Oxford Instruments Nanotechnology Tools

Capital Equipment considerations for 2d materials moving from Lab to Fab

Dr Ravi Sundaram
HVM Graphene+ 2014 Conference
Oxford, UK 15 May
www.hvm-uk.com

Our History

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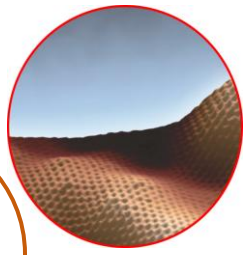
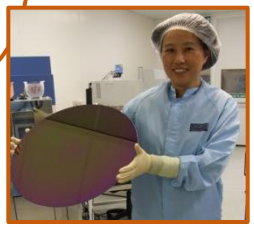
Tools for nanotechnology research



World's first liquid helium free dilution refrigerator with an integrated high-field superconducting magnet

World's first large area Silicon Drift Detector for SEMs

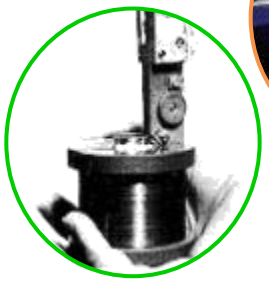


World's first 450mm PECVD

Plasma etch & Deposition tools for semiconductor industry

Floated on London Stock Exchange

World's first MRI



World's first commercial superconducting magnet

1959 1969 1979 1989 1999 2009 2012

Our Businesses

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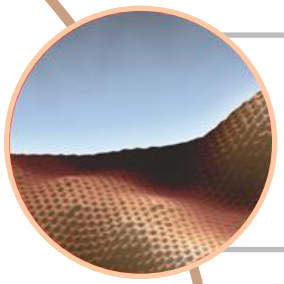

Nanotechnology Tools Sector

Fabrication & Analysis at the Nanoscale

Global Service

3rd party Service
- MRI and CT

OI Product Support
- Global presence

Industrial Products Sector

Industrial Analysis
- XRF, OES, MRI

Industrial Products
- Superconductors
- X-Ray Technology
- Cryopumping

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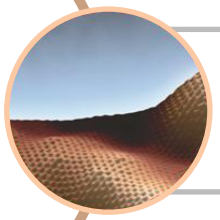

Nanotechnology Tools Sector

Omicron NanoScience

NanoAnalysis

Plasma Technology

Our Strategy

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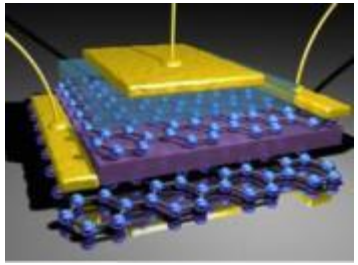
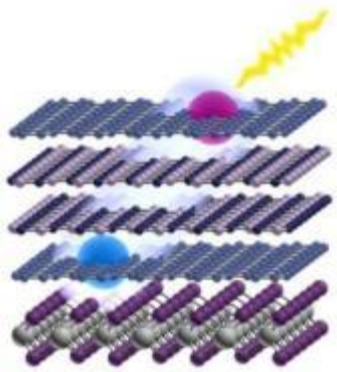
Partnering with customers and suppliers to:

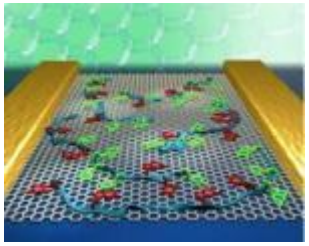
- Understand needs of the research field and develop tools to meet requirement
- Provide world leading tools and process solutions to emerging production markets

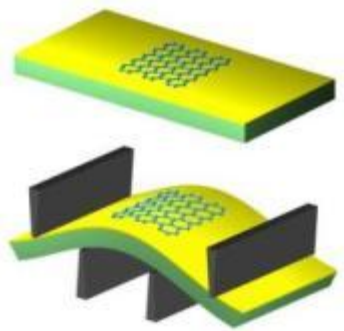
Challenges

- Electronic devices
  - Reducing growth costs
  - Wafer level scaling
  - Handling thin films
  - Band gap engineering
  - Encapsulation
  - Atomic level lithography
  - New device Physics
  - System integration
- Energy Storage
  - Electrochemical interactions
  - Development of heterostructures
  - Producing stable doping
- Composite Materials
  - Producing materials cost effectively
  - Bonding with polymer matrix
- Sensors
  - Selectivity
  - Surface activation and functionalisation

