**3° International Conference on Frontiers of Plasma Physics and Technology**

# Trends in plasma applications

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# Plasma processing

## Trends towards atmospheric pressure:

- Most industrial processes are performed in open air or at atmospheric pressure.
- Many materials do not like to be exposed to vacuum.
- Processes are integrated in a chain with an almost continuos feeding of the materials to be treated.

