In Vacuo XPS Study of Al_2O_3 Atomic Layer Deposition on GaN

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Vertical GaN-based switching transistors are currently receiving increased attention as an alternative to Si and SiC-based devices. GaN-based metal insulator semiconductor field effect transistors are among the most promising vertical power switching transistor architectures.[1] For secure typically OFF operation, a broad gate positive voltage span and a stable threshold voltage, reliable gate insulators are needed. For this reason, an Atomic Layer Deposited (ALD) Al_2O_3 layer with a relatively high permittivity, large band gap, and high breakdown electric field is often used as a gate insulator. Jackson *et al.*[2] demonstrated that different wet surface treatments of GaN prior to Al_2O_3 ALD influence the chemical composition and affect the electrical device performance. In this work, *in vacuo* X-ray Photoelectron Spectroscopy (XPS) is used to study the GaN surface composition after plasma pre-treatment and after the initial ALD cycles for both thermal (using water as precursor) and plasma-enhanced (using O_2-plasma) ALD growth of Al_2O_3 onto GaN, without exposing the sample to air.

First, the effect of a plasma treatment prior to ALD is investigated. Both NH_3- and H_2-plasma pre-treatment can successfully remove spurious C-contamination from the pristine GaN surface while a heat treatment at 400 ºC alone is not sufficient (Fig. 1). In addition, only NH_3-plasma is found to remove a large fraction of the O-species that are present on the pristine GaN surface. After the first ALD-half cycle i.e. after exposure to trimethylaluminium (TMA), the signal of the Al2p and C1s XPS spectra are found to increase which is consistent with the adsorption of TMA to the surface (data not shown here). This observation demonstrates the in vacuo XPS method is sensitive to detect the growth of a signle (sub)monolayer of TMA on the surface. During the second ALD half-cycle, the TMA treated surface is exposed to water (thermal ALD) or O_2-plasma (plasma-enhanced ALD process). In both cases, the data (Fig. 2) is consistent with the growth of Al_2O_3. Water exposure is found to offer insufficient reactivity to remove all of the adsorbed TMA ligands from the surface, while O_2-plasma removes all detectable C. Further it is observed that the O concentration in the near-surface region increases dramatically after O_2-plasma exposure, coinciding with the formation of O-Al, O-Ga and NO-Ga species on the surface.

Electrical data show that the density of trap states is lower for the NH_3-plasma treated samples, which seems to correlate to the enhanced removal of Ga_xO_y of the pristine GaN surface.[3] In addition, more trap states were observed for samples deposited using the thermal ALD process, likely related to the presence of C-impurities, caused by the incomplete removal of the TMA ligands by water as detected by XPS. For the plasma-enhanced ALD process more hysteresis is observed between the forward and reverse bias stress sweep CV cycles, indicating a high content of stress indued interface traps. This might be explained by the presence of O-defects created during the O_2-plasma pulse. The best electrical data were achieved when combining a NH_3-plasma pre-treatment, followed by initial Al_2O_3 growth using thermal ALD, and then switching to plasma-enhanced ALD to thicken the Al_2O_3 layer.

