

# Atomic Layer Deposition Systems

ALD Process Solutions using FlexAL® and OpAL®



**OXFORD**  
INSTRUMENTS

*The Business of Science®*



# Introduction to ALD

## Self limiting digital growth

Atomic Layer Deposition (ALD) offers the opportunity to create precisely controlled ultra-thin films for advanced applications on nanometre and sub-nanometre scales, with conformal coating into high aspect ratio structures.

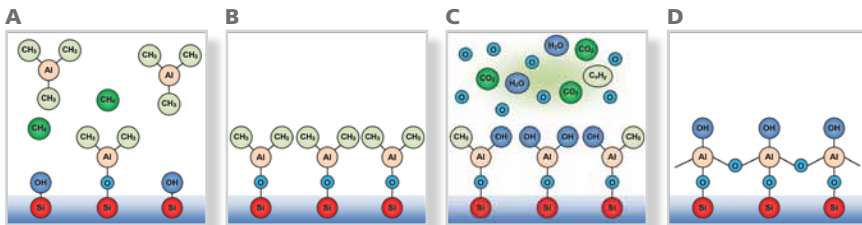
Oxford Instruments' ALD product family offers a unique new range of flexibility and capability in the engineering of nanoscale structures and devices by combining remote plasma ALD processes with thermal ALD.

### Exploit the benefits of plasma ALD

The remote plasma option allows for the widest possible choice of precursor chemistry with enhanced film quality:

- Plasma enables low-temperature ALD processes and the remote source maintains low plasma damage<sup>5</sup>
- Effective metal chemistry through use of hydrogen plasma rather than complex thermal precursors
- Eliminates the need for water as a precursor, reducing purge times between ALD cycles
- Higher quality films through improved removal of impurities, leading to lower resistivity, higher density, etc.

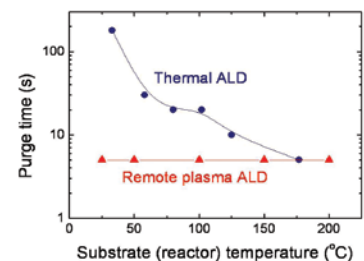
ALD cycle for  $\text{Al}_2\text{O}_3$  deposited using TMA and  $\text{O}_2$  plasma<sup>6</sup>. Only step C varies between  $\text{H}_2\text{O}$  for the thermal process or  $\text{O}_2$  plasma.



- A. TMA chemisorption
- B. TMA purge
- C.  $\text{O}_2$  plasma
- D. Short post plasma purge

### Example applications of ALD

- Nano-electronics
- High-k gate oxides<sup>1</sup>
- Storage capacitor dielectrics<sup>2</sup>
- High aspect ratio diffusion barriers for Cu interconnects
- Pinhole-free passivation layers for OLEDs and polymers<sup>3</sup>
- Passivation of crystal silicon solar cells<sup>4</sup>
- Highly conformal coatings for microfluidic and MEMS applications
- Coating of nanoporous structures
- Bio MEMS
- Fuel cells



Purge time for thermal ALD of  $\text{Al}_2\text{O}_3$  ( $\text{H}_2\text{O}$ ) and remote plasma ALD of  $\text{Al}_2\text{O}_3$  ( $\text{O}_2$ ).  
Data courtesy of Eindhoven University of Technology

# FlexAL and OpAL

## Remote plasma and thermal ALD in one tool

### A family of tools to meet your needs

The ALD product family encompasses a range of tools to meet the varied demands of academia, corporate R&D and small scale production.

#### FlexAL tool

- Remote plasma & thermal ALD in one flexible tool
- Automated 200mm load lock for process flexibility
- Clusterable for vacuum transfer of substrates
- Cassette to cassette handling increases throughput suitable for production



FlexAL

#### OpAL tool

- Open loaded thermal ALD tool with plasma option
- Field upgrade available for plasma option
- Small wafer pieces up to full 200mm wafers – equally suitable for academic and industry R&D



OpAL

### FlexAL and OpAL Precursor Delivery

- Multiple liquid or solid precursor delivery systems
- Vapour draw or bubbling up to 200°C source temperature
- Rapid gas delivery



*Designed for safe handling of hazardous precursors by enclosing them in a stainless steel extracted cabinet with attachable glove box for use during precursor exchange*