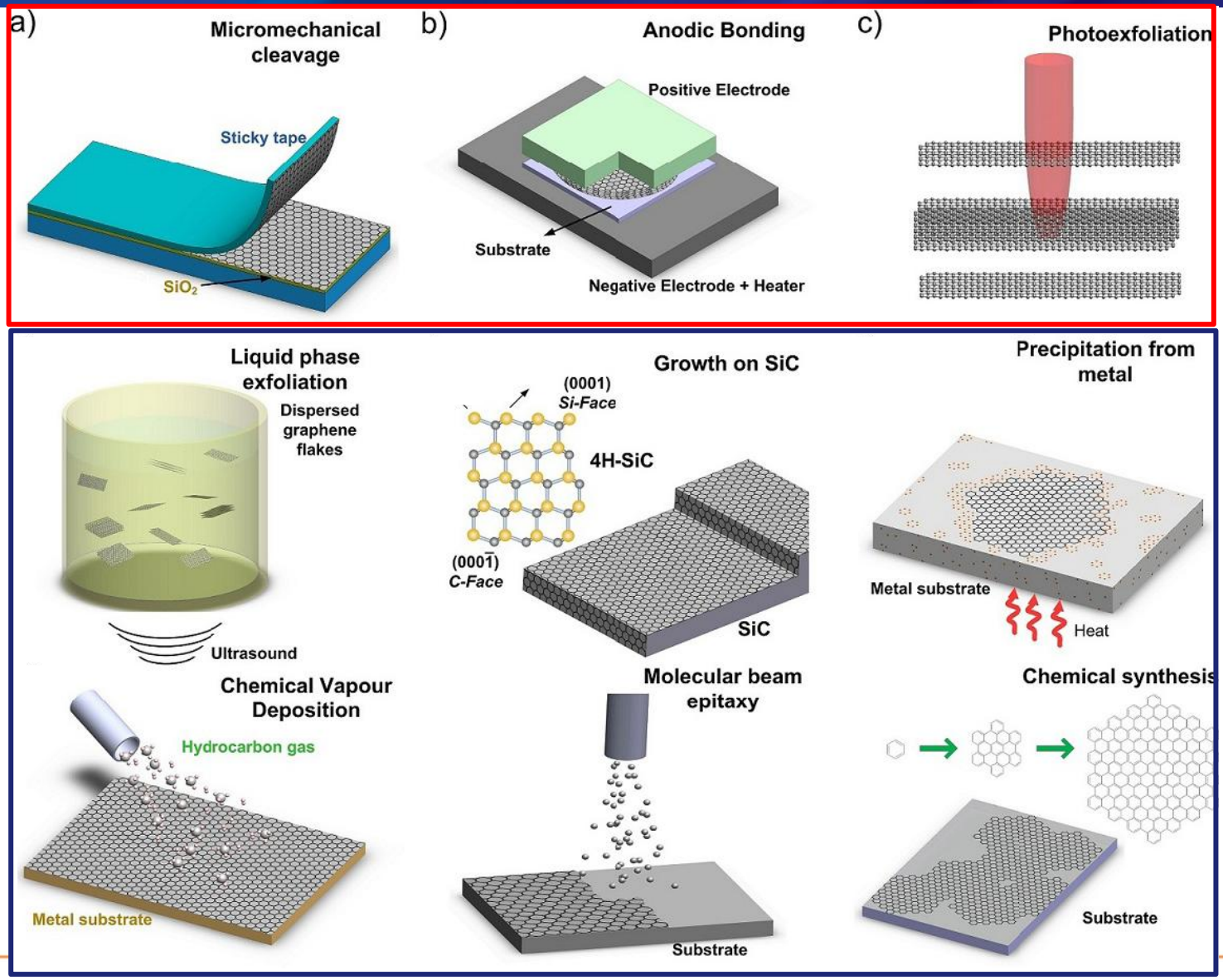


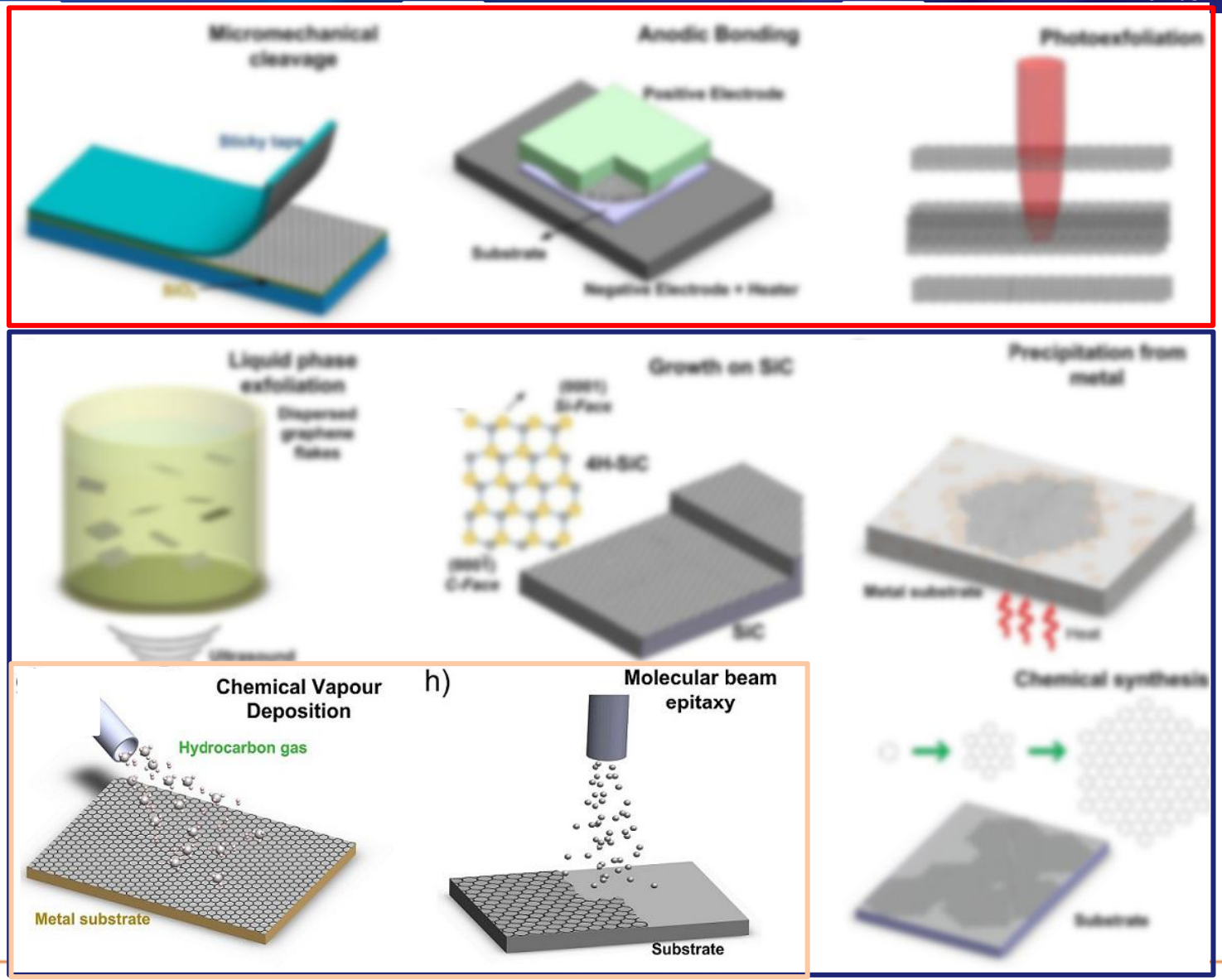






2d materials synthesis



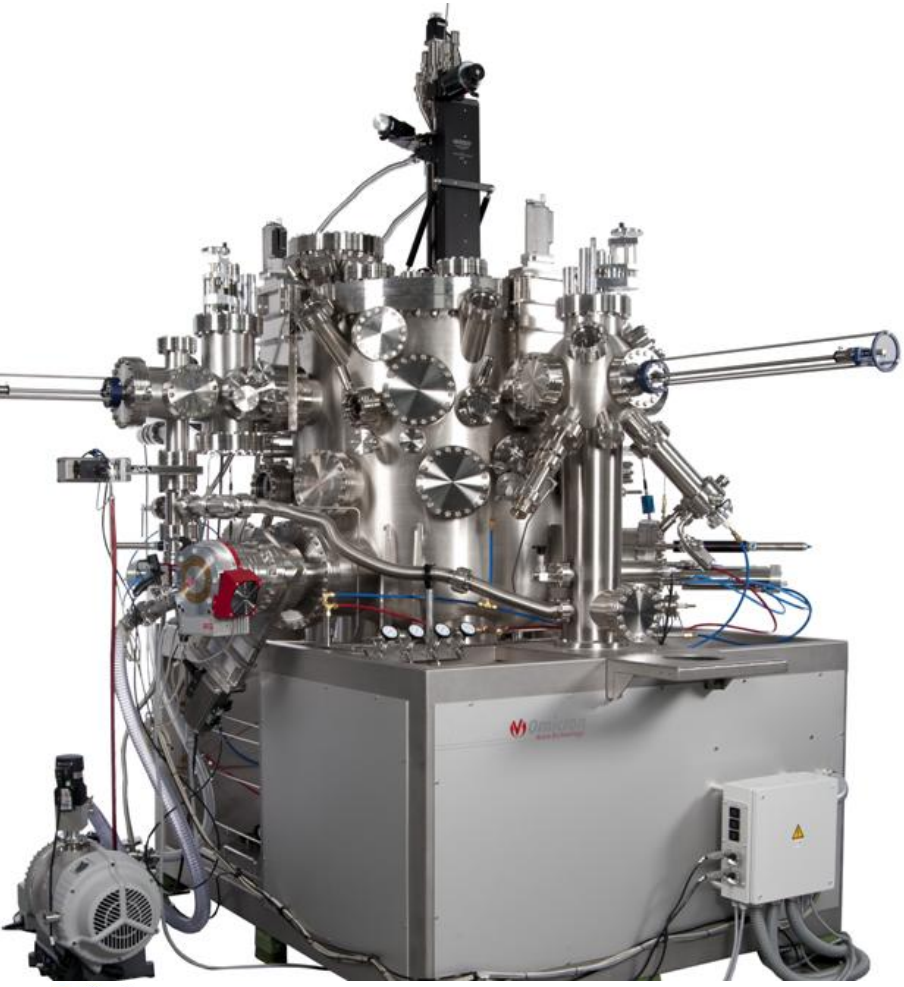


Solutions for fundamental research

MBE and Cluster tools

- **MBE - Wafer scale fabrication of Graphene based devices**

  Ö. Barbaros, NUS Singapore



- **Use of wafer-scaled Graphene in spintronics**
