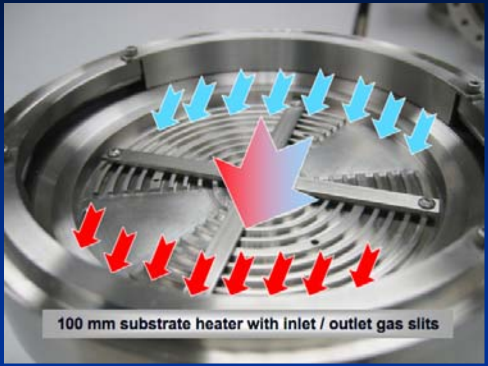
Spatially Distributed Experimentation to Understand ALD Process Chemistry

Rubloff Research Group Accomplishments

Spatially Distributed Atomic Layer Deposition (ALD)

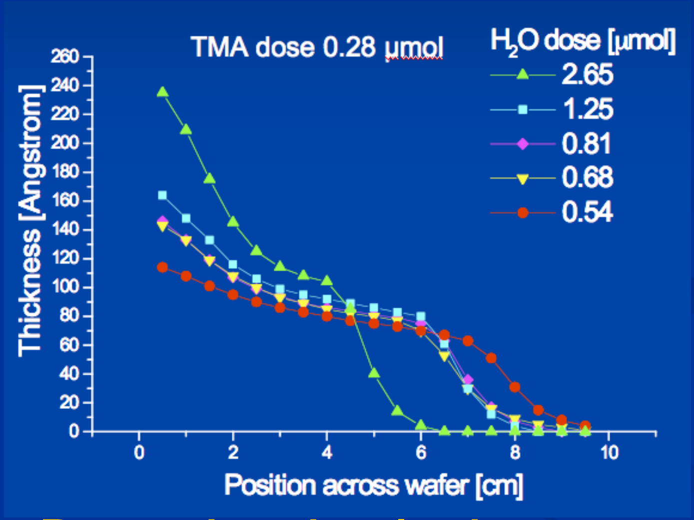


Accomplishment

- 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

Laurent Henn-Lecordier, Gary W. Rubloff

Support

NSF IMI, PAT-IRST MicroCombi, Laboratory for Physical Sciences, MKS Instruments

Spatially Distributed Atomic Layer Deposition (ALD)

Intellectual merit

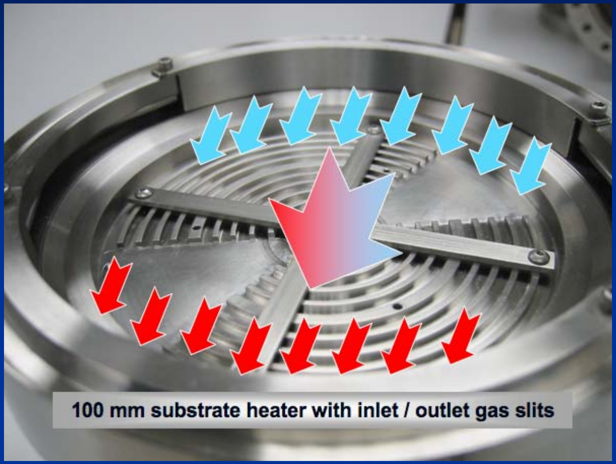
Atomic layer deposition (ALD) enables atomic-level control of ultrathin film deposition over 3-D surfaces. It relies on alternating doses of molecules that saturate surface sites to achieve these benefits.

ALD surface chemistry is not well-understood, so finding suitable dose recipes is hampered by the numerous permutations available.