# ALD Process Benefits

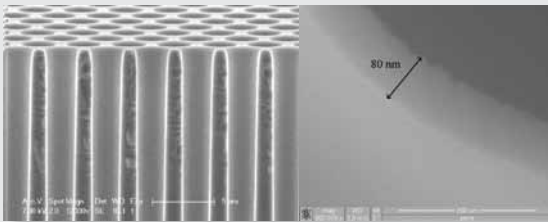
## Conformal, controlled, low pin-hole nano-scale growth

### General ALD process benefits

- Excellent process control with wafer to wafer repeatability  $<\pm 1\%$
- Up to 200mm wafer with typical uniformity  $<\pm 2\%$
- Excellent step coverage even inside high aspect ratio structures
- Virtually pin-hole free films
- Low film impurities; particularly with plasma ALD
- Growth at room temperature 25°C possible with plasma ALD

### Specific material properties by ALD

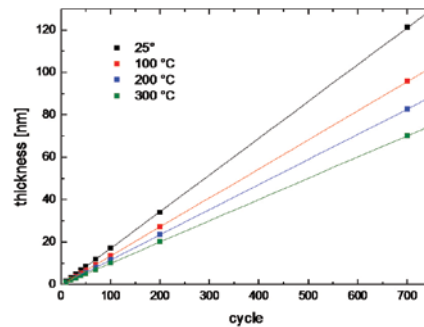
- High  $k$
- High breakdown voltage
- Low resistivity for conductive nitride and metal films by plasma ALD
- Superb thin film barrier properties



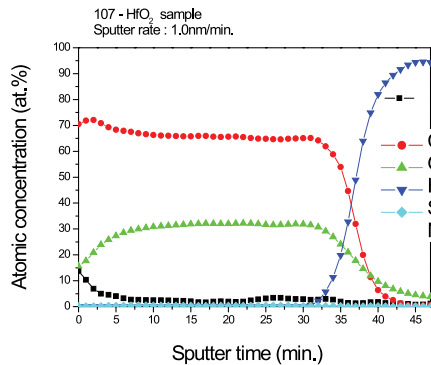
Plasma ALD of 80 nm Al<sub>2</sub>O<sub>3</sub> from TMA and O<sub>2</sub> plasma in a 10:1 aspect ratio deep trench capacitor structure. Courtesy of Eindhoven University of Technology and NXP

Parameter	Al <sub>2</sub> O <sub>3</sub>	HfO <sub>2</sub>
Dielectric Constant	8	18
Breakdown voltage	~9 MV/cm	~3 MV/cm

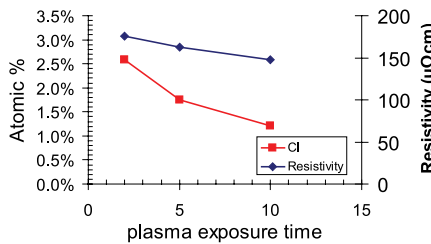
High breakdown voltage<sup>2</sup> of Al<sub>2</sub>O<sub>3</sub> and high dielectric constant<sup>1</sup> of HfO<sub>2</sub>. HfAlO can provide an average  $k$  value, but high breakdown voltage.



Excellent repeatability due to linear self-limiting growth. Example shown of Al<sub>2</sub>O<sub>3</sub> by plasma ALD measured by in-situ spectroscopic ellipsometry at deposition temperatures down to room temperature (25°C). Data courtesy of Eindhoven University of Technology<sup>2</sup>

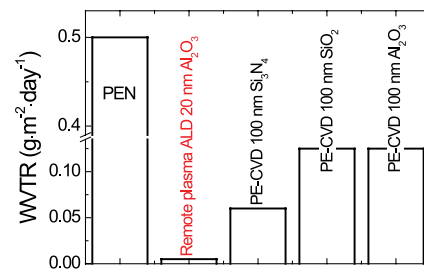


HfO<sub>2</sub> from TEMA and O<sub>2</sub> plasma – Auger analysis showing low carbon content of  $<2\%$  obtained by FlexAL remote plasma ALD



Chlorine impurities of TiN by RBS and resistivity by FPP deposited at 350°C.

Resistivity  $<200\mu\Omega\text{cm}$  possible with plasma ALD even at low temperatures. (350°C plasma = 550°C thermal)



Al<sub>2</sub>O<sub>3</sub> barrier deposition at room temperature. Graph shows excellent single layer moisture and oxygen diffusion barrier (20 nm Al<sub>2</sub>O<sub>3</sub> with WVTR = 5.0.10<sup>-3</sup> g.m<sup>-2</sup>.day<sup>-1</sup>).