- **Magnetic devices based on spin transfer torque in graphene**
- **Most advanced UHV and source technology tailored to the application**

Combination of Growth and Analysis Systems

Omicron An Oxford Instruments Company

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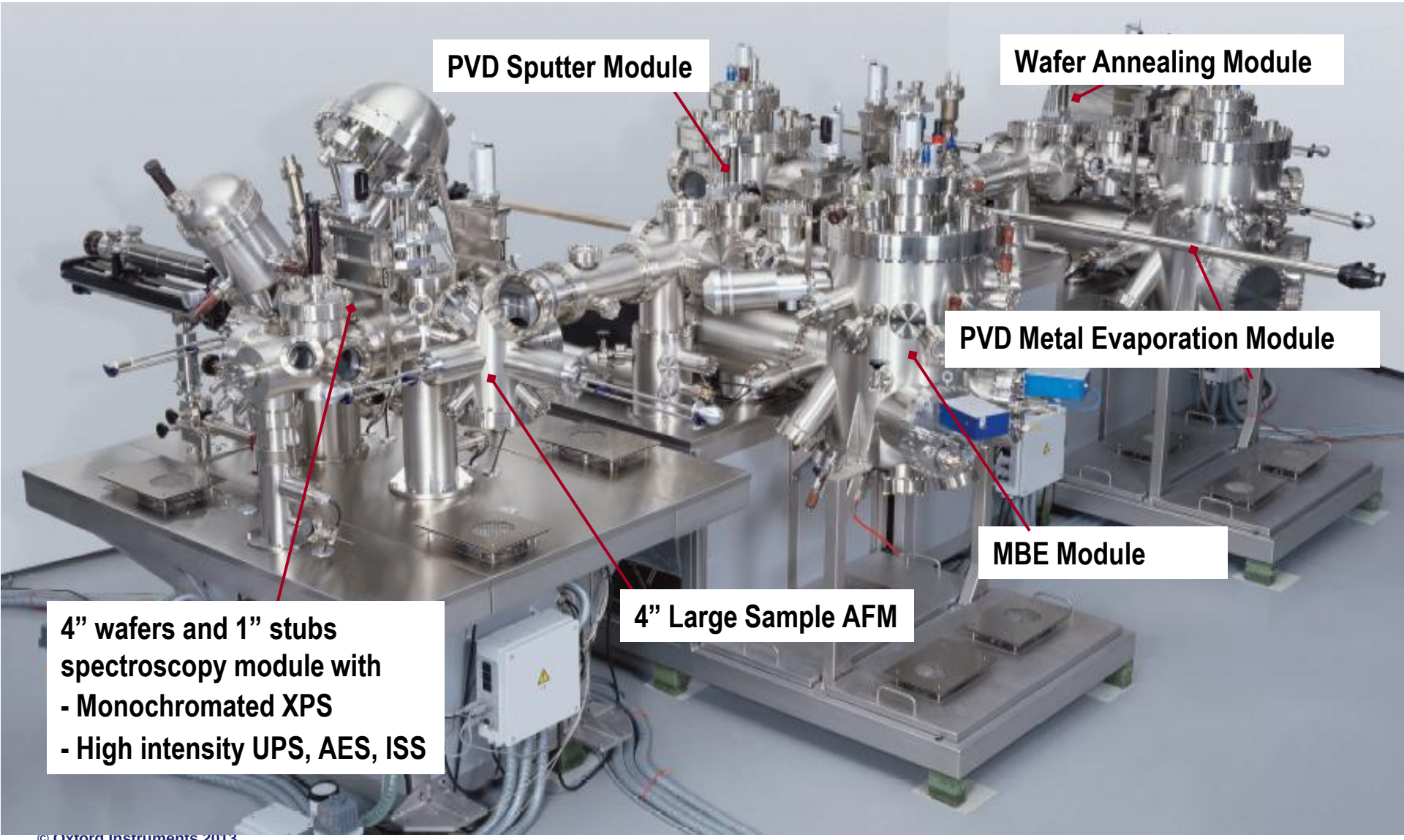
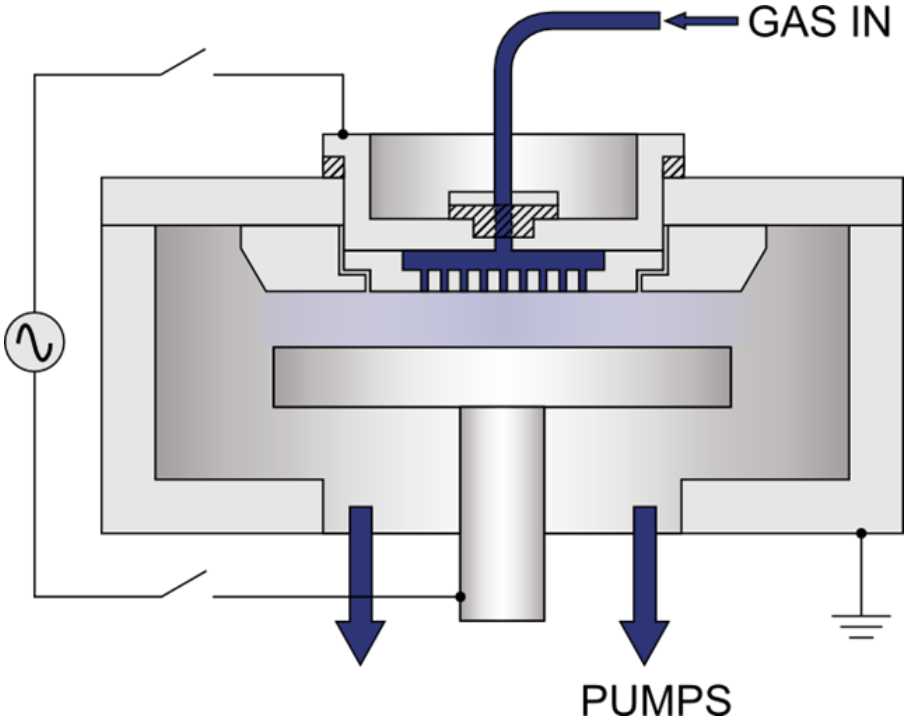