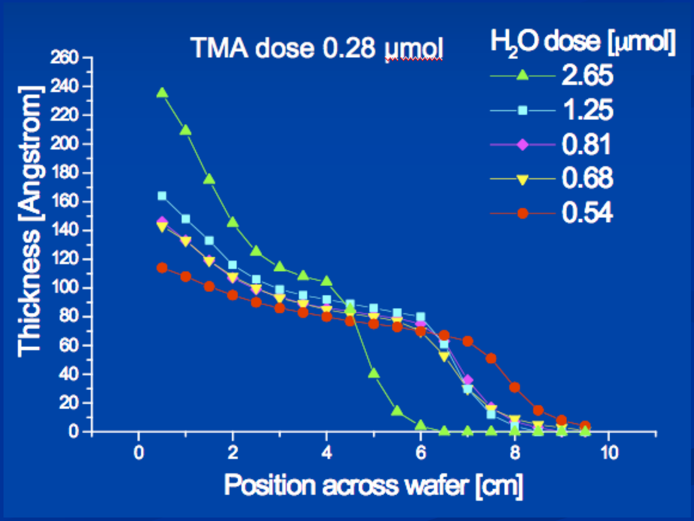
We have designed and implemented an ALD reactor design that uses cross-flow of precursor gases to achieve combinatorial variation of surface reaction conditions across a 4” wafer.

We have demonstrated the fabrication of spatial gradients in thickness and material properties for an Al_2O_3 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.



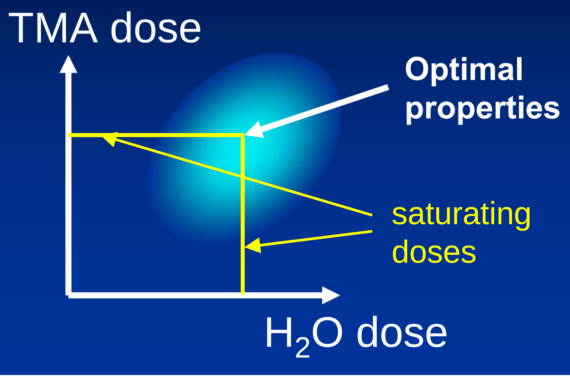
100 mm substrate heater with inlet / outlet gas slits

