Characterization of a supersonic plasma source for nanostructured thin film deposition

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Introduction

Nanostructured thin films
PIUMA reactor
Research and experiments

Thin films:
- High surface to volume ratio
- Different properties from bulk material
- Applications in microelectronic devices, resistant coating, photovoltaic, sensors, catalysts... and much more

Nanoparticles:
- Building units of thin films
- Can produce films with different morphology or stoichiometry
- No techniques for mass production and assembly
Introduction

**Plasma Induttivo Supersonico per Materiali Avanzati**

**Plasma chamber:**
- Inductively Coupled Plasma (Ar and O₂)
- Precursor dissociation

**Deposition chamber:**
- Supersonic jet expansion
- TiO₂ deposition
Introduction

- Nanostructured thin films
- PIUMA reactor
- Research and experiments

Mass spectrometer: RGA analysis of neutrals, ions at different positions

Characterization of chemical species along the jet
Radiative emission from bound electrons:
• Identification of excited atoms and molecules
• Line intensities due to collision and radiative transitions can be related to $T_e$ and $n_e$
Theory: Supersonic expansion

\[ M(z) = A \left( \frac{z - z_1}{D} \right)^{\gamma - 1} - \frac{1}{2} \frac{\left( \frac{\gamma + 1}{\gamma - 1} \right)}{A \left( \frac{z - z_1}{D} \right)^{\gamma - 1}} \]

\[ \frac{P(z)}{P_p} = A^{-2/(\gamma - 1)} \left( \frac{\gamma + 1}{\gamma - 1} \right)^{\gamma/(\gamma - 1)} \left( \frac{\gamma + 1}{2\gamma} \right)^{1/(\gamma - 1)} \left( \frac{z - z_2}{D} \right)^{-2} \]

\[ D = \text{nozzle diameter} \]
\[ R = \text{pressure ratio} \]
\[ z_M = 0.67D\sqrt{R} \]
\[ D_M = D \left( 0.36R^{0.6} - 0.59 \right) \]
\[ \theta_M = 5.3R^{0.6} \]

D = 4.9 mm  2 < R < 40
4.5 mm < Z_M < 21 mm

First results

- Gas
- Plasma
- Precursor

Ar and O₂ measurements at different pressure ratios

- Supersonic expansion theory valid until the shock position for each trend
First results

- Gas
- Plasma
- Precursor
First results

Introduction of organic precursor:
- Dissociation in the plasma chamber
- Fragments acceleration along the supersonic jet
First results

- Gas
- Plasma
- Precursor

Graphs showing the ratios of different species as a function of Z (mm).
First results

Deep characterization of the plasma source has been performed...

...Still much work to do:

• More data acquisition with the mass spectrometer varying different parameters (O$_2$ concentration inside the plasma chamber, TTIP stagnation time inside the chamber, radical analysis)
• Probe measurements along the supersonic jet
• Study of the morphology and the chemical composition of the nanostructured films
Work in progress

Ion Energy Distribution functions:

- Well defined double peak
- Variations along the supersonic expansion

Which mechanisms characterize the energy of the ions?
Work in progress

- IED simulation
- Depositions

Z = 5 mm

Z = 10 mm

Z = 15 mm

Z = 20 mm
Work in progress

Dye-sensitized meso-porous TiO$_2$ film as an electron transporting layer:

• Nanostructured TiO$_2$ morphology can raise electron conduction and cell efficiency
• How important is thin film thickness?