OXFORD INSTRUMENTS

Atomic Scale Processing

ALD, ALE & CVD Process Solutions

Atomic Scale Processing

Driving innovation at the atomic scale

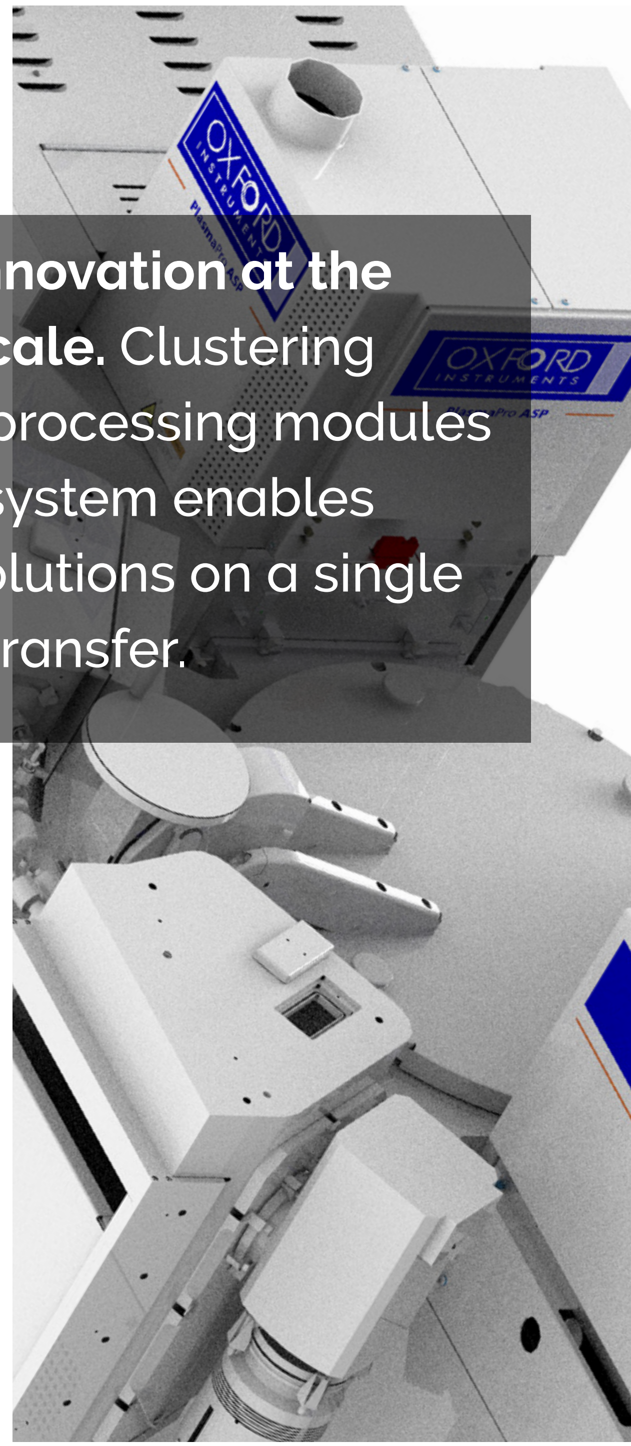
Atomic scale processing means wafer-scale processing with control at the atomic scale. This atomic-level control extends to deposition of thin films, removal or etching of material, and growth of 1D and 2D materials.

Fundamental Research and Development Toolkit – Clusterable Atomic Scale Processing Technology

- Atomic Layer Deposition (ALD) of dielectrics & conductive materials with low damage
- Atomic Layer Etch (ALE) of Silicon, GaN & 2D materials
- 1D & 2D materials growth - Chemical Vapour Deposition (CVD) & ALD of atomically thin structures

Example applications

- GaN, SiC and next generation power devices
- Highly conformal, low oxygen content nitrides for quantum applications
- Conformal dielectric coatings for high-K gates, photonics, microfludics, MEMS
- Graphene and other 2D materials
- Biocompatible layers for medical devices
- Passivation layers for BioMEMS, OLEDs, solar cells
- Electron and hole transport layers in perovskite solar cells
- High aspect ratio diffusion barriers for Cu interconnects
- Storage capacitor dielectrics



Driving innovation at the atomic scale. Clustering multiple processing modules into one system enables unique solutions on a single vacuum transfer.