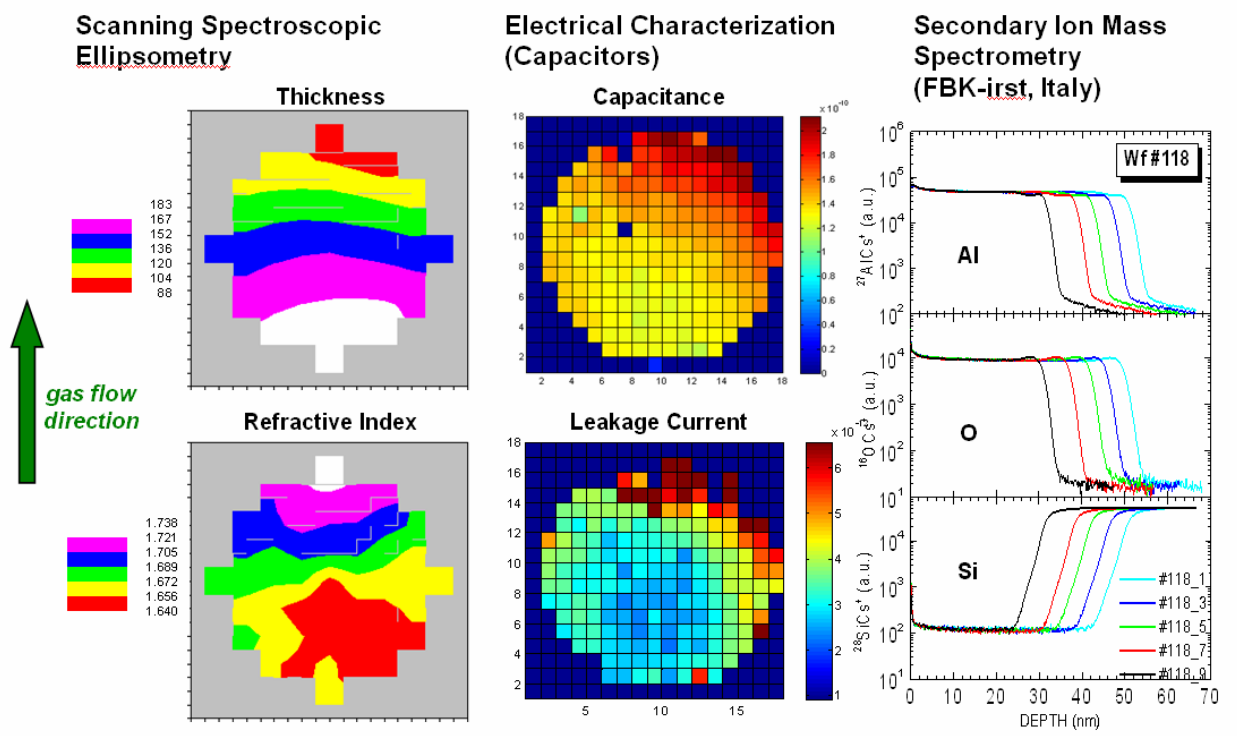


Spatially Distributed Atomic Layer Deposition (ALD)