Applied Research and Pilot line tools

CVD,PECVD and ALD

Nanofab 100

- PECVD
  - 200 mm substrate, parallel plate configuration



Nanofab 100: A multi process tool

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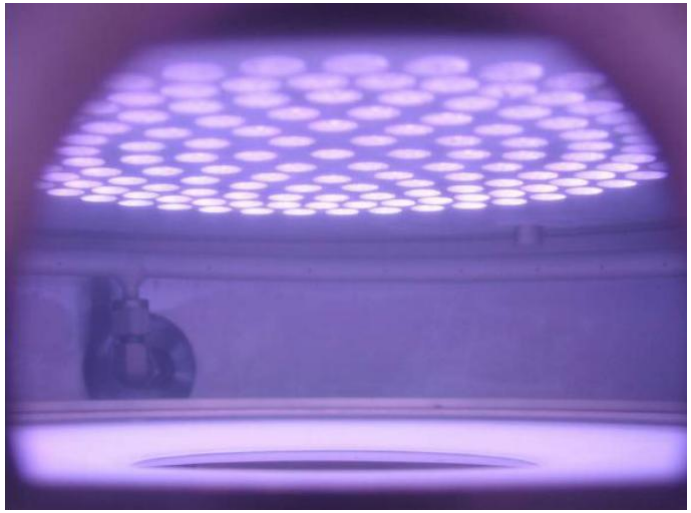
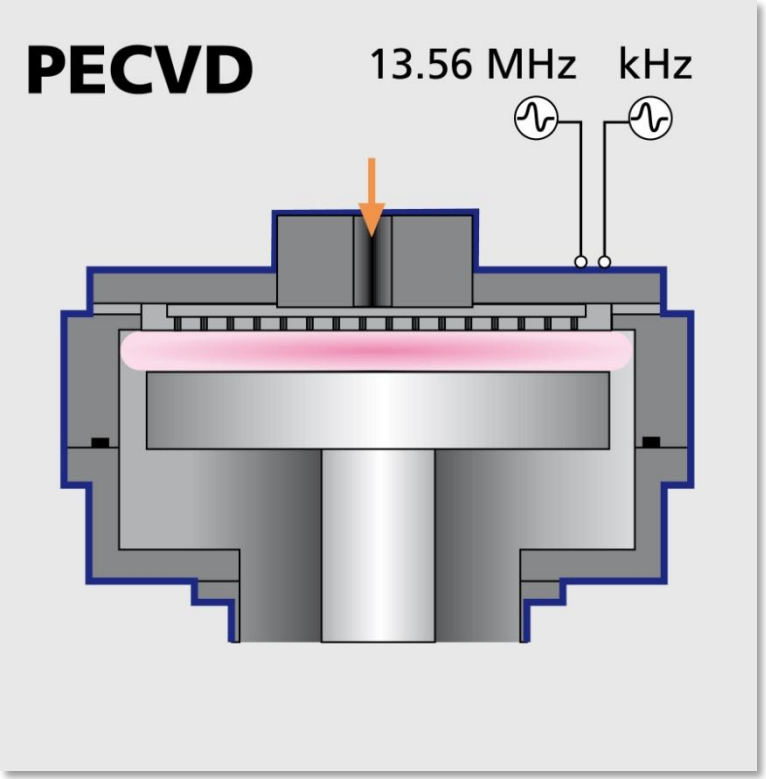
- PECVD/ CVD process, cold wall
- 400°C for silicon nanowires
- 700°C for multiwall carbon nanotubes, ZnO
- 800°C for single wall nanotubes
- 1000°C graphene
- External delivery module for liquid precursors



