Al_2O_3 Deposition and Characterization on III-Nitride Surfaces for Improvement of Dielectric/Semiconductor Interface Properties and Device Reliability

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Primary CNF Tools Used: Oxford FlexAL ALD, Woollam spectroscopic ellipsometer

Abstract:

We investigate the use of atomic layer deposition (ALD) to deposit Al_2O_3 and the effect of a post deposition forming gas anneal on the structural properties of the dielectric. Scanning transmission electron microscopy (STEM) and energy dispersive x-ray spectroscopy (EDS) indicate that after low temperature (350°C) anneal in forming gas, the oxide bulk structure and interface do not undergo significant change.

Summary of Research:

Gallium nitride (GaN) is considered as an excellent candidate for the high voltage device platform because of its superior material properties. It has the potential for lower power losses, higher efficiency, and smaller system volume and weight [1,2]. The next generation of reliable and enhancement mode AlGaN/GaN based high electron mobility transistors (HEMTs) requires further development of high quality passivation and gate dielectric materials. Passivation dielectric is used to reduce current collapse, and gate dielectric is used to reduce gate-leakage current. However, the introduction of a dielectric layer leads to issues associated with the dielectric/(Al)GaN interface trap states, bulk trap states within the dielectric, and surface defect states. Device properties depend on the dielectric used and the density of these interface, bulk, and surface states associated with the dielectric. Decreasing the density of these trap states is essential for good device quality.

Unintentionally doped (UID) GaN was grown on c-plane sapphire using metal-organic chemical vapor deposition (MOCVD). 20 nm of Al_2O_3 was deposited using the Oxford FlexAL ALD system at CNF. Trimethylaluminum (TMA) was used as the aluminum precursor and water as the oxidant; the substrate was maintained at 300°C during the deposition. After the oxide deposition, the thickness of the layer was confirmed using the Woollam spectroscopic ellipsometer at CNF. A piece of the wafer was then cleaved off and subjected to annealing in forming gas (95% N_2/ 5% H_2) ambient at 350°C for 10 minutes.

Lamellae were cut from the as-deposited Al_2O_3-on-GaN and the annealed Al_2O_3-on-GaN samples using focused ion beam (FIB). STEM imaging and EDS mapping were used to evaluate structural evolution in the Al_2O_3, especially at the interface with GaN, as a result of the anneal. Figure 1 shows a high angle annular dark field (HAADF) image of the as-deposited Al_2O_3. As expected, the interface between the Al_2O_3 and GaN is abrupt since the ALD process is surface reaction limited and no additional processes were performed after the deposition. Figure 2 shows a HAADF image of the annealed sample. Additionally, Figures 3a and 3b show the EDS mapping of aluminum and oxygen, respectively in the annealed sample.

From these images, it can be concluded that at moderate temperatures of 350°C or less, the structure of the Al_2O_3/ GaN interface is stable, and minimal interdiffusion between the dielectric and semiconductor are observed.

Additionally, metal-insulator-semiconductor (MIS) capacitors were fabricated. Capacitance-voltage (C-V) characteristics were measured to evaluate the effects of forming gas anneal on the electrical properties of the dielectric/semiconductor interface. Both frequency dispersion and C-V hysteresis were reduced in the sample that underwent the anneal, compared to the as-deposited sample, indicating that the density of interface states was reduced as a result of the forming gas anneal.

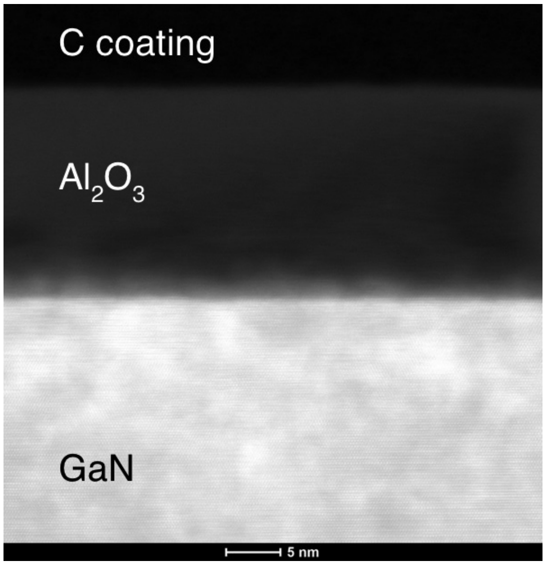

Figure 1: HAADF image of as-deposited Al_2O_3-on-GaN. The apparent thickness of the interface is most likely due to roughness of the surface of the GaN.

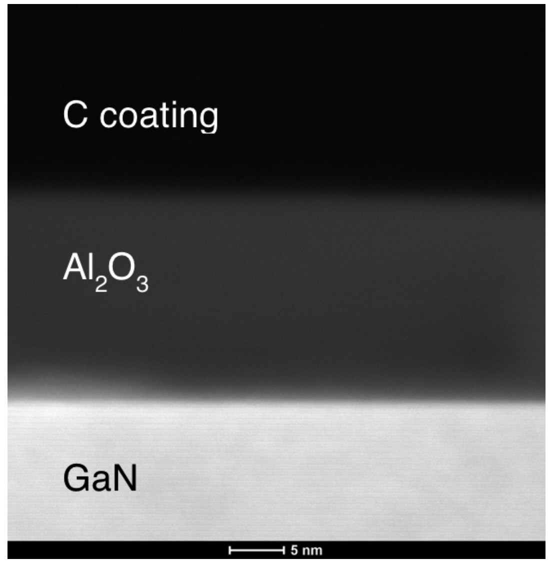

Figure 2: HAADF image of Al_2O_3-on-GaN subjected to annealing in forming gas at 350°C for 10 min.

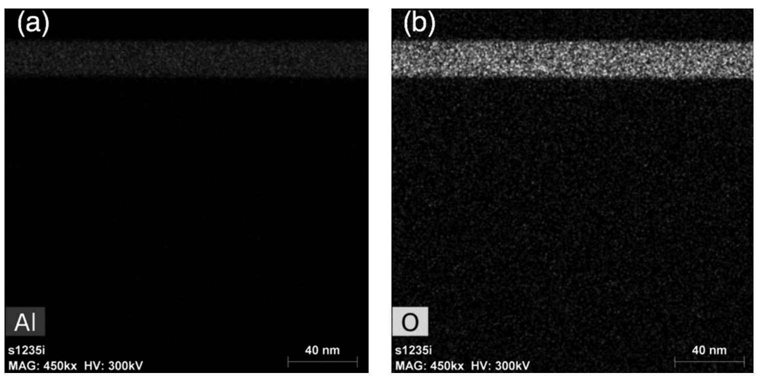

Figure 3: (a) EDS map of Al and (b) EDS map of O from Al_2O_3-on-GaN subjected to annealing in forming gas at 350°C for 10 min. The Al and O are segregated to the oxide layer and no interdiffusion between the Al_2O_3 and GaN is observed. (Find full color on pages xiv-xv.)

References:

[1] K. Shenai, R. S. Scott and B. J. Baliga, "Optimum Semiconductors for High-Power Electronics," Transactions on Electron Devices, vol. 36, no. 9, pp. 1811-1823, 1989.

[2] M. Bhatnagar and B. J. Baliga, "Comparison of 6H-SiC, 3C-SiC, and Si for power devices," Transactions on Electron Devices, vol. 40, no. 3, pp. 645-655, 1993.