Spatially Distributed Experimentation to Understand ALD Process Chemistry

Rubloff Research Group Accomplishments
Accomplishment

Designed and implemented ALD reactor to achieve spatial distribution of impingement fluxes.
Demonstrated spatial gradients in thickness and material properties.

Significance

Atomic layer deposition (ALD) is widely sought for its atomic-scale thickness control and unprecedented uniformity and conformality.
Precursor dose permutations add complexity to ALD process recipes, where underlying surface chemistry is not well understood.
Spatially distributed ALD enables rapid investigation of ALD process/dose recipes and optimization of material properties.

Researchers involved
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Spatially Distributed Atomic Layer Deposition (ALD)

**Intellectual merit**

Atomic layer deposition (ALD) enables atomic-level control of ultrathin film deposition over 3-D surfaces. It relies on alternating doses of molecules that saturate surface sites to achieve these benefits. ALD surface chemistry is not well-understood, so finding suitable dose recipes is hampered by the numerous permutations available.

We have designed and implemented an ALD reactor design that uses cross-flow of precursor gases to achieve combinatorial variation of surface reaction conditions across a 4” wafer.

We have demonstrated the fabrication of spatial gradients in thickness and material properties for an Al₂O₃ ALD process.

Coupled with rapid characterization of across-wafer material and electrical properties, the cross-flow ALD reactor provides a platform for addressing the relation of ALD process chemical conditions to resulting material properties.
Atomic layer deposition (ALD) is widely sought for its atomic-scale thickness control and unprecedented uniformity and conformality, key benefits for existing technologies (e.g., semiconductors) and for a broad set of nanotechnology applications.

The numerous precursor dose permutations inhibits fundamental understanding of ALD surface chemistry and process applications.

Our cross-flow ALD design and associated material characterization provide a platform for rapid learning in ALD process behavior and enhanced development of ALD applications.

Close collaboration with Italy group (FBK-irst) has been essential in chemical, compositional, and structural characterization of ALD layers.
Atomic Layer Deposition (ALD)

- Alternating doses of chemical precursors, repeated approximately once per atomic layer
- Self-limiting adsorption/reaction for each dose
Cross-Flow ALD Reactor

- Z-axis pneumatic actuator
- UHV chamber
- Moveable cap
- 100 mm wafer
- Substrate heater

MKS RGA

Gas Outlet
Gas Inlet

50µm orifice

10⁻⁵ torr
0.1 torr
Across-Wafer $\text{Al}_2\text{O}_3$ ALD Film Properties

Under-dose $\text{H}_2\text{O}$ conditions (0.8µmol)

![Graph showing the variation of thickness, capacitance, permittivity, and refractive index across the wafer.](Image)
**Al₂O₃ ALD: TMA under-dosing**

Moderate under-dosing
TMA causes uniformity degradation & depletion

Larger under-dosing
TMA condition generates very strong nonuniformity, nearly discontinuous profile

Enhance growth rate at inlet with dramatic depletion at outlet

→ Possibly OH oversaturation at inlet which getters and reacts the under-dosed TMA

![Graph showing thickness vs. position across wafer for different TMA doses](image)

- Saturating H₂O dose (1.25 μmol)
- TMA dose [μmol]:
  - 3.6
  - 0.43
  - 0.33
  - 0.30
  - 0.28
  - 0.26
Al₂O₃ ALD: H₂O under-dosing

H₂O/TMA < 2

- Improved uniformity but mean thickness decreases due to insufficient reactant supply

H₂O/TMA > 2

- Profound nonuniformity at front and rear, with limited uniformity at middle

9/6/2007, graph 2