Data courtesy of Eindhoven University of Technology<sup>4</sup>

# Process Library

## Rapidly populating the periodic table

Oxford Instruments has an extensive process library, and new processes are continually being developed.

### Process Development

The list of developed processes is continually expanding; please contact your Oxford Instruments sales representative for the latest information; alternative chemistries may also be available for certain materials. Oxford Instruments provides free on-going process support for the lifetime of any ALD tool offering advice on developing new materials and continued access to our latest ALD process developments including new process recipes.



**Global Applications Support** - As a global company, processes developed in the UK Applications Laboratory and with collaboration partners are delivered to customers via local front-line support. Oxford Instruments' network of process support engineers is based in the USA, Asia and Europe.

### Precursors

#### Metal Precursors

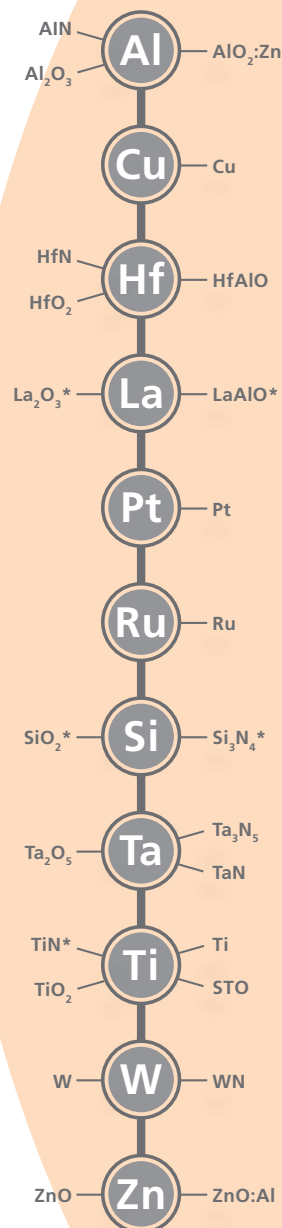
Liquid or solid precursors vapours can be delivered to the reaction chamber by heating up to 200°C.

#### Delivery modes:

- Vapour under own vapour pressure
- Vapour draw with carrier gas assist
- Bubbling with carrier gas

#### Non-metal Precursors

<b>H<sub>2</sub>O</b>	Thermal Oxides
<b>Ozone</b>	Thermal Oxides
<b>O<sub>2</sub></b>	Plasma oxides, plasma metals, thermal metals
<b>N<sub>2</sub></b>	Plasma nitrides
<b>H<sub>2</sub></b>	Plasma metals, plasma nitrides, some thermal metals
<b>NH<sub>3</sub></b>	Thermal nitrides and some plasma nitrides



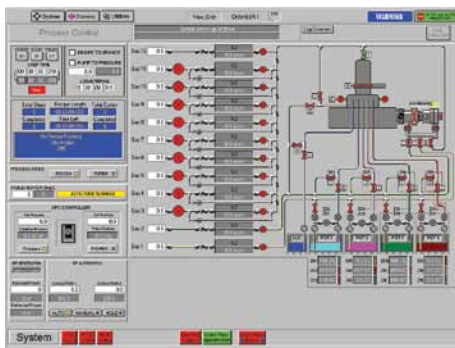
\*Requires or strongly benefits from plasma

# Product Overview

## Flexible, configurable, powerful tools

Both **FlexAL** and **OpAL** can be fitted with the Oxford Instruments Plasma Technology remote Inductively Coupled Plasma (ICP) ALD source. This source is close coupled to an Oxford Instruments matching unit with dedicated control systems to enable rapid plasma striking.

