Atomic Layer Deposition Dielectric Film Quality

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Summer Program(s): 2026 Cornell NanoScale Facility Summer Internship

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Primary Source(s) of Research Funding: NORDTECH

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Summer Program Website(s): https://www.cnf.cornell.edu/education/reu

Primary CNF Tools Used: Oxford FlexAL, Oxford ASP, Woolam RC-2 Ellipsometer, Kiethy Probe Station

Abstract:

As semiconductor devices continue to scale, dielectric films must become thinner while maintaining reliable electrical isolation. Atomic Layer Deposition (ALD) can be used to create thin oxide layers. These oxide layers are used to passivate electrical signals from one electrode to another with a very thin layer of oxide material. The Oxford FlexAl and Oxford ASP tools allow for thin oxide Atomic Layer Deposition (ALD) films. Deposition parameters including temperature, oxide chemistry, and ALD tool can influence film growth, density, and electrical properties. The Oxford ASP is a new ALD tool in the Cornell Nanoscale Facility (CNF) Cleanroom. The purpose of this experiment is to explore baselining the ASP. Due to tool availability and the duration of the study, the results presented represent an initial baseline rather than a complete process optimization. SiO_2 and Al_2O_3 films were deposited under varying process conditions and characterized using deposition rate, wet etch rate, and electrical measurements. Deposition rate was used to evaluate film growth behavior, while wet etch rate provided a relative indication of film density. Metal-oxide-semiconductor capacitors (MOSCAPs) were fabricated to evaluate electrical behavior using capacitance-voltage (C–V) and current-voltage (I–V) measurements. Together, these measurements establish preliminary relationships between ALD process conditions and resulting dielectric film properties and provide a foundation for continued optimization of the Oxford ASP.

Summary of Research:

This research investigated the quality of dielectric films deposited by atomic layer deposition (ALD), with emphasis on establishing baseline processes for the Oxford ASP and comparing its performance with the established Oxford FlexAL system. The study focused primarily on silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3) films. Process variables included deposition temperature, oxide chemistry, deposition method, and ALD tool. Film quality was evaluated through deposition behavior, wet chemical etch behavior, and electrical characterization of fabricated metal-oxide-semiconductor capacitors (MOSCAPs).

ALD Film Deposition and Characterization

Overall, the deposition-rate measurements demonstrate measurable differences between the two ALD systems as well as temperature-dependent growth behavior.

Wet Etch Characterization

Wet chemical etching was used as an indirect method of comparing film density and chemical resistance. This data is drawn from the Oxford FlexAl.

For FlexAL Al_2O_3, the measured etch rate decreased with increasing deposition temperature as expected.

The FlexAL SiO_2 results displayed a different trend. The measured etch rate reached a maximum at the intermediate 200 °C deposition condition. Because this trend differed from the expected decrease in etch rate with increasing deposition temperature, additional measurements are required to determine its reproducibility.

MOSCAP Fabrication

MOSCAP devices were fabricated to characterize the electrical properties of the deposited dielectric films. The fabrication sequence consisted of wafer cleaning, ALD dielectric deposition, dielectric thickness measurement, patterned top-metal deposition, backside cleaning, backside-metal deposition, and electrical characterization. SiO_2 and Al2O3 dielectric layers were deposited using either the Oxford FlexAL. SiO2 films were deposited for device fabrication from the ASP while Al2O3 films were not available for deposition on the ASP. Top-metal electrodes were deposited through a shadow mask using the AJA Sputter, producing an array of circular MOSCAP structures with different electrode areas. Completed devices were electrically characterized using the Keithley Probe Station.

Electrical Characterization

Capacitance vs. voltage (C–V) measurements were performed to characterize the electrical response of the fabricated MOSCAP structures during a voltage sweep. The measured curves demonstrate transitions between accumulation, depletion, and inversion behavior. Both p-type and n-type silicon substrates were used during device fabrication, causing the direction and voltage of the C–V transition depending on substrate type. FlexAl film devices were constructed on p-type wafers while ASP devices were constructed on n-type wafers. This difference should be considered when comparing samples.