Atomic Layer Deposition (ALD)

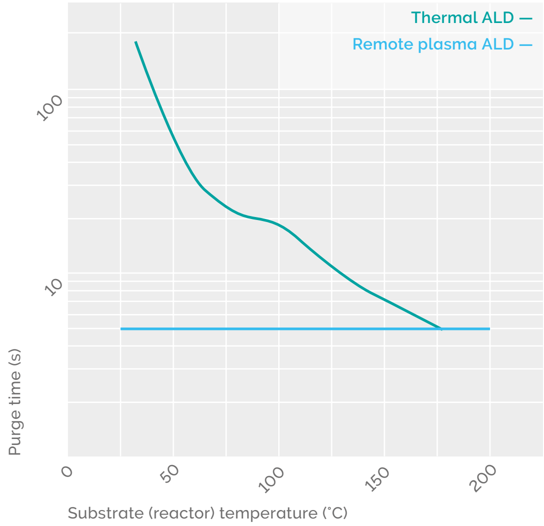
ALD offers precisely controlled ultra-thin films for advanced applications on the nanometre scale.

Oxford Instruments' ALD equipment offers unique capability by combining remote plasma ALD processes with thermal 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

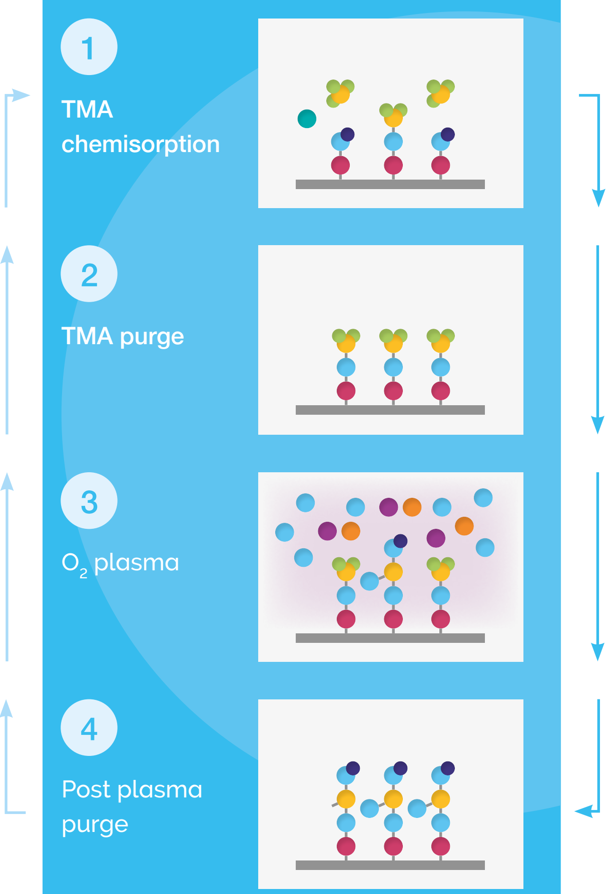
The reactivity of plasma and volatility of the species used allows for short purge times, even at very low sample temperatures.