PECVD Hardware

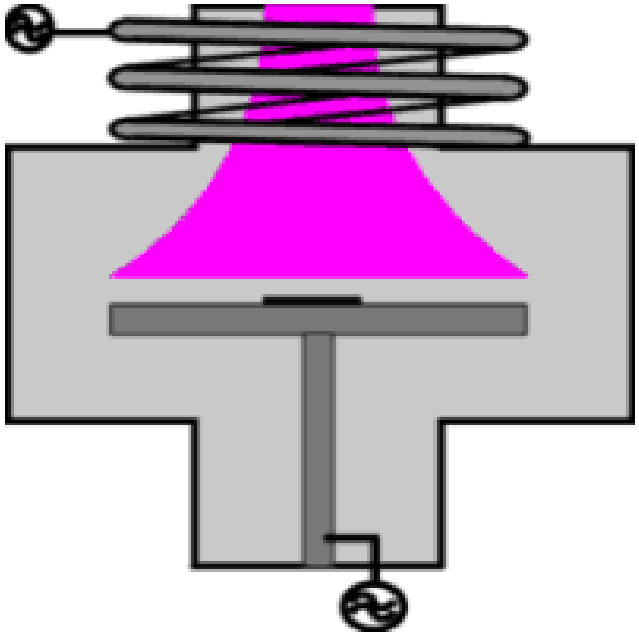
- Dual frequency 13.56MHz and 50KHz power applied to upper electrode enabling stress control and film densification
- Gas inlet and showerhead assembly designed for uniform gas flow and low particle generation
- View port and optical emission spectroscopy (OES) port



ICP remote plasma head

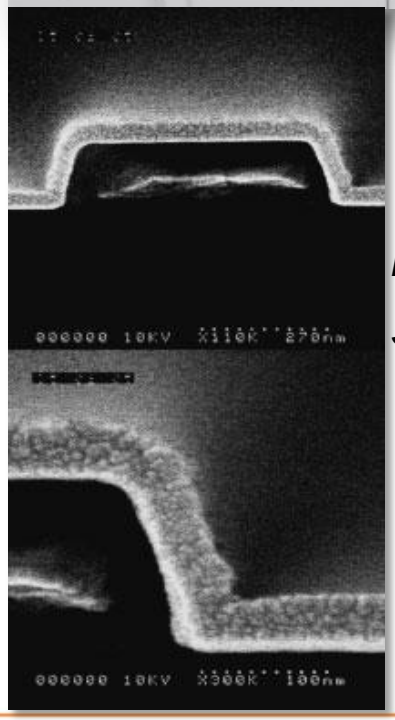
- High density films for much lower temperatures than PECVD.
- High density plasmas in low pressure range
- Low damage deposition on to temperature sensitive substrates
- Processes specifically developed to minimise surface ion damage

Inductively Coupled coil
(connected to 13.56MHz generator)



Cobra - High Density Plasma Source

- Active spacer for independent uniformity control and increased plasma density
- Optimised AMU which delivers greater efficiency, enhanced process repeatability and hardware reliability
- Easy striking (via matching unit control and/or electromagnet option)
- Low power operation (<200W) for low damage/nano applications
- Diagnostic ports available for OES, interferometry, and in-line RF diagnostics



Low Temp SiNx at 80ºC

Process Capability

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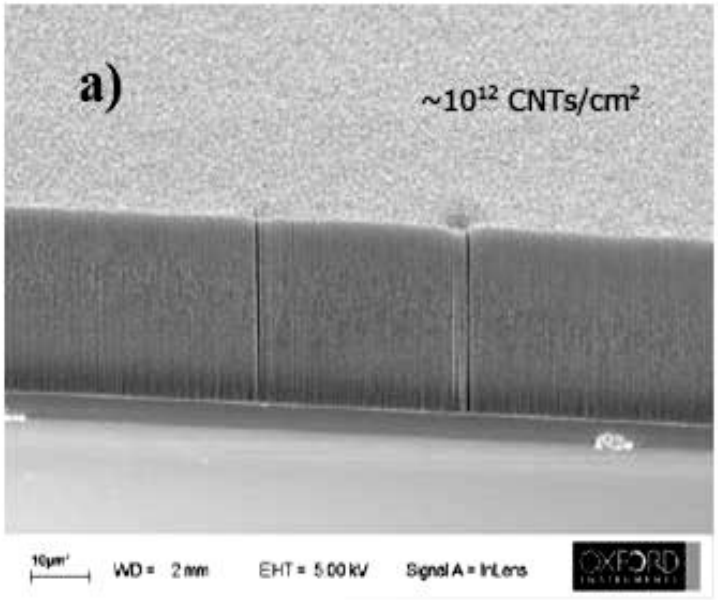
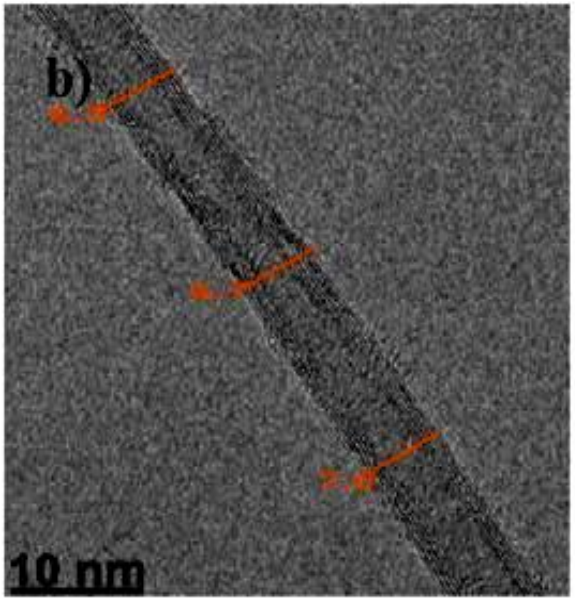
Process \ Tool	Nanofab 700	Nanofab 800 Agile	Nanofab 1000 Agile
Thin Film Process	SiO_x, SiN_x, *a*SiC, *a*Si, *µc*-Si, *poly*Si*	SiO_x, SiN_x, *a*SiC, *a*Si, *µc*-Si *poly*Si	SiO_x, SiN_x, *a*SiC, *a*Si, *µc*-Si, *poly*Si
1D Nano materials	MWNTs Si, Ge NWs ZnO NWs	MWNTs, SWNTs* Si, Ge NWs	MWNTs, SWNTs Si, Ge NWs
2D Nano materials		NCG, Vertical Graphene	NCG, Vertical, CVD Graphene, BN,* MoS_2*
O_2 compatibility (>400°C)	Compatible	Non- Compatible	Non- Compatible