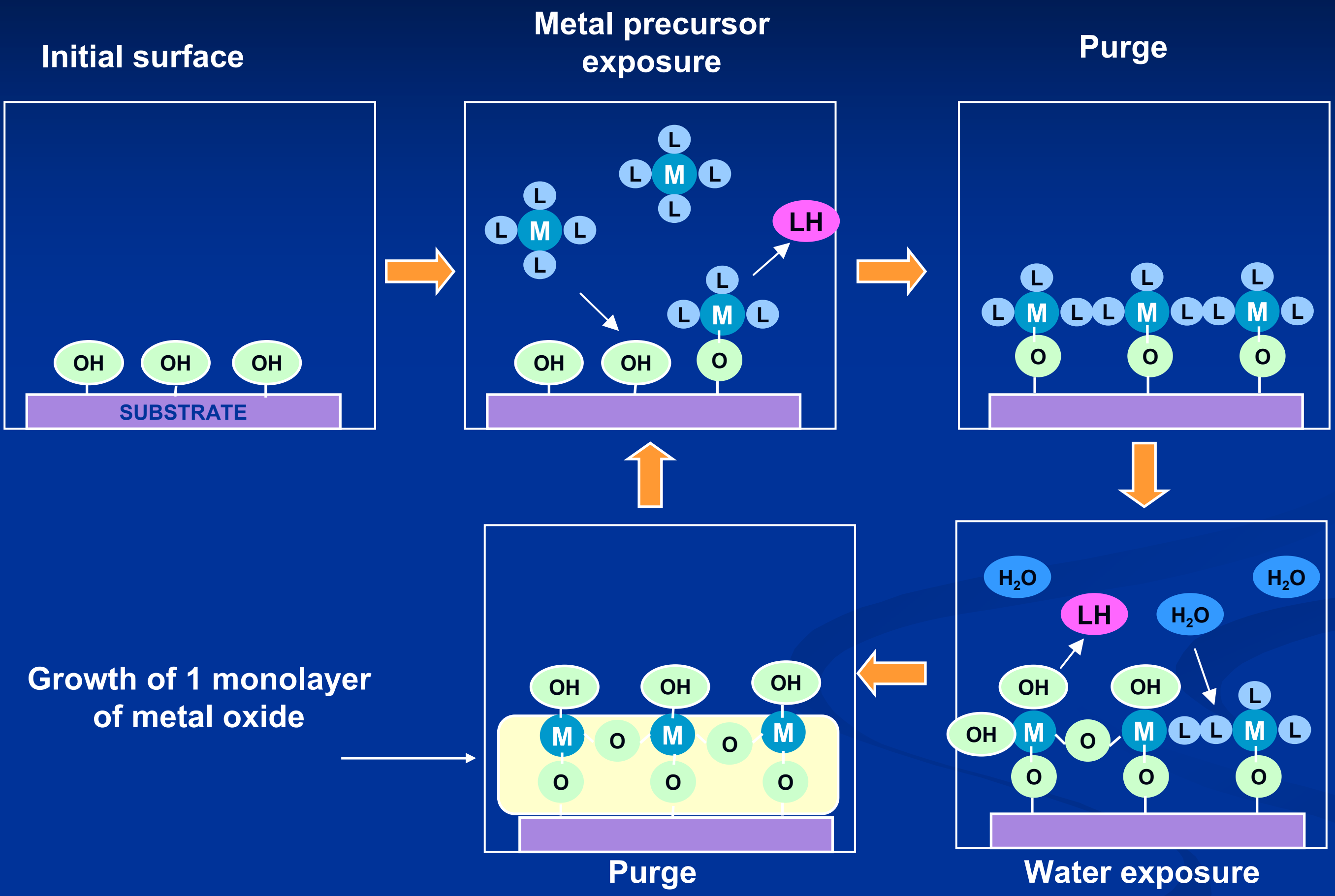
Broader Impacts

- 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.