ALD cycle

—for Al_2O_3 deposited using TMA and O_2 plasma

Key: O, Si, Al, H, CH_3, CO_2, H_2O, CH_4

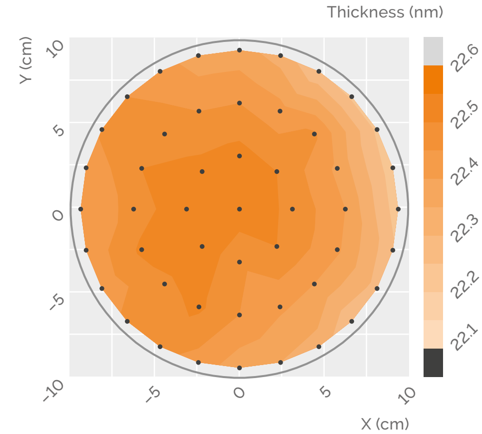


ALD Benefits

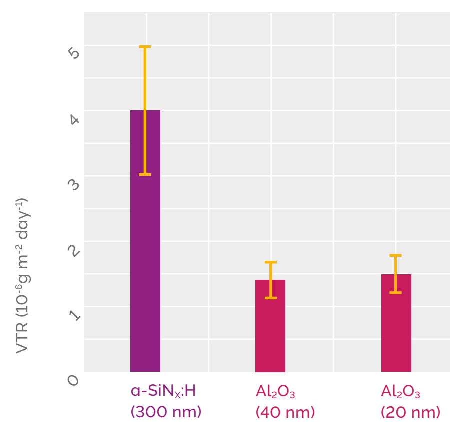
Conformal, controlled, low pin-hole nanoscale growth

Process benefits:

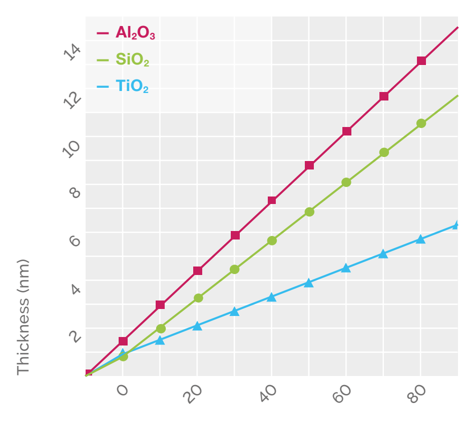
- High quality films grown with ultimate thickness accuracy, one atomic layer at a time
- Tuneable film properties using RF bias
- Low damage plasma ALD
- Up to 200 mm wafer with typical uniformity <±2%
- Excellent step coverage even inside high aspect ratio structures
- Virtually pin-hole free films
- 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



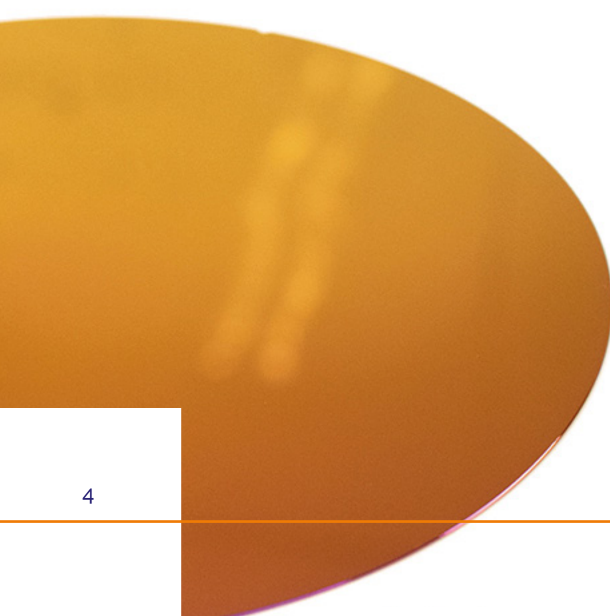
High thickness uniformity for standard plasma ALD Al_2O_3 process on 200 mm wafers. Similar uniformities are expected for many of our plasma and thermal ALD processes.



Diffusion barriers with excellent water vapour transmission rates. 20 and 40 nm Al_2O_3 deposited using plasma ALD at room temperature, perform even better than a 300 nm a-SiNX:H deposited by PECVD. Data courtesy of TU/e.



Al_2O_3, SiO_2 and TiO_2 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.



ALD Process

Process library and development

ALD materials list

● Nitrides ● Oxides ● Metals ● Fluorides ● Sulphides

AlN		GaN	HfN				NbN		Si_3N_4		TaN	TiN	WN		
Al_2O_3	Co_3O_4	Ga_2O_3	HfO_2	In_2O_3	Li_2CO_3	MoO_3	Nb_2O_5	NiO	SiO_2	SnO_2	Ta_2O_5	TiO_2	WO_3	ZnO	ZrO_2
				Pt	Ru			AlF_3	MgF_2			MoS_2	WS_2		

