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3D Characterization Study of High-k Dielectric on GaN Using Atom Probe Tomography

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Atom probe tomography (APT) has been rapidly expanding its applications in different types of materials due to the advances in pulsed-laser APT [1]. In the semiconducting industry, it is being used regularly for 3D compositional imaging, analysis of interdiffusion at interfaces, local fluctuations in atomic compositions etc. A recent challenge in the power electronics is the control of high-k/GaN interfaces from unwanted oxidation of the GaN layer during either deposition or processing which promotes the formation of electrically active defects in low densities [2]. Additionally, any knowledge about impurities in thin dielectric layers is valuable for understanding trapping behavior. APT can provide the desired information. However analyzing oxides/dielectrics are still difficult, even with laser-assisted APT. At high evaporation rates, micro fractures and irregular evaporation can make an analysis difficult or impossible. Additionally, optimizing different experimental parameters such as temperatures, laser energy, and detection rate etc. are crucial and contribute majorly the analysis. In this study we have shown that a high measurement yield is still possible for the high-k dielectric, Al_2O_3/GaN analysis by using suitable experimental parameters and a capping layer.

The Al_2O_3 layers were grown on GaN both by metal organic chemical vapor deposition (MOCVD) and atomic layer deposition (ALD) system for a comparison study. Initially this structure was very challenging to analyze in atom probe due to the following reasons, (a) The optimum field evaporation condition for GaN is at low temperature with low laser energy and high detection rate [3] which is an unfavorable condition for dielectric. By optimizing the experimental condition, the Al_2O_3 layer was possible to be analyzed but the yield of the measurement was quite low, and (b) a conventional metal cap layer was grown on top of dielectric layer that was grown on GaN. High measurement yield was not possible to achieve using metallic (Ni, Cr) cap layer owing to the very different evaporation fields of the metal/insulator/semiconductor stack resulting in frequent sample rupture. Finally a low temperature (LT) GaN deposited on Al_2O_3/GaN increased the measurement yield more than 90% and was subsequently used for all the samples. Figure 1a and c represent the 3D elemental map of the whole structure grown by ALD and MOCVD respectively. Compositional measurement was done using a cylindrical volume perpendicular to the Al_2O_3 layer and shown in Fig 1b and d. They also show the nature of interfacial abruptness between Al_2O_3 and GaN. Al_2O_3/GaN interface was not found very abrupt in either case however ALD grown Al_2O_3/GaN reveals more diffuse interface and relatively rough compared to LT GaN/Al_2O_3. As it is well known that the interfacial diffuseness can be an artifact of the technique, backside orientation analysis [4] was performed to verify the nature of this interface. It was also found that the interface shows no presence of Ga_xO_y in both cases. The additional information this technique could deliver was the impurity i.e, carbon quantification within the dielectric. The presence of C in the dielectric could play an important role in device performance. A rigorous estimation of carbon impurity within dielectric was done for both the oxides which was found to be in the order of $10^{19}/cm^3$, Fig 2. In conclusion atom probe was successfully used for dielectric/III-V system for the first time. With proper experimental step the data can be presented with more confidence.

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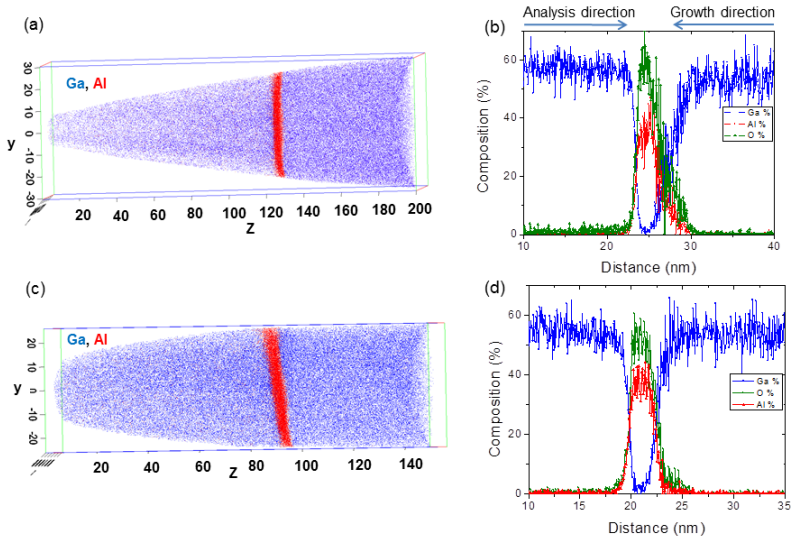

Figure 1. (a) and (c) 3D elemental maps showing the distribution of Al(Red) and Ga (Blue) in an ALD and MOCVD grown Al_2O_3/GaN system. (b) and (d) show the 1D chemical profile respectively.

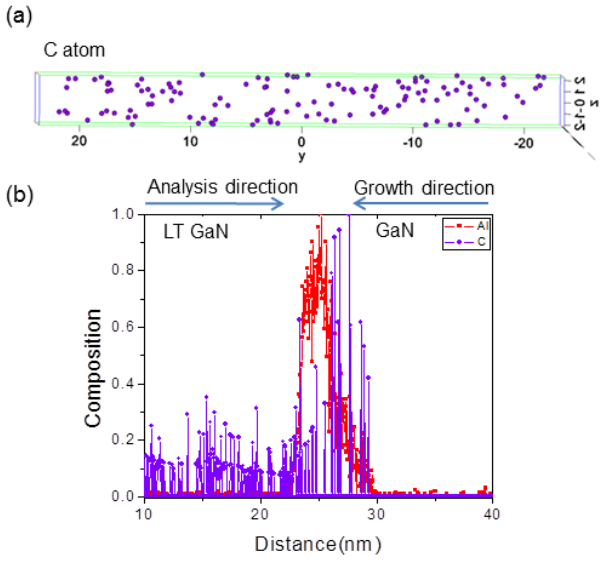

Figure 2. (a) Carbon mapping within Al_2O_3 layer. (b) Chemical profile of Al and C plotted together to show its presence within dielectric but not in GaN layer.

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