High Mobility ($210\ cm^2/Vs$), High Capacitance ($7.2\ \mu F/cm^2$) ZrO_2 on GaN Metal Oxide Semiconductor Capacitor via ALD

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Abstract
ZrO_2 has been deposited on GaN by atomic layer deposition. Chromium was sputtered and patterned on the ZrO_2 to create Metal Oxide Semiconductor Capactors (MOSCAPs). Capacitance voltage measurements yielded capacitance density of 7.2μF/cm^2, and a mobility of 210 cm^2/Vs. This is a fundamental step in the creation of a viable enhancement mode MOSFET.

Introduction
Gallium Nitride (GaN) is an III-V semiconductor material currently investigated for high frequency, high power electronics. GaN gives electrical engineers a wide variety of promising material properties including a high saturation velocity (v_s = 3x10^{17} cm/s), high critical electric field (Ec = 4.2 MV/cm) [1], and a large band gap (3.4 eV).

Creating high quality dielectric-semiconductor interfaces is a critical step to achieve higher performance for GaN MOSFETs. Many different dielectrics have been investigated for their effects on interface quality. MOSCAPs can be used to investigate the effects of different dielectrics on electrical characteristics.

A number of different high-κ dielectrics have been recently investigated including HfO_2 [3], Sc_2O_3[4], Gd_2O_3[5], and La_2O_3 [6]. Many problems exist when using high-κ dielectrics. One such problem is the high parasitic conductance between the dielectric and gate, which can be reduced by using high-κ dielectrics with a high permittivity and a large band gap [6]. Recent investigation of MOCVD HfO_2 and ZrO_2 on GaN has shown low leakage current, and good capacitance characteristics [7].

When evaluating the different problems with high-κ dielectrics, ZrO_2 stands out as a promising gate dielectric. With use of improved deposition techniques, it becomes possible to deposit very low defect density oxides with good interface characteristics via Atomic Layer Deposition (ALD). In the following, we present ZrO_2 deposited via ALD on GaN.

MOSCAP structure and Fabrication
The GaN/Sapphire templates were acquired from Kyma Technologies. The templates consisted of 5 μm thick GaN grown on a 2 inch sapphire substrate.
Two different samples were prepared with the ZrO2 gate dielectric deposited onto the GaN layer via plasma assisted ALD for 40 and 68 cycles at 100 ^oC and 1 Torr. The thickness was measured insitu and post deposition using an ellipsometer on a Silicon wafer for calibration and predicted to be 6.9 nm and 10 nm respectively. Approximately 100 nm of Cr was deposited by sputtering. It was then annealed at 400 ^oC for 15 minutes. The contacts were patterned by contact lithography using HPR 504 positive photoresist. Figure 1 illustrates the top view and cross sectional layout of the MOSCAP.

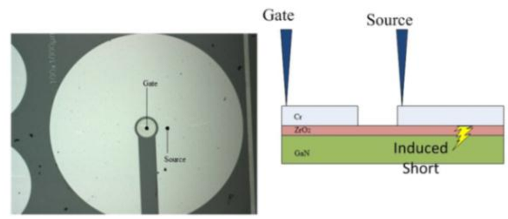

Figure 1: The top view of a typical 100 x 1000 um MOSCAP, and an illustrated cross section.

Results and Discussion
The electrical characteristics were measured using the Keithley 4200-SCS. As is well known when testing hetero-epitaxial wide band-gap semiconductors, the use of backside contacts is prohibitive but what was unknown at the time of experimental design was the quality of the gate oxide would allow leakage less than 1 A/cm^2 for the thinner structure. Because buffered layers stored a significant charge, an electrical short was induced between the source and the substrate with a significant voltage (5 V).

The capacitance density in the thinner sample was 7.2μF/cm^2 (20 KHz) as seen in Figure 2. Spreading effects lowered the effective capacitance as the frequency increased. Analysis of this effect displayed a distributed model [8].

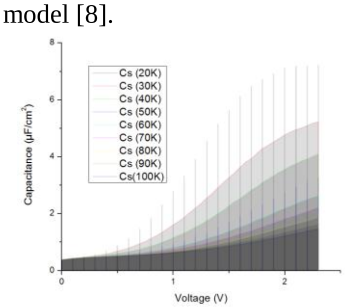

Figure 2: Spreading effects lower the effective capacitance as the measurement frequency increased.

Figure 3 shows a voltage sweep of the thinner sample at 20 KHz. Further investigation of the CV characteristics revealed a hysteresis of less then 6 mV, indicating low density of interface traps, D_{it}. .

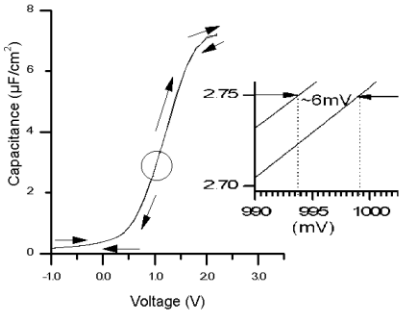

Figure 3: A CV sweep of the thinner at 20 KHz revealed the MOSCAP displayed little hysteresis.

Through analysis of the C-V characteristics, a mobility model was created for the GaN MOSCAP [9]. This revealed that the peak electron mobility was $210\ cm^2/Vs$.

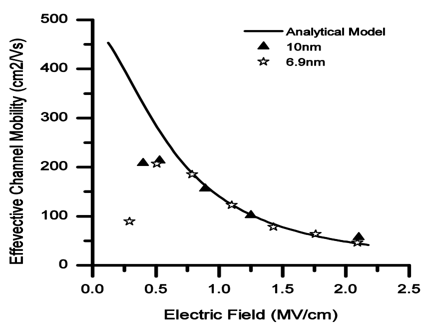

Figure 4: The effective electron mobility through the GaN is consistent for both the 6.9nm and 10 nm oxides.

IV measurements are shown in Figure 5 for the thicker and thinner sample. Temperature measurements performed on the thinner sample revealed minimal temperature dependence, as seen in Figure 6.

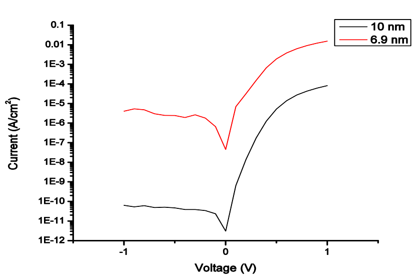

Figure 5: The gate oxides display near ideal tunneling current that scales appropriately with oxide thickness.

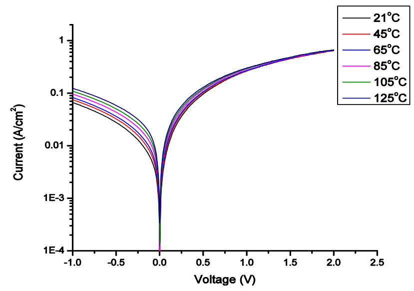

Figure 6: Variations in temperature had little effect on the thinner gate oxide consistent with direct tunneling.

Conclusion

A low D_{it} ZrO_2 oxide was deposited onto GaN/Sapphire templates using ALD. The electrical characteristics measured displayed high capacitance densities (7.2 μF/cm^2) and mobility (210 cm^2/Vs). IV measurements conducted on the samples revealed low gate oxide leakage, with minimal temperature dependence. The measurements indicate a ZrO_2 oxide with extremely low D_{it} and a good ZrO_2/GaN interface.

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