Precursors

Metal precursors

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

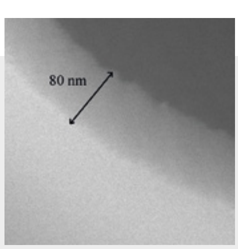
Non-metal precursors

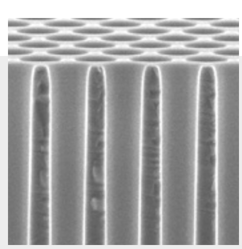
H_2O	Thermal Oxides
Ozone	Thermal Oxides
O_2	Plasma oxides, plasma metals, thermal metals
N_2	Plasma nitrides
H_2	Plasma metals, plasma nitrides, some thermal metals
NH_3	Thermal nitrides and some plasma nitrides

Precursor delivery

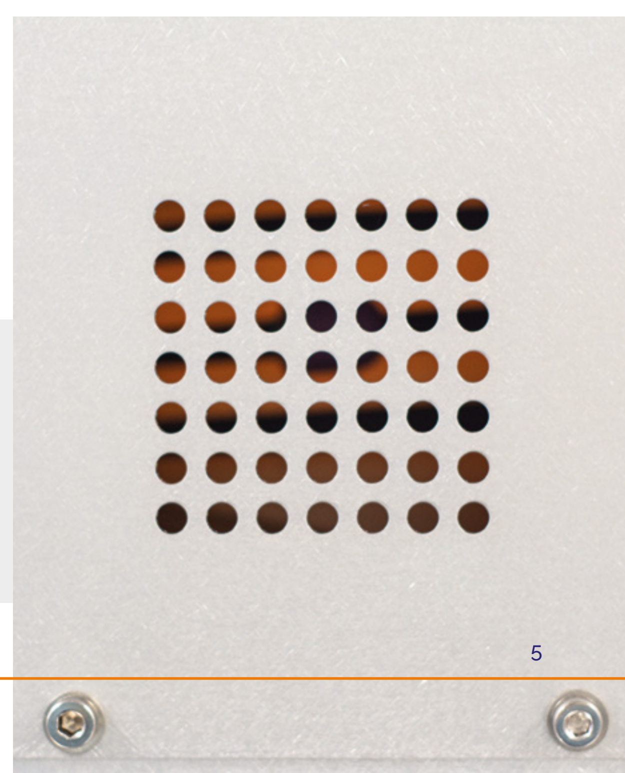
Delivery modes:

- Multiple liquid or solid precursor delivery systems
- Vapour draw or bubbling up to 200 ˚C source temperature
- Precise control through fast ALD valves and wide range of plasma gas mixtures possible with independent MFC control of gases





Plasma ALD of 80 nm Al_2O_3 from TMA and O_2 plasma in a 10:1 aspect ratio deep trench capacitor structure.



Atomic Layer Etching (ALE)

ALE is a technique designed to allow the accurate removal of one atomic layer at a time; a level of control unachievable using conventional etching.

As layers become thinner to enable the next generation semiconductor devices there is a need for ever more precise process control to create and manipulate these layers.

The **PlasmaPro® 100** ALE delivers this through specialised hardware including:

- Precise control of gas dose
- Excellent repeatability of low power RF delivery
- Rapid switching enabled by fast PLC

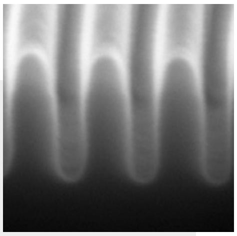
All these combine to enable etching with accuracy at the atomic scale.

Process benefits:

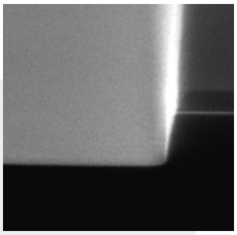
- High accuracy of etched depth
- Ideal for nanoscale layer removal
- Possibility of single atomic layer etch (e.g. for 2D materials)
- Smooth etch surfaces
- High selectivity
- Low damage
- Excellent uniformity
- Minimal aspect ratio dependence