* *Please contact OIPT for more detail on the marked material with the tool.*

Carbon Nanotubes





Results courtesy IMEC

- MWCNT growth on Fe/Ni

Dense Bush Carbon Nanotubes

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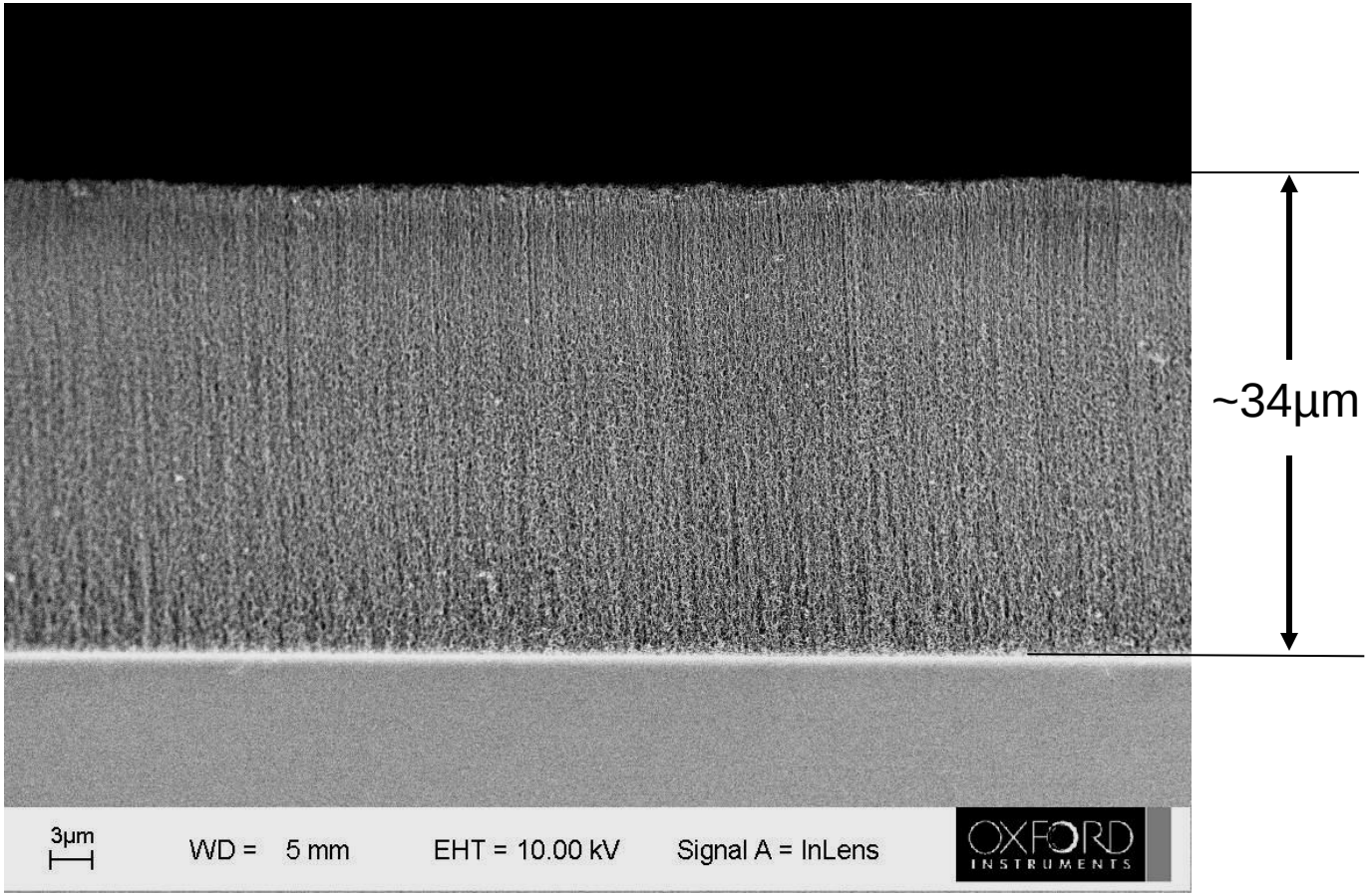


