Atomic Layer Deposition of Ternary Dielectrics for Gate Insulation and Passivation of GaN-based Metal-Insulator-Semiconductor Heterojunction Field Effect Transistors

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Conventional Schottky-gate AlGaN/GaN Heterostructure Field Effect Transistors (HFETs) can be problematic because of its high gate leakage currents and high frequency drain current collapse[1,2]. One approach to solve some of these problems is to insert a high-κ dielectric between the gate metal and semiconductor to form a Metal-Insulator-Semiconductor Heterojunction (MISH) device. However, there are limitations of commonly used dielectrics such as HfO_2 and Al_2O_3 with respect of breakdown strength, crystallization temperature, and dielectric constants, all of which are preferred to be high. Typically, choosing between various materials involves compromising between said limitations. One example being TiO_2, which has a large dielectric constant but poor crystallization temperature and conduction band offset to GaN, while Al_2O_3 has the opposite characteristics. Creating a ternary compound such as Ti-Hf-O or Ti-Al-O may result in a reasonably good insulator in terms of said properties. To date, there is limited knowledge of ternary dielectric performance on AlGaN/GaN and even less on InAlN/GaN.

To approach this problem, we fabricated MISH capacitors with ternary dielectrics, Ti-Al-O and Ti-Hf-O, deposited by Atomic Layer Deposition (ALD). The film growth was achieved by alternating cycles of Ti-O and either Al-O or Hf-O using different ratios of ALD cycles. Circular capacitors, shown in Figure 1, on both InAlN/GaN and AlGaN/GaN samples were fabricated by a multi-layered process patterned by electron-beam lithography. The process involved device isolation by Reactive Ion Etching, followed by Ohmic contact realization using multi-layered metal stacks, and finally, gate contact post-dielectric deposition.

Figure 2 depicts the measured gate leakage current density from the MISH capacitors. Ti-Hf-O exhibited the lowest leakage current density of the two materials; while the InAlN/GaN devices show higher leakage than the AlGaN/GaN counterparts (due to the thinner barrier layer thickness). Figure 3 shows the measured 10 MHz-signal capacitance-voltage sweeps. The Ti-Hf-O dielectrics show a sharper transition from inversion to accumulation, which may indicate a better interface, although further studies are required to support and confirm these results.

1 A. Colón and J. Shi, Solid-State Electronics **99** (0), 25 (2014).
2 C. Liu, E. F. Chor, and L. S. Tan, Applied Physics Letters **88** (17), 173504 (2006).

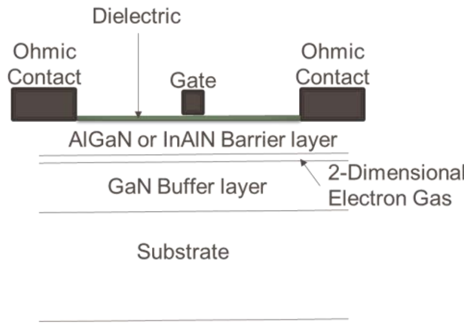

Figure 1: Cross-sectional view of the MISH Capacitor. The barrier layer is either AlGaN or InAlN. The Ohmic contact is an outer ring which forms one electrode and the gate is an inner metal contact forming the other electrode in the MISH capacitor structure. The dielectrics studied are Ti-Hf-O and Ti-Al-O.

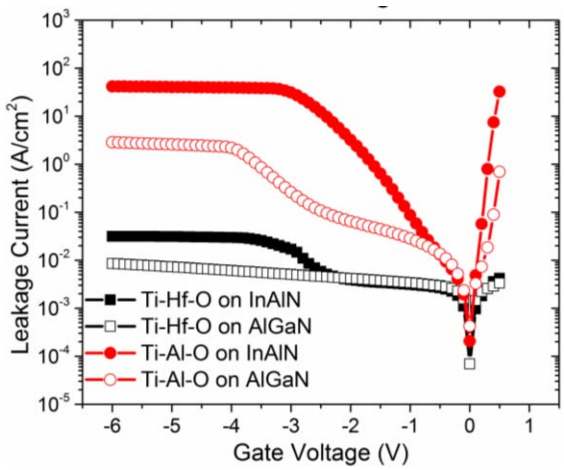

Figure 2: Gate leakage current densities of the two dielectrics on both AlGaN/GaN and InAlN/GaN substrates.

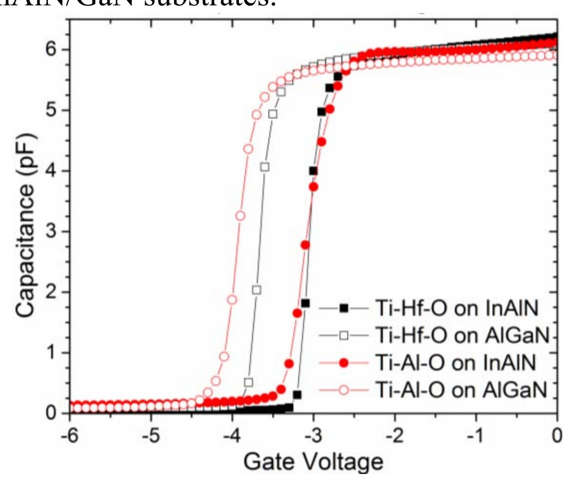

Figure 3: Capacitance-Voltage sweeps from inversion to accumulation using a 10 MHz signal.

Use of the Center for Nanoscale Materials, an Office of Science user facilities, was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.