Wide range of materials

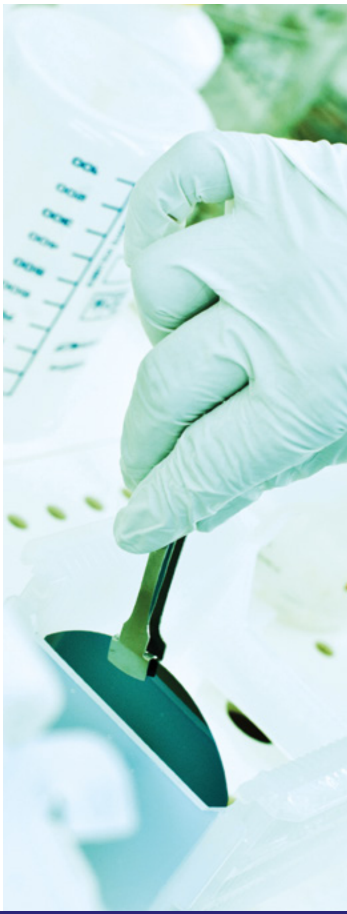
Material etched	Dose gas	Etch gas
Si or a-Si	Cl_2	Ar
MoS_2	Cl_2	Ar
SiO_2	CHF_3 or C_4F_8	Ar or O_2
AlGaN/GaN	Cl_2 BCl_3	Ar
AlGaN/GaN	N_2O	BCl_3
SiC	Cl_2	Ar



25 nm wide Si trenches etched to 110 nm depth, 150 cycles; HSQ mask still in place.

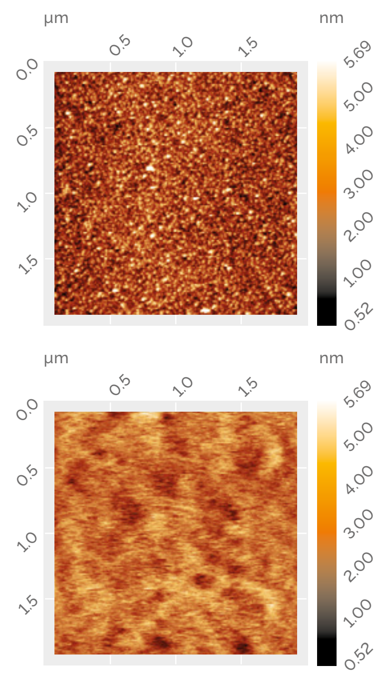


Smooth Si etch surface after 150 ALE cycles.

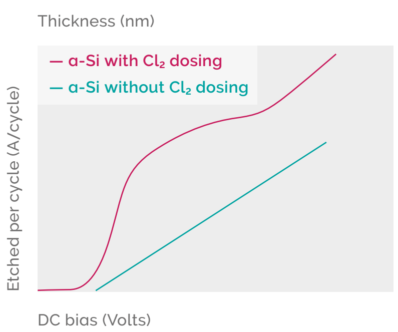


ALE Process

Process library and development



AFM images show AlGaN surface roughness reduced by 0.3 nm within 30 cycles.



Graph showing true ALE plateau when etching a-Si, the precise control of the RF power is essential to achieve repeatable ALE.

ALE cycle

1

Dose

Chamber is given a short dose with a chemically reactive species (Cl_2 for GaN, AlGaN or Si).

This forms a layer on the substrate surface.

2

Purge

Excess Cl_2 is pumped away to leave just a layer on the substrate surface.

3

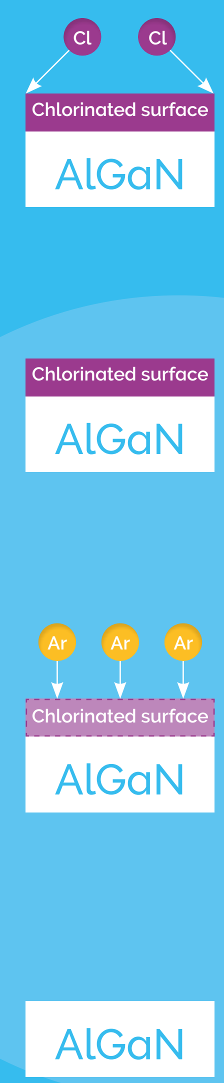
Etch

A small amount of DC bias power is applied causing Ar ion bombardment to remove the top layer and leave a fresh substrate surface.

