DPF for Material Processing

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Outline of Presentation

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1. Plasma Nanotechnology

Plasma Nanotechnology

Nanotechnology:

- Manipulation of matter with size of nanometers to create materials.
- Synthesis is the most active areas of research.

Plasma nanotechnology:

- Utilizes plasma to synthesize materials.
- Plasma Based and plasma-assisted process provide a complex, reactive and far from equilibrium chemical factory.

Classification of Plasmas in Plasma Nanotechnology

- low temperature (cold) plasmas which are used by industry and material research community
- high temperature (hot) high energy density plasmas from fusion, pinch and intense discharge sources with densities and temperatures many orders of magnitude higher than that of cold plasmas

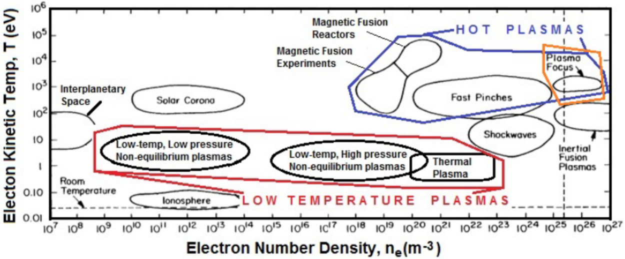

Figure 1: The plasma parameters of various types of plasmas. The low temperature plasmas routinely used in plasma nanotechnology are inside the red box while the high energy density DPF source is shown orange and blue box which belong to the category of hot plasmas. [7]

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Low Temperature (Cold) Plasmas for Plasma Nanotechnology

- Mainly produced by ac or dc electric gas discharge or by gas discharges initiated by RF or microwave electromagnetic fields.
- Electron kinetic temperature: fractions to few tens of eV with low degree of gas ionization.

The non-equilibrium plasmas are formed when either

- The low operating pressure results in insufficient collisions between electrons and ions and neutrals
- Or high operating pressure having higher collision rates but the plasmas are short lived interrupting the equilibration process.

The thermal plasmas are

- The plasmas in thermal equilibrium where the frequent collision between the electrons and ions and neutrals results in equilibration of temperatures among the charged and neutral species.

High Energy Density High Temperature (Hot) Plasmas for Plasma Nanotechnology

- Have temperatures from few to several keV.
- Almost fully-ionized.
- DPF device is able to make such plasmas.

DPF: Device Layout, Plasma Dynamics and Key Features

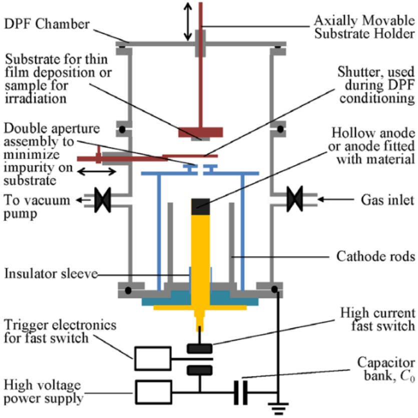

Figure 2: The schematic of DPF material processing/synthesis facility with its various subsystems. [7]

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Top-down and Bottom-up Nanoscale Fabrications using DPF devices.

- Bottom-up: Creates nanoscale materials from assembling atoms and molecule.
- Top-down: Relies on the successive fragmentations or processing of macro-scale materials to smaller nano-sized objects.

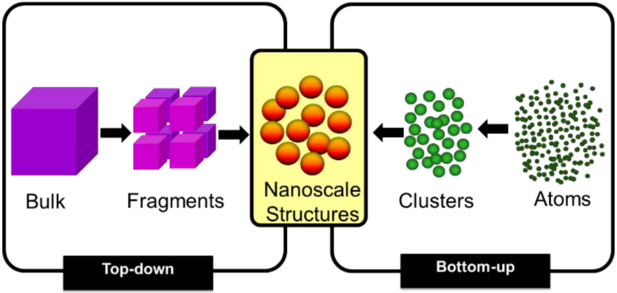

Figure 3: "Top-down" and "bottom-up" synthesis of nanofabrication.

