Atomic Layer Deposition

ALD process solutions using FlexAL and OpAL

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Oxford Instruments

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Introduction to ALD

Self limiting digital growth

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

Oxford Instruments’ ALD product family offers a unique 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
- 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 conducting layers and higher density insulators

Example applications of ALD:

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

ALD Process Benefits

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

- Excellent process control with wafer to wafer repeatability <±1%
- Up to 200mm wafer with typical uniformity <±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 possible with plasma ALD
- Low resistivity for conductive nitride and metal films by plasma ALD
- Superb thin film barrier properties

HfO₂, from TEMAH and O₂ plasma - Auger analysis showing low carbon content of <2% obtained by FlexAL remote plasma ALD

Al₂O₃, SiO₂ and TiO₂ grown at room temperature. Due to the high reactivity of plasma ALD, many materials can be deposited at lower temperature as compared to when using thermal ALD.

HfO₂, from TEMAH and O₂ plasma - Auger analysis showing low carbon content of <2% obtained by FlexAL remote plasma ALD

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Diffusion barriers with excellent water vapour transmission rates. 20 and 40nm Al₂O₃ deposited using plasma ALD at room temperature, perform even better than a 300nm a-SiNx:H deposited by PECVD. Data courtesy of TUE.

ALD cycle for Al₂O₃ deposited using TMA and O₂ plasma

Only step C varies between H₂O for the thermal process or O₂ plasma.
Oxford Instruments has an extensive process library, and new processes are continually being developed. We provide 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.

**Precursors**

**Metal Precursors**

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

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

**Non-metal precursors**

<table>
<thead>
<tr>
<th>Precursor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>Thermal Oxides</td>
</tr>
<tr>
<td>O₃</td>
<td>Thermal Oxides</td>
</tr>
<tr>
<td>O₂</td>
<td>Plasma oxides, plasma metals, thermal metals</td>
</tr>
<tr>
<td>N₂</td>
<td>Plasma nitrides</td>
</tr>
<tr>
<td>H₂</td>
<td>Plasma metals, plasma nitrides, some thermal metals</td>
</tr>
<tr>
<td>NH₃</td>
<td>Thermal nitrides and some plasma nitrides</td>
</tr>
</tbody>
</table>

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

**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

**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

**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

**In Situ Diagnostic Options**

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

**Quartz Crystal Microbalance (QCM)**
- Saturation growth
- Linear growth
- Reaction mechanism

**Mass Spectrometer (QMS)**
- Reaction mechanisms
- Background chamber condition
- Precursor condition

**Optical Emission Spectroscopy (OES)**
- Saturation growth
- Reaction mechanism

Plasma ALD of 80 nm Al₂O₃ from TMA and O₂ plasma in a 10:1 aspect ratio deep trench capacitor structure. Courtesy of Eindhoven University of Technology and NXP.
Configuration Options

Systems easily configured for cutting edge research or production

Product Overview

Flexible, configurable, powerful tools

Both FlexAL and OpAL can be fitted with the 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.

<table>
<thead>
<tr>
<th>Feature:</th>
<th>OpAL</th>
<th>FlexAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrates</td>
<td>Up to 200mm wafers and pieces directly on stage</td>
<td>Up to 200mm wafers and pieces on carrier plate</td>
</tr>
<tr>
<td>Bubbled liquid and solid precursors</td>
<td>Up to 4</td>
<td>Up to 8</td>
</tr>
<tr>
<td>Max precursor source temperature</td>
<td>200ºC (jacket) for all precursors</td>
<td>200ºC (oven and jacket) for all precursors</td>
</tr>
<tr>
<td>Additional precursors</td>
<td>Water + ozone</td>
<td>Water + ozone</td>
</tr>
<tr>
<td>MFC controlled gas lines with rapid delivery system; 1) thermal gas precursors e.g. NH₃, O₂ 2) plasma gases e.g. O₂, N₂, H₂</td>
<td>2 internally. Up to 8 in externally mounted gas pod</td>
<td>Up to 10 in externally mounted gas pod</td>
</tr>
<tr>
<td>Plasma</td>
<td>Option / field upgrade</td>
<td>Option</td>
</tr>
<tr>
<td>Loading</td>
<td>Open load / glove box</td>
<td>Loadlock or cassette</td>
</tr>
<tr>
<td>In situ diagnostic ports</td>
<td>Ellipsometry, QCM, OES, QMS (on foreline)</td>
<td>Ellipsometry, QCM, OES, QMS</td>
</tr>
<tr>
<td>10ms rapid pulsing ALD valves</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Removable inner chamber</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PC2000 rapid control software</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Clusterable to other process modules</td>
<td>No</td>
<td>Yes - including third party MESC modules as special option</td>
</tr>
<tr>
<td>Wafer stage temperature range</td>
<td>25ºC – 400ºC (500ºC option)</td>
<td>25ºC – 400ºC (550ºC option)</td>
</tr>
<tr>
<td>Bias</td>
<td>No</td>
<td>Option to apply bias voltage to substrate table for increasing ion energies</td>
</tr>
</tbody>
</table>

OpAL system in glovebox for handling moisture sensitive samples

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Global Service and Support

For further information about our tools, please contact your local Oxford Instruments Plasma Technology 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:

- Flexible service agreements to meet your needs
- Tailored system training courses
- System upgrades and refurbishments
- Immediate access to genuine spare parts and accessories

visit www.oxinst.com/plasma for more information

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