4

Pump by-products

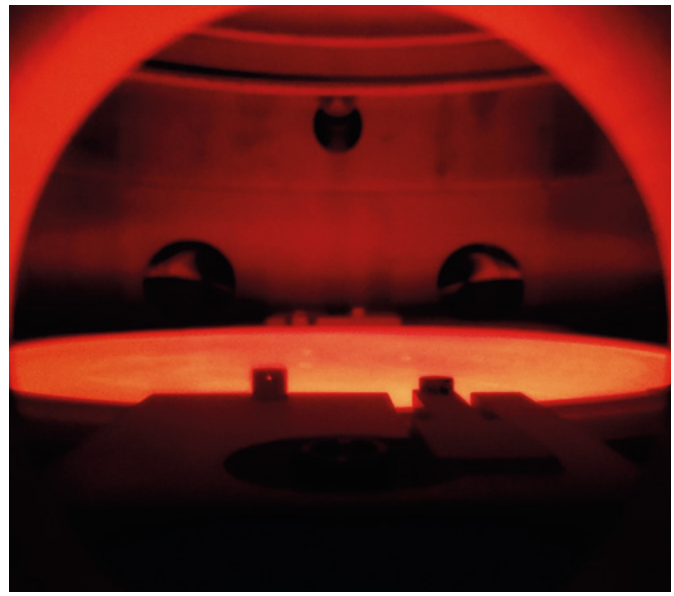
Pump out step to remove all by-products from the chamber before a fresh dose of Cl_2 is introduced.



Chemical Vapour Deposition (CVD)

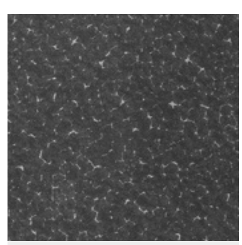
CVD systems for growth of nanomaterials

PlasmaPro® 100 Nano is a high temperature CVD/PECVD system tailored for high quality deposition of nanostructured materials and Silicon based thin films.

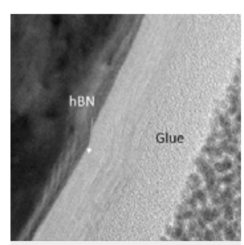


Features:

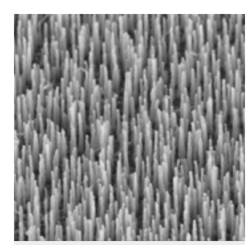
- Cold wall design with showerhead based uniform gas delivery
- Plasma options for PECVD and chamber cleans: Parallel Plate (capacitively coupled) or remote plasma (ICP)
- Vacuum load lock for quick sample exchange
- Excellent temperature uniformity
- Optional multiple liquid/solid source delivery systems for growth of MoS_2, $MoSe_2$ and other TMDCs
- Variable sample sizes up to maximum 200 mm wafers
- Multiple view ports for diagnostics



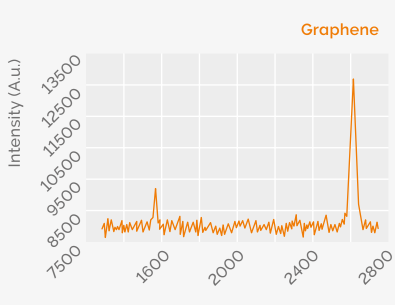
CVD of graphene domains growing on copper substrates.

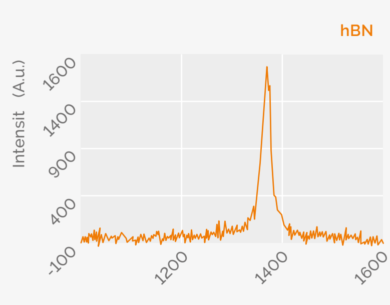


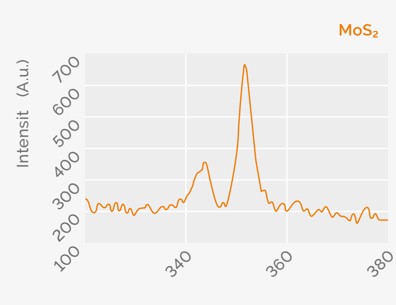
CVD Growth of hBN.