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Top-down Nanoscale Fabrication by Transient Processing of Bulk/Thin Films in DPF

- Involves the exposure of bulk or thin film samples to the different number of DPF shots.
- Nanostructurization of the entire thickness of the thin film can be achieved by its exposure to DPF shots.
- For bulk material only the top surface layer of the bulk sample is processed and nanostructurized by its exposure to DPF shots.

SEM Images of Unexposed and Irradiated Ti and W samples in Different DPF Devices

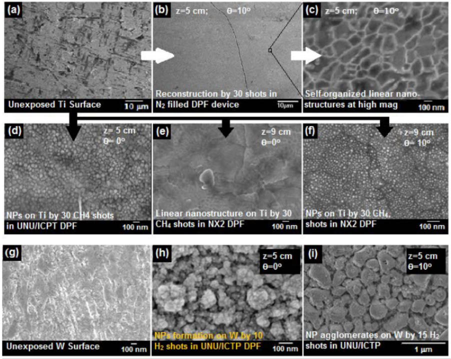

Figure 4: SEM images of unexposed and irradiated Ti and W samples in different DPF devices. The distance (z) and angular position (θ) of the samples, number of DPF irradiation shots and DPF operating gas for each of the exposure experiment are mentioned in SEM images. [7]

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Combined Schematic of DPF Device

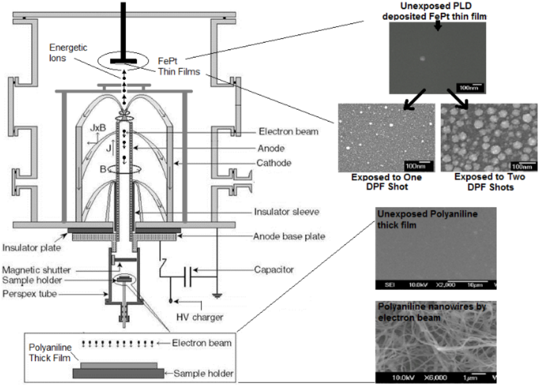

Figure 5: The combined schematic of DPF device showing the exposure of FePt thin film to energetic ions in UNU/ICTP device in Singapore and PA thick film to energetic electrons in another DPF device in Guwahati, India. The images on the right show the changes in surface morphology to nanoparticles and nanowires after DPF exposure. [7]

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Mechanism of Nano-structuring

1. Most of the H+ ions stop and deposit bulk of their energy in silicon substrate at the Bragg peak position as the thickness of FePt thin films was only about 67 or 100 nm.
2. This results in heating of silicon substrate to very high temperature in a very short span of time.
3. The thermal energy is then conducted to the FePt thin films and causes the diffusion of metal atoms either through the lattice or along grain boundaries.
4. The diffusion releases the thermal expansion mismatch stresses between the silicon oxide layer of the silicon substrate surface and the PLD coated FePt thin film.

Bottom-up Nanoscale Fabrication in DPF

- The spherical nanoparticles (NPs) seen in Fig.6 (a-d) are the examples of 0-dim nanostructures synthesize in DPF devices.
- While NPs are visibly present over the entire substrate surface in Fig.6 (a and b), they are also present as the background in Fig.6 (c and d).
- Once background carpet of 0-dim NPs is formed on the substrate surface then higher dimensional nanostructures can grow on this NP carpet.

Synthesis of 0-, 1-, 2-, and 3-dimensional Nanostructures using DPF Device.

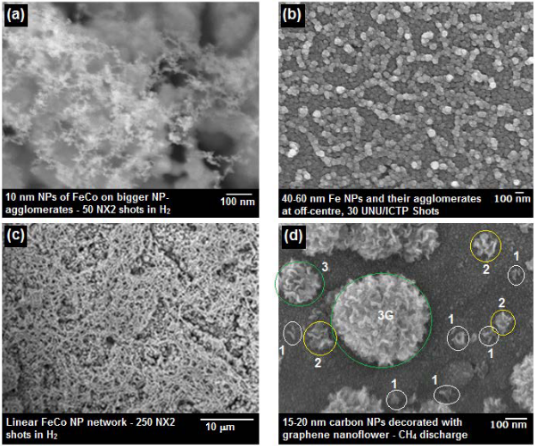

Figure 6: Synthesis of 0-, 1-, 2- and 3- dimensional nanostructures using DPF devices. [7]

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