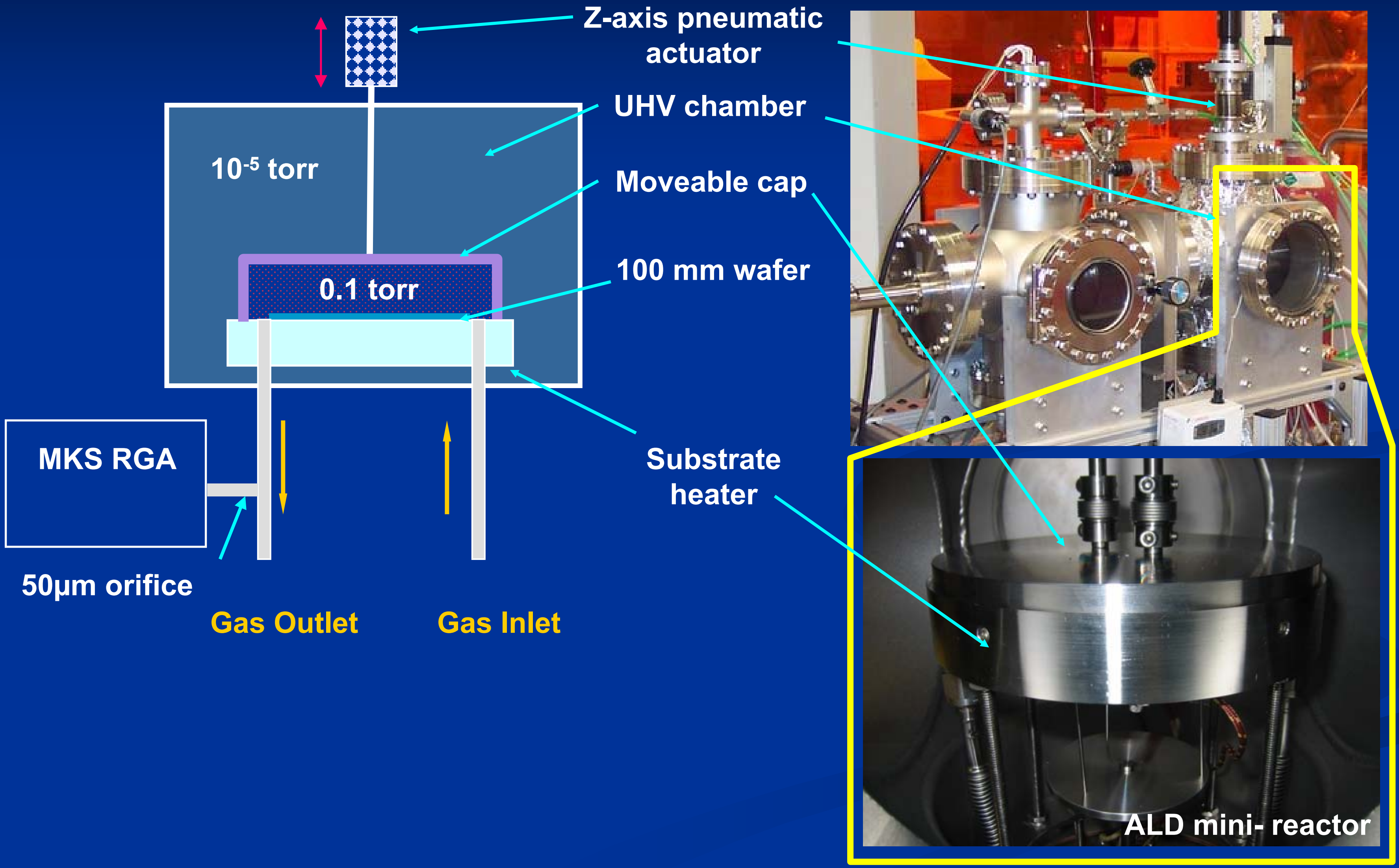


Atomic Layer Deposition (ALD)