CVD ZnO nanowire growth using DEZn precursors.





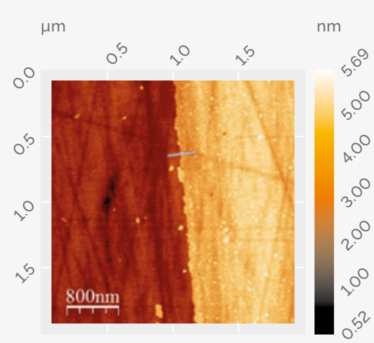


Chemical Vapour Deposition (CVD)

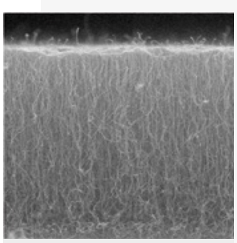
CVD systems for growth of nanomaterials

Wide range of materials

	700˚C table	800˚C table	1200˚C table
Thin film process	SiO_x, SiN_x, a-SiC, a-Si, µc-Si, polySi*	SiO_x, SiN_x, a-SiC, a-Si, µc-Si, polySi	SiO_x, SiN_x, a-SiC, a-Si, µc-Si, polySi
1D Nanomaterials	MWNTs, Si, Ge NWs, ZnO NWs	MWNTs, SWNTs*, Si, Ge NWs	MWNTs, SWNTs, Si, Ge NWs
2D Nanomaterials	NA	Nano-crystalline Graphene, Vertical Graphene	Graphene, hBN, MoS_2, WS_2, Vertical Graphene, Nano-crystalline Graphene

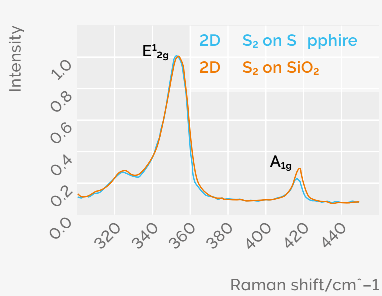


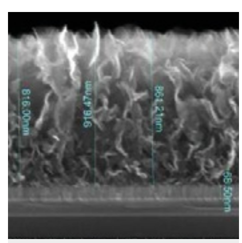
CVD growth of 2D MoS_2.



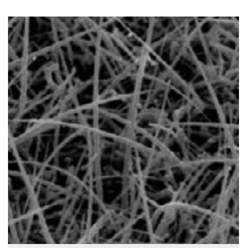
Dense Carbon Nanotubes grown by PECVD.

Raman shift of CVD of WS_2.



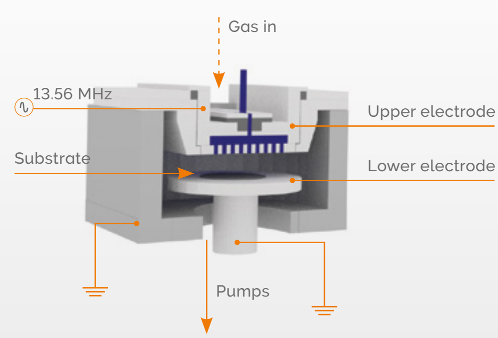


PECVD of vertically aligned graphene.



CVD growth of Silicon nanowires using Au nanoparticle catalysts.

PlasmaPro® **100** Nano chamber with capacitively coupled plasma hardware for PECVD processing.



Hardware

Plasma processing systems that provide a complete solution to ASP

PlasmaPro® ASP

- Unique patented plasma source, operating with speed
- Higher deposition rate and low damage ALD
- Cooled/heated vapour and heated bubbler precursors for maximum process flexibility
- Clusterable for vacuum transfer of substrates
- Optional cassette to cassette handling

PlasmaPro® 100 ALE

- Superb etch depth control
- Smooth etch surface
- Low damage process
- Digital/Cyclical etch process
- High selectivity
- Process capability up to 200 mm wafers
- High aspect ratio (HAR) etch process

Inside view of precursor pot for liquid/ solid precursors.