For the FlexAL Al_2O_3 samples, the 200 °C wafer exhibited a C-V transition voltage of approximately +0.88 V with a median hysteresis of 2.29 V, while the 300 °C wafer exhibited a median transition voltage of approximately +0.58 V and a lower median hysteresis of 1.01 V. This reduction in hysteresis suggests improved electrical stability at the higher deposition temperature.

The FlexAL SiO_2 sample deposited at 300 °C exhibited a transition voltage of approximately −3.05 V and a median hysteresis of 0.18 V. For ASP SiO_2, the 200 °C sample exhibited a transition voltage of approximately -4.79 V and median hysteresis of 1.07 V, while the 300 °C sample exhibited a transition voltage of approximately -4.05 V and median hysteresis of 0.62 V. The lower hysteresis measured at 300 °C suggests a possible improvement in electrical stability with increasing ASP deposition temperature.

Current vs. voltage (I-V) measurements were used to evaluate dielectric leakage.

The ASP results show a decrease in median leakage at the higher deposition temperature, although additional measurements are necessary for conclusivity.

Significant variation was observed in several I-V measurements when measuring the same size electrode, with leakage spanning multiple orders of magnitude. This variability may result from local dielectric defects, wafer nonuniformity, probe contact, electrode-area uncertainty, contamination, or fabrication effects such as shadow-mask bowing and unintended metal deposition beneath the mask. Based on acquired data, samples should be sorted to determine accuracy of each measurement. The electrical measurements should be considered preliminary indicators of process performance rather than definitive material properties. Additional device measurements and improved fabrication repeatability are recommended before establishing electrical baselines for the ASP.

Figure 1.

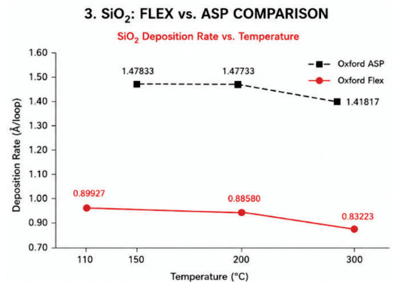
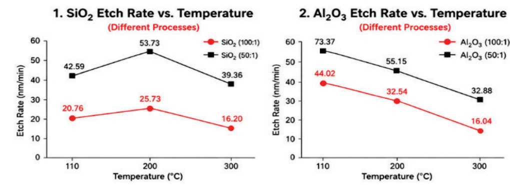


Figure 2.



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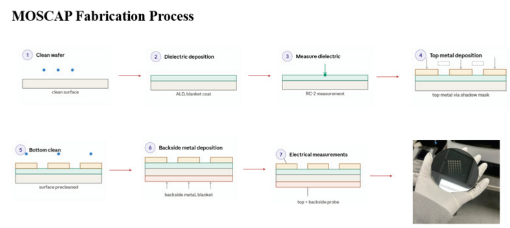
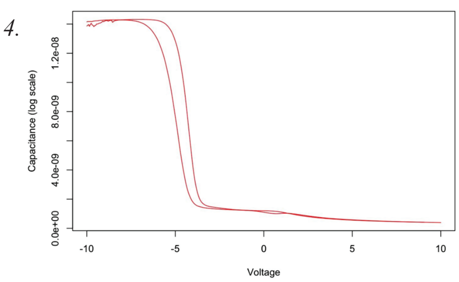


Figure 4.



Conclusions and Future Steps:

This study established repeatable experimental procedures for ALD deposition characterization, wet etch testing, MOSCAP fabrication, and electrical measurement. The deposition results demonstrate that film growth rate depends on both deposition temperature and ALD system. Wet etch measurements further indicate that deposition conditions affect the chemical resistance of the resulting films, although the unexpected intermediate temperature behavior observed for FlexAL SiO_2 requires additional investigation. MOSCAP fabrication successfully enabled C-V and I-V characterization of selected dielectric films. These measurements provide an electrical complement to the deposition and etch-rate studies by evaluating the behavior of the dielectric within a functional device structure. MOSCAP construction and electrical measurements should be expanded to test a wider variety of oxide films. Upon further research, results will provide a complete comparison between the Oxford ASP and Oxford FlexAL and contribute to establishing baseline dielectric processes for the ASP system.