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Scaling Fabrication Methods from Micro to Nano

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Researchers need tools that will operate flexibly over many different length scales. The whole idea of nanotechnology is to unlock useful phenomena which only gain significance at length scales below 100 nm, so the tools used to manipulate matter at these scales must control dimensions with a precision ten to one hundred times smaller still. Oxford Instruments work in this field, and its customers benefit from the precision of their techniques.

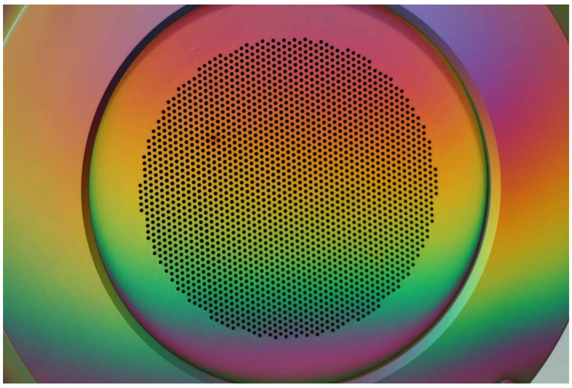

Fig. 1. Ion beam grids, shown coated with SiO_2.

In layer deposition, Oxford Instruments Plasma Technology (OIPT) offers one of the widest ranges of technologies:

- Magnetron sputtering or physical vapour deposition — PVD;
- Thermal chemical vapour deposition — CVD;
- Plasma enhanced chemical vapour deposition — PECVD;
- High density plasma CVD, using an induction coupled plasma — ICP-CVD;
- Ion beam deposition — IBD;
- Atomic layer deposition — ALD;
- Plasma enhanced ALD — PEALD.

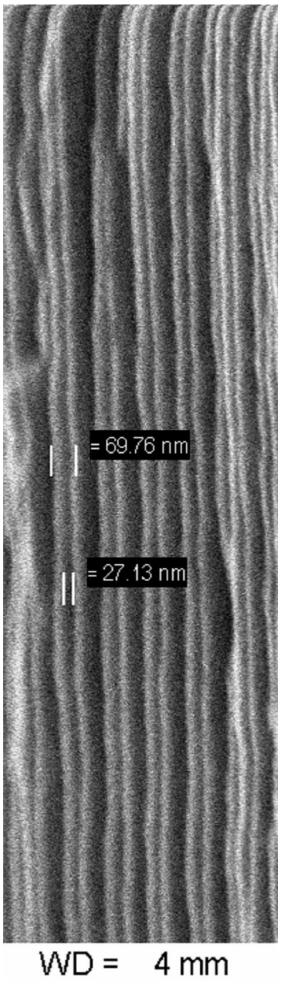

Fig. 2. ZnO nanowires, created by ALD into the pores of anodised aluminium.

These are distinguished by the deposition temperature, the source materials, and typical deposition rates. The techniques used at the smallest scales tend to be those with the lower deposition rates, for precision and at the lower temperatures, to maintain sharp interfaces between dissimilar materials. They also demand a lower level of background gas, to maintain material purity in the face of competition between wanted and unwanted species arriving at the surface. With every deposition process, there

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is also the need for a cleaning method to remove material; for example the ion beam grids (Fig. 1) become coated. Such material needs to adhere well to keep particle levels low during processing.

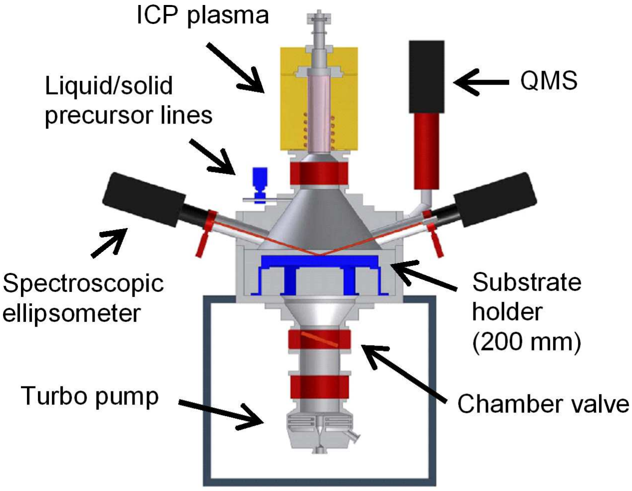

Fig. 3. PEALD chamber schematic.

It is noticeable in Table how plasma and high density induction coupled plasma drive the process temperatures down, getting similar material quality to thermally driven CVD processes but at substantially lower temperatures. Many of these techniques will be very familiar, but in Fig. 3 we show a recent introduction — plasma enhanced atomic layer deposition.

Atomic layer deposition is remarkably *conformal*: it maintains the same thickness on fully exposed top surfaces and on deeply re-entrant surfaces, unlike PVD and IBD, which are far more *directional*. It has been shown that anodised aluminium can be used as a template for atomic layer deposition, by filling the anodising pores with zinc oxide nanowires using ALD (Fig. 2). When the anodising is removed by a selective wet etch, extraordinarily thin, tall ZnO structures remain.

PEALD uses an ICP plasma adjacent to the wafer, but not strongly bombarding it with energetic particles — its use is as a rich source of reactive radicals. In keeping with the need for lower background gases in depositing the thinnest layers, OIPT fit a turbomolecular pump to their PEALD tools; the plasma source also gives the facility to perform light etching *in situ*.

TABLE

Typical parameters of the technologies used.

Method	Substrate temperature	Deposition rates [nm/min]	Typical applications and special features
PVD	20–300 °C	5–500	any materials with high melting point targets available; very versatile
CVD	400–800 °C	10–100	polycrystalline silicon, SiO_2 silicon nanowires, carbon nanotubes
PECVD	200–400 °C	5–500	best known for silicon nitride and oxide, many other processes available
ICP-CVD	50–150 °C	5–100	SiO_2 and silicon nitride materials equivalent to PECVD films, but deposited much cooler
IBD	50–200 °C	1–10	high precision thin layers, optical coatings. Reactive deposition of oxides and nitrides from metal targets.
ALD	100–300 °C	0.1–3	cyclical exposure to chemical gases which produce self-limiting surface reactions. Many oxide materials
PEALD	50–300 °C	0.1–3	as ALD, but uses plasma instead of water vapour