PlasmaPro® 100 Nano

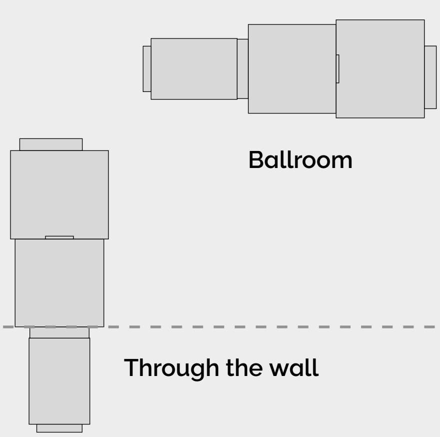
- Excellent uniformity
- Options of a 700 ˚C, 800 ˚C, or 1200 ˚C table
- Sample sizes up to 200 mm
- Vacuum load lock—quick sample exchange
- Optional liquid/solid source delivery system for growth of MoS_2 $MoSe_2$ and other TMDCs

Configuration Options

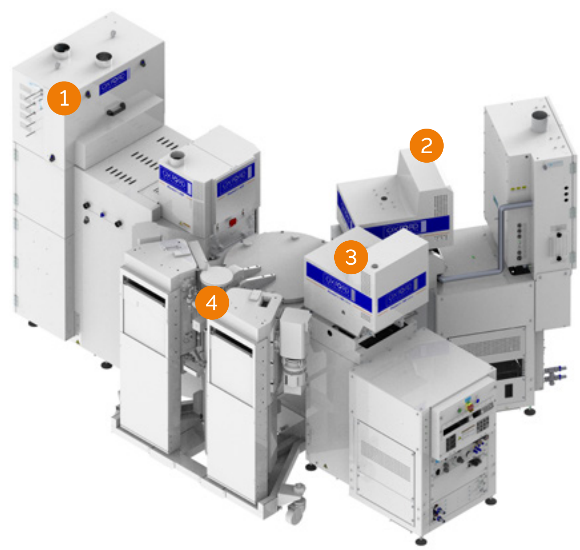
Systems easily configured for cutting edge production or research

We provide unique cluster capability or stand-alone systems enabling the manipulation of matter with atomic scale precision on a production scale.

Configurations can be located entirely within the cleanroom or through-the-wall

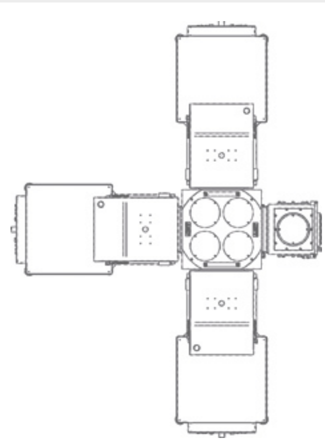


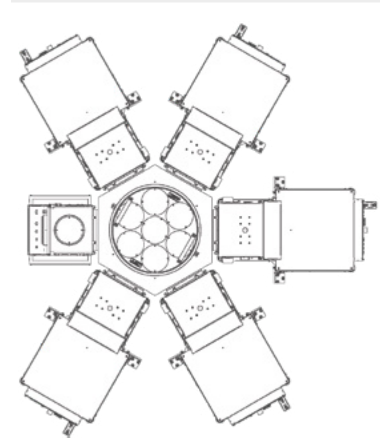
1. Plasma ALD
2. ICP CVD & thermal CVD
3. ALE
4. Handler



Cluster options

4-way square handler	6-way hex handler





Worldwide Service

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

For further information please contact your local Oxford Instruments Plasma Technology office.

Email
plasma@oxinst.com

UK
Yatton
+44 (0) 1934 837000

Germany
Wiesbaden
+49 (0) 6122 937 161

India
Mumbai
+91 22 4253 5100

Japan
Tokio
+81 3 5245 3261

PR China
Beijing
+86 10 6518 8160/1/2
Shanghai
+86 21 6132 9688

Singapore
+65 6337 6848

Taiwan
+886 3 5788696

US, Canada & Latin America
Concord, MA
TOLLFREE: +1 800 447 4717

visit **plasma.oxinst.com**

OXFORD INSTRUMENTS