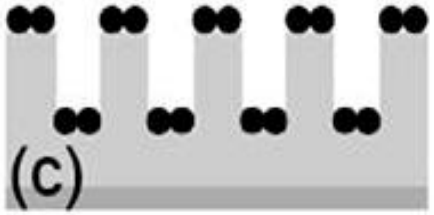
Carbon nanotubes

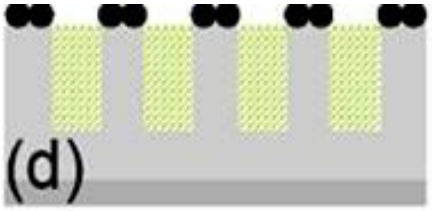
– process flow for via interconnect

Vias in Si

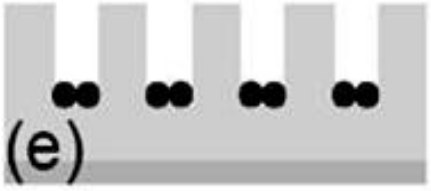
Thin film dep

Nanoparticle formation by annealing





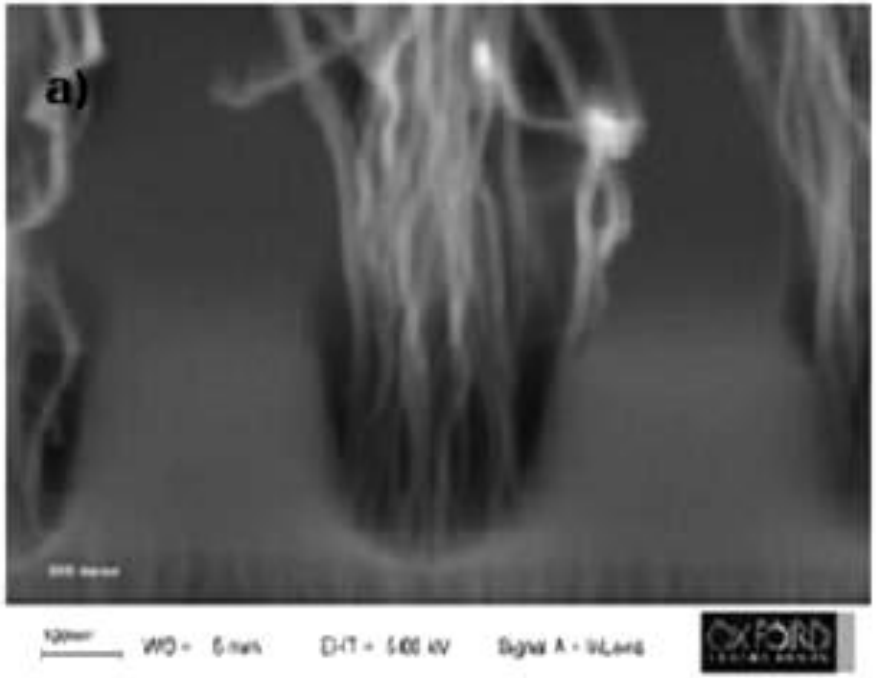
Protection of NPs in via

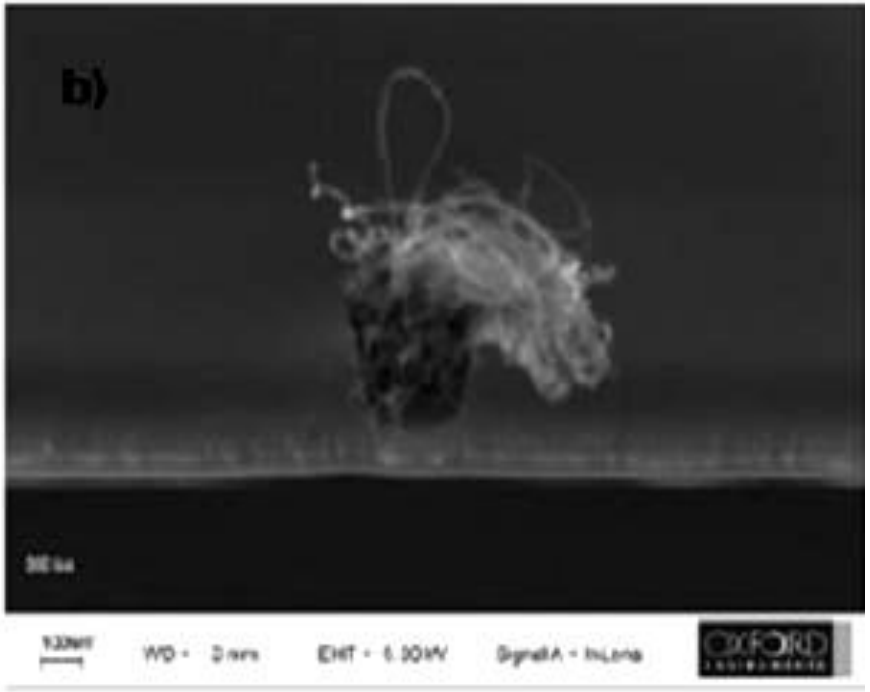


CMP

CVD growth of CNTs

Via interconnect CNT growth





ALD

Dielectric deposition for nanoelectronics

FlexAL-Atomic Layer Deposition Systems: Dielectrics deposition for 2d nanoelectronics

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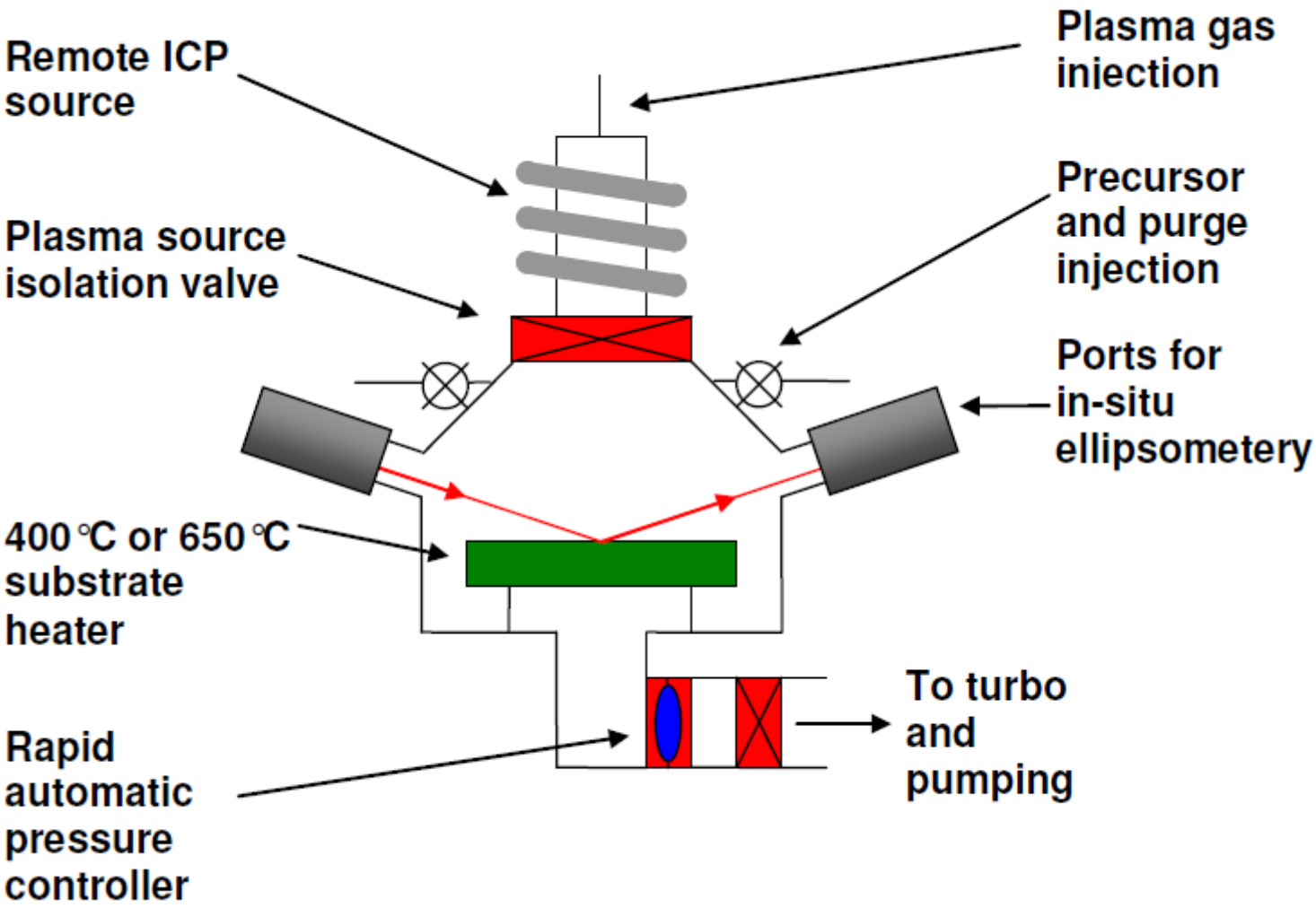
- Load lock System
- Extensive process capability
  - Precursor options for research (up to 100g) and production (up to 500g)
  - Up to 8 liquid/solid precursors (3+3+1+1)
  - Up to 10 gas precursors
  - Water as standard
  - Ozone as option
- Clusterable
- Optional turbo pump for moisture sensitive nitrides