- **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

10^{-5} torr

0.1 torr

MKS RGA

50µm orifice

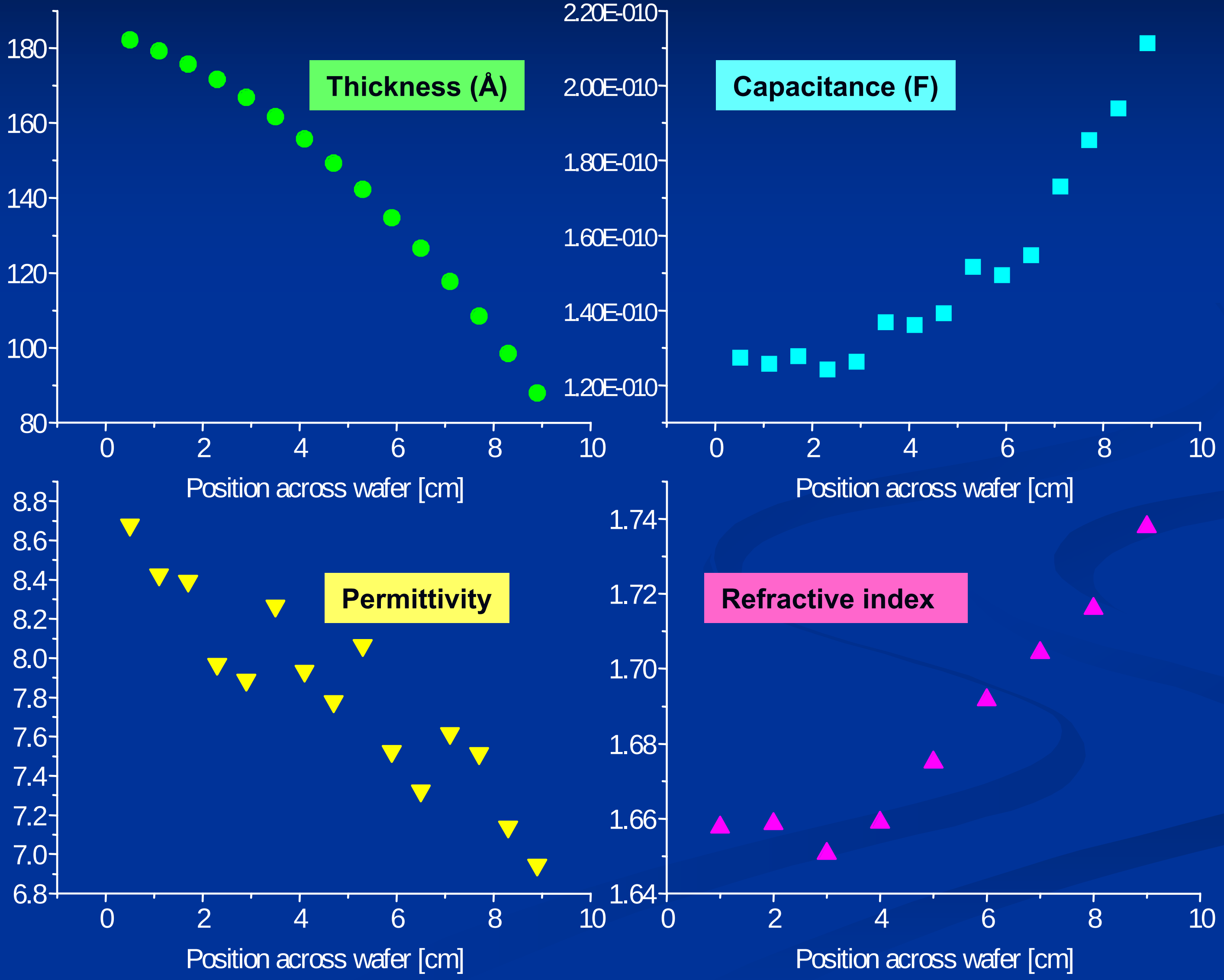
Gas Outlet

Gas Inlet

ALD mini- reactor

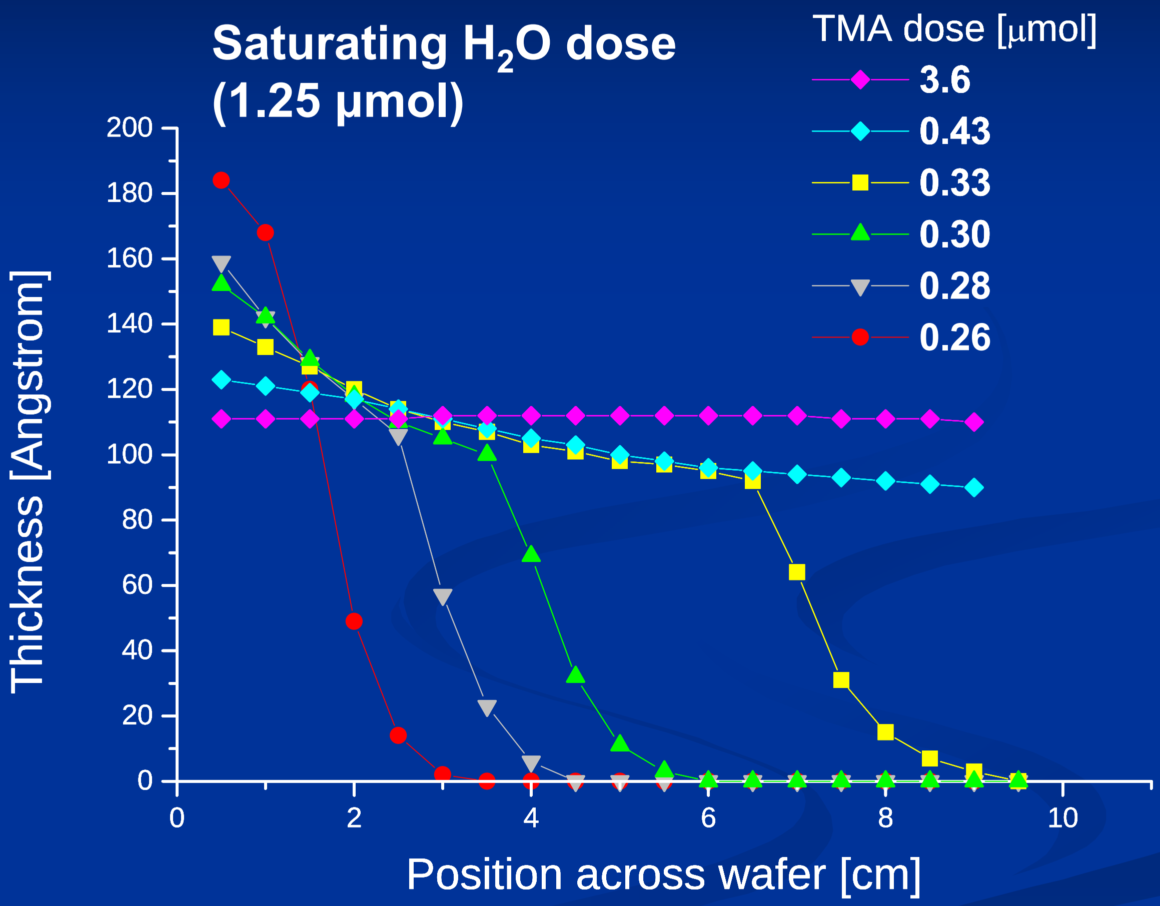
Across-Wafer Al_2O_3 ALD Film Properties

