2/Al_2O_3. The on-state characteristic with stack structure of SiO_2/Al_2O_3 is superior to that with SiO_2.

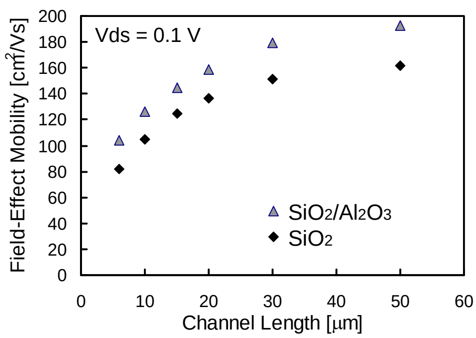

Fig. 8. Field-effect mobility versus channel length of AlGaN/GaN hybrid MOS-HFETs with SiO_2 and SiO_2/Al_2O_3. The field-effect mobility with stack structure of SiO_2/Al_2O_3 is higher in all channel length.