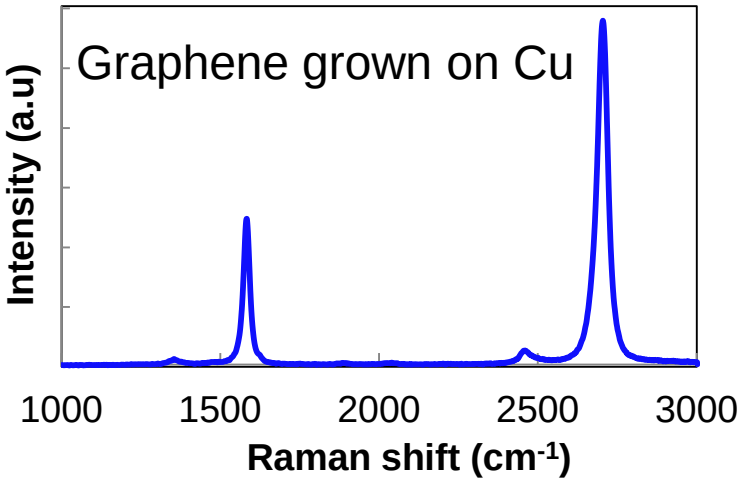
FlexAl in situ Analysis



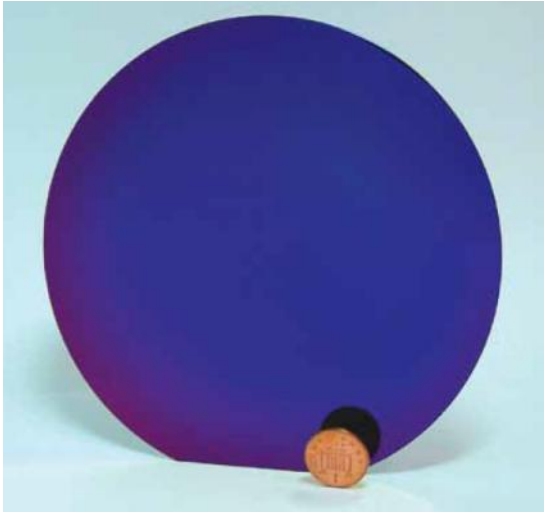
Graphene and other 2d Materials

Nanofab tools

Graphene Growth



- Nanofab™ 1000Agile
  - High performance growth of nanotubes & nanowires
  - PECVD and ICP options
  - Rigorous process control



NCG Film on 150mm Silicon Wafer

Marek E. Schmidt[1)], Cigang Xu[2)], Mike Cooke[2)], Hiroshi Mizuta[1)], and Harold M. H. Chong[1)]

[1] Nano Research Group, School of Electronics and Computer Science, University of Southampton, UK

[2] Oxford Instruments Plasma Technology, Bristol, UK

NCG Film on 150mm Silicon Wafer

Precursor Delivery: Towards other 2D materials

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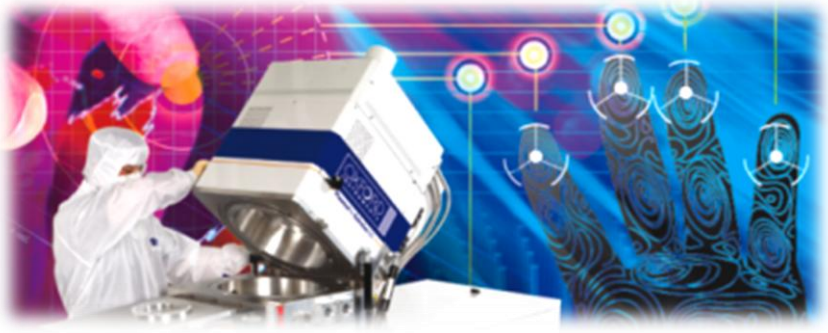
- OIPT already has proven capability for the growth of novel materials using liquid precursors
  - PECVD
  - ALD

- Combining these techniques could advance the fabrication of hetero-structures and commercial viable devices based upon 2D materials

Summary

- Need for reliable process tools
- Development in collaboration with end users
- Reliability and automation would be issues to look out for going from lab to fab
- 30+ years experience in providing a long term support to both research and production customers

Thank You!



OIPT: Shaping The Future

Using innovation to turn smart science into world class products