Feature	OpAL	FlexAL
Substrates	Up to 200mm wafers and pieces directly on stage	Up to 200mm wafers handling and pieces on carrier plate
Bubbled liquid and solid precursors	Up to 4	Up to 8
Max precursor source temperature	200°C (jacket)	200°C (oven and jacket)
Additional precursors	Water + ozone	Water + ozone
Mfc controlled gas lines with rapid delivery system; 1) thermal gas precursors (e.g. NH <sub>3</sub> , O <sub>2</sub> ) 2) plasma gases (e.g. O <sub>2</sub> , N <sub>2</sub> , H <sub>2</sub> )	2 internally. Up to 8 in externally mounted gas pod	Up to 10 in externally mounted gas pod
Plasma	Option / field upgrade	Option
Loading	Open load	Loadlock or cassette
In situ diagnostic ports	Ellipsometry, QCM, OES, QMS (on foreline)	Ellipsometry, QCM, OES, QMS
Swagelok 10ms rapid pulsing ALD valves	Yes	Yes
Removable inner chamber	Yes	Yes
<b>PC2000</b> rapid control software	Yes	Yes
Clusterable to other process modules	No	Yes - including third party MESC modules as special option
Wafer stage temperature range	25°C – 400°C (500°C option)	25°C – 400°C (550°C option)



Powerful **PC2000** Software

### Power ahead with intuitive software

Easy to use, multi-user level, **PC2000™** cross platform control software is tailored for rapid cycle ALD.

### Be reassured with global support

Local engineers based worldwide.

### Save time with process guarantees

Developed in our applications laboratory and backed by on-site process acceptance and support.



# Configuration Options

Systems easily configured for cutting edge research or production

## FlexAL

Research Solutions



Single wafer loadlock

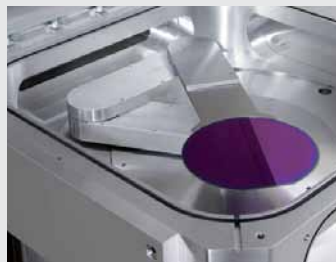


Entry handler clustered to other process modules

Production Solutions



All configurations can be located entirely within the cleanroom or through-the-wall



Handler with robot and 25 wafer cassette for 4", 6" or 8" wafers

## OpAL

A nitrogen purged glove box can surround the **OpAL** chamber for dry loading of samples, giving lower oxygen contamination in nitride and metal films.



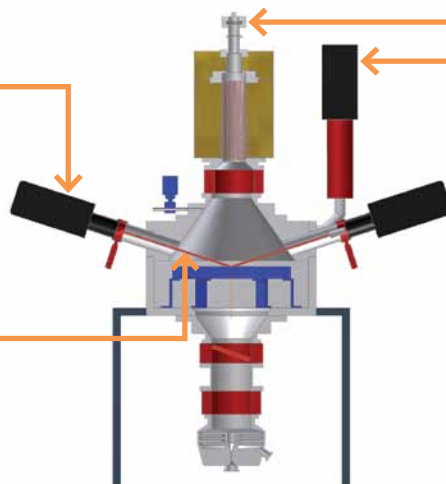
## In situ options

### Ellipsometer

- Nucleation delay
- In situ resistivity
- Linear growth
- Saturation growth

### Quartz Crystal Microbalance (QCM)

- Saturation growth
- Linear growth
- Reaction mechanism



### Optical emission spectroscopy (OES)

- Saturation growth
- Reaction mechanism

### Mass Spectrometer (QMS)

- Reaction mechanisms
- Background chamber condition
- Precursor condition

# Global Service and Support

For more information about our ALD tools,  
please contact your local Oxford Instruments office

## Worldwide Service and Support

Oxford Instruments is committed to supporting our customers' success. We recognise that this requires world class products complemented by world class support. Our global service force is backed by regional offices, offering rapid support wherever you are in the world.

We can provide:

- Tailored service agreements to meet your needs
- Comprehensive range of structured training courses
- Immediate access to genuine spare parts and accessories
- System upgrades and refurbishments



## REFERENCES

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- [3] Plasma-assisted atomic layer deposition of Al<sub>2</sub>O<sub>3</sub> moisture permeation barriers on polymers. E. Langereis, M. Creatore, S.B.S. Heil, M.C.M. van de Sanden, and W.M.M. Kessels, *Appl. Phys. Lett.* 89, 081915 (2006).
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- [5] Remote Plasma Atomic Layer Deposition of Hafnium Oxide, Hyeongtag Jeon, AVS 5th International Conference on Atomic Layer Deposition 2005.
- [6] Reaction mechanisms during plasma-assisted atomic layer deposition of metal oxides: A case study for Al<sub>2</sub>O<sub>3</sub>. S.B.S. Heil, J.L. van Hemmen, M.C.M. van de Sanden and W.M.M. Kessels, *J. Appl. Phys.* 103 (2008) 103302

[www.oxford-instruments.com/plasma](http://www.oxford-instruments.com/plasma) for more information

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