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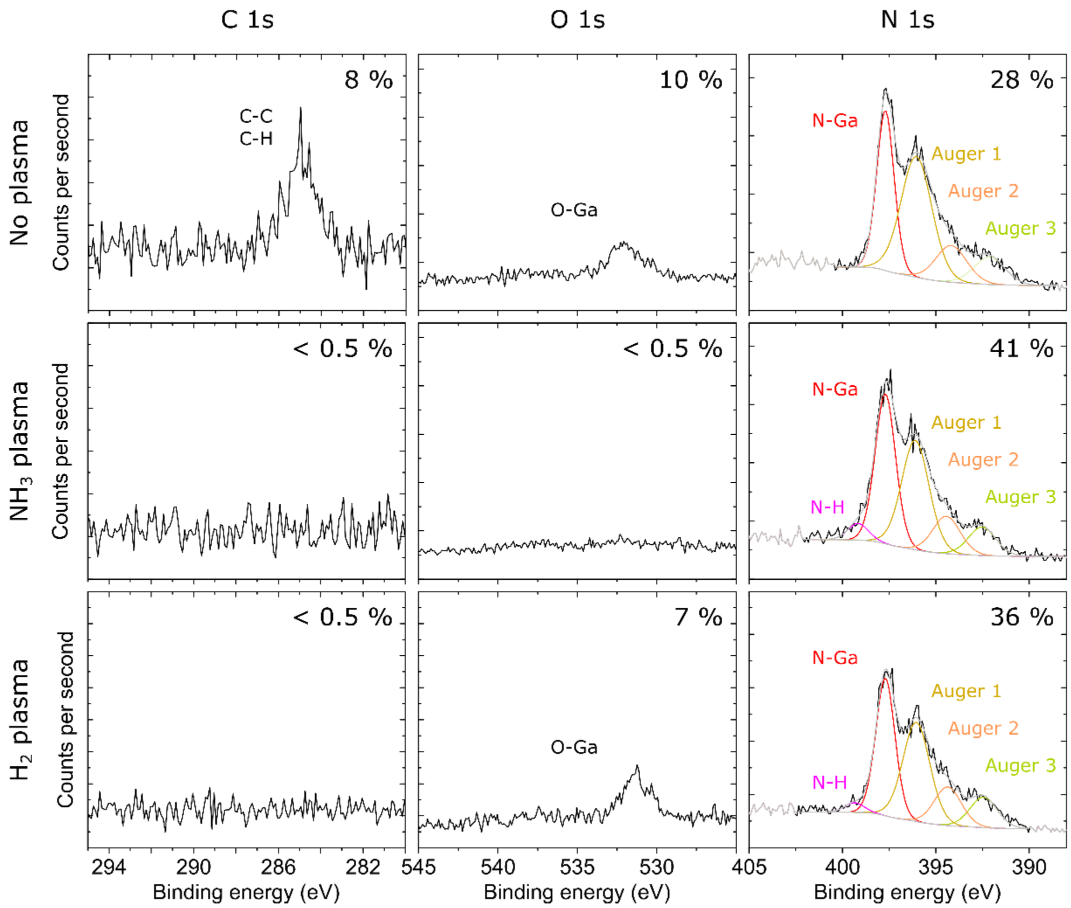

Figure 1 In vacuo XPS spectra acquired after heat pre-treatment and no plasma (top), NH_3-plasma (middle) and H_2-plasma (bottom) of a n-GaN surface.

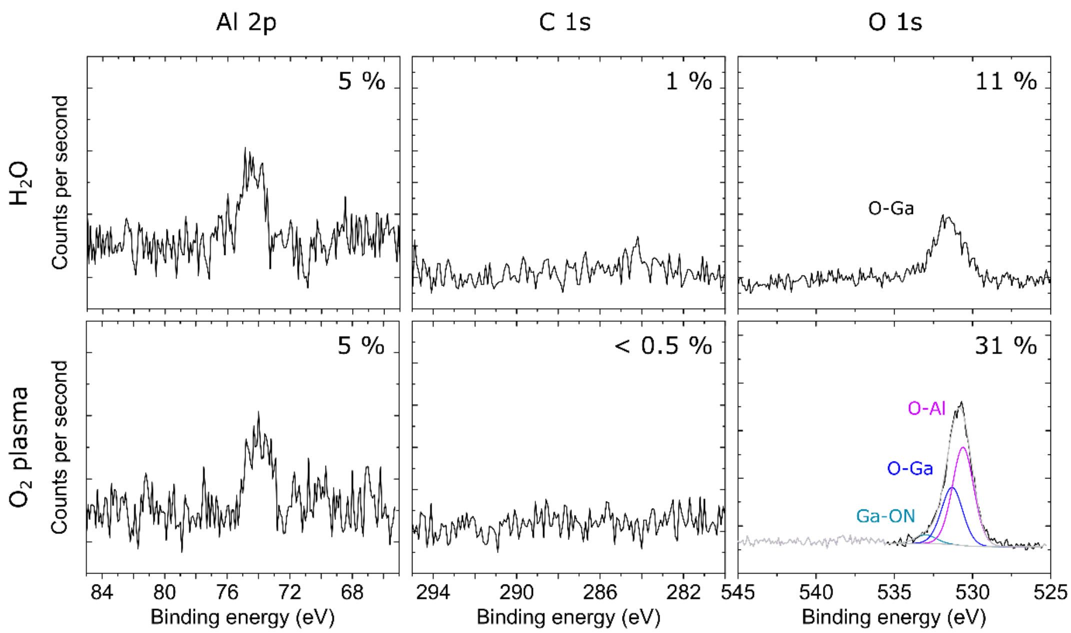

Figure 2 In vacuo XPS spectra acquired after water exposure (top) and O_2-plasma (bottom) during respectively the thermal and plasma-enhanced Al_2O_3 ALD process on a H_2-plasma pre-treated GaN surface.