Under-dose H_2O conditions (0.8μmol)



Al_2O_3 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


Saturating H_2O dose (1.25 µmol)

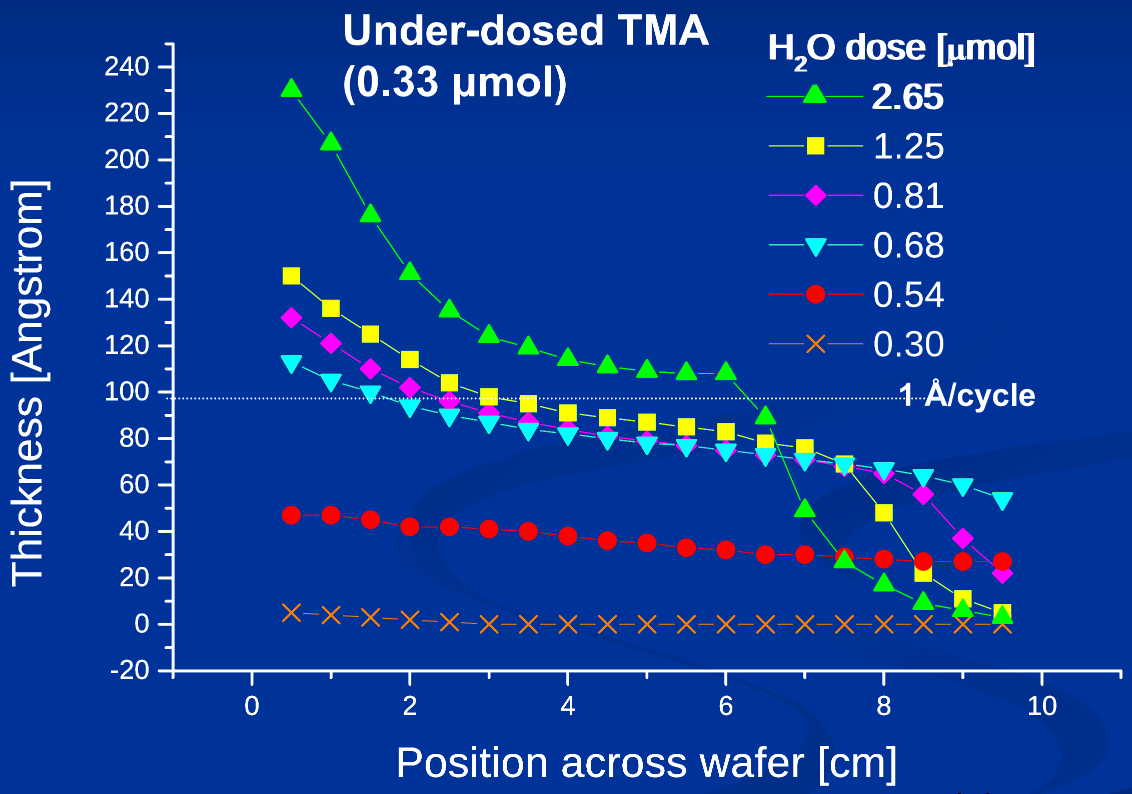
Al_2O_3 ALD: H_2O under-dosing

H_2O/TMA < 2

➔improved uniformity but mean thickness decreases due to insufficient reactant supply

H_2O/TMA > 2

➔profound nonuniformity at front and rear, with limited uniformity at middle



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