High performance normally-off GaN MOSFETs on Si substrates

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GaN has excellent physical properties for power devices such as a high breakdown field, a high carrier mobility, and a high saturation velocity compared with Si and SiC. For power transistors, normally-off operation is strongly required from the fail-safe point of view. GaN MOSFET is one of the good candidates to achieve good normally-off operation. AlGaN/GaN hybrid MOS-HFETs have the advantages of both MOS channel and an AlGaN/GaN heterostructure with high mobility two dimensional electron gases. Therefore, this type of GaN MOSFETs is promising for high efficiency power device. In this work, high performance normally-off AlGaN/GaN hybrid MOS-HFETs on Si substrates have been demonstrated.

Fig. 1 shows the schematic cross-sectional view of the AlGaN/GaN hybrid MOS-HFET. To achieve a high-breakdown voltage, thick epitaxial layers with a highly resistive layer and a thin unintentional GaN (u-GaN) channel layer are important. The breakdown voltage of AlGaN/GaN hybrid MOS-HFET fabricated on 7.3 μm epilayer with a thin (50 nm) u-GaN channel layer on highly resistive carbon-doped GaN (C-GaN) achieved over 1.71 kV with the gate-drain length (L_{gd}) of 18 μm as shown in Fig. 2. This transistor has 40-nm SiO_2 formed by Capacitive Coupled Plasma (CCP)-CVD as the gate insulator and shows a good normally-off operation with the threshold voltage of 2.0 V and the maximum field-effect mobility of 102 cm^2/Vs. Furthermore, we confirmed that gate field structure is effective for AlGaN/GaN hybrid MOS-HFETs to suppress the current collapse.

To improve the properties of GaN MOSFET, a high quality gate insulator is required. SiO_2 and Al_2O_3 are good candidates as the gate insulators of GaN MOSFETs since these insulators have large direct wide bandgaps, a large conduction band offsets and a valence band offsets on GaN, respectively. We have first investigated the formation process of SiO_2 films by Microwave (2.45 GHz: MW) Plasma Enhanced Chemical Vapor Deposition (PECVD), LP (Low Pressure)-CVD, and CCP-CVD for the gate insulator of GaN MOS devices. MW plasma is capable of exiting a low-electron temperature and a high-plasma density at the substrate surface position. The SiO_2 films were deposited below 400°C by the MW-PECVD and the CCP-CVD and at 800°C by the LP-CVD. As the results, the GaN MOS capacitor with MW-PECVD SiO_2 has shown the lowest interface state density (D_{it}) of SiO_2/GaN with 4.5×10^{11} $cm^{-2}eV^{-1}$, the highest breakdown electric field with over 11 MV/cm, and the largest charge-to-breakdown (Q_{bd}) with over 1 C/cm^2, respectively, of these GaN MOS capacitors. However, the D_{it} is still higher compared with Si devices. So, we applied Al_2O_3 to the gate insulator of GaN MOS devices. The GaN MOS capacitor with Al_2O_3 has a low D_{it} with 2.3×10^{11} $cm^{-2}eV^{-1}$ by suppressing the Ga diffusion to gate insulator. However, it has a low breakdown electric field with below 7 MV/cm. From the both advantages of MW-PECVD SiO_2 and Al_2O_3, SiO_2/Al_2O_3 stacked structure has been employed for good interface property and a high insulating in GaN MOS devices. In this experiment, 3 nm Al_2O_3 formed on GaN and then 50 nm SiO_2 was deposited on Al_2O_3. Fig. 3 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. The GaN MOS capacitor with SiO_2/Al_2O_3 stacked structure shows a low D_{it} as well as Al_2O_3. The MOS capacitor also exhibits a high-breakdown field, and a high Q_{bd} as well as MW-PECVD SiO_2, respectively.

Furthermore, we have fabricated AlGaN/GaN hybrid MOS-HFETs with the SiO_2/Al_2O_3 gate stack and the MW-PECVD SiO_2 gate insulator and compared the properties of these transistors. Both MOS-HFETs show good normally-off operation with the threshold voltage of 4.2 V. The on-state characteristic of MOS-HFET with the SiO_2/Al_2O_3 is superior to that with MW-PECVD SiO_2. The maximum field-effect mobility of MOS-HFET with the SiO_2/Al_2O_3 is 192 cm^2/Vs, which is superior to that with the MW-PECVD SiO_2 of 161 cm^2/Vs.

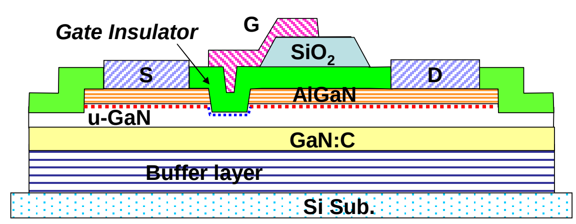

Fig. 1. Schematic cross section of AlGaN/GaN hybrid MOS-HFET.

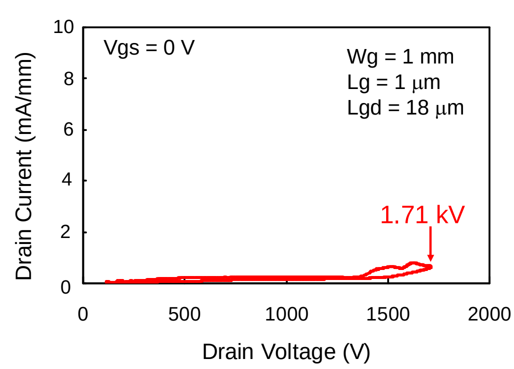

Fig. 2. Breakdown characteristics of AlGaN/GaN hybrid MOS-HFET with the Lgd of 18 μm.

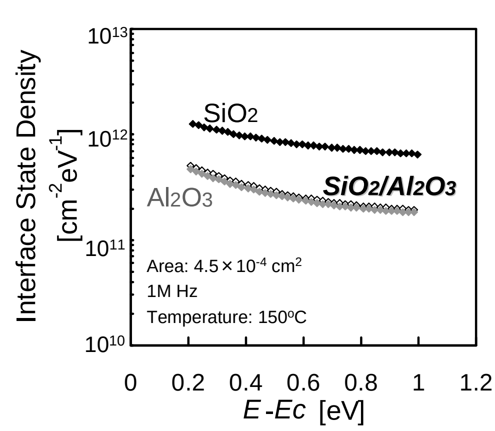

Fig. 3. D_{it} of GaN MOS capacitors with SiO_2, Al_2O_3 and SiO_2/Al_2O_3 calculated from the *C-V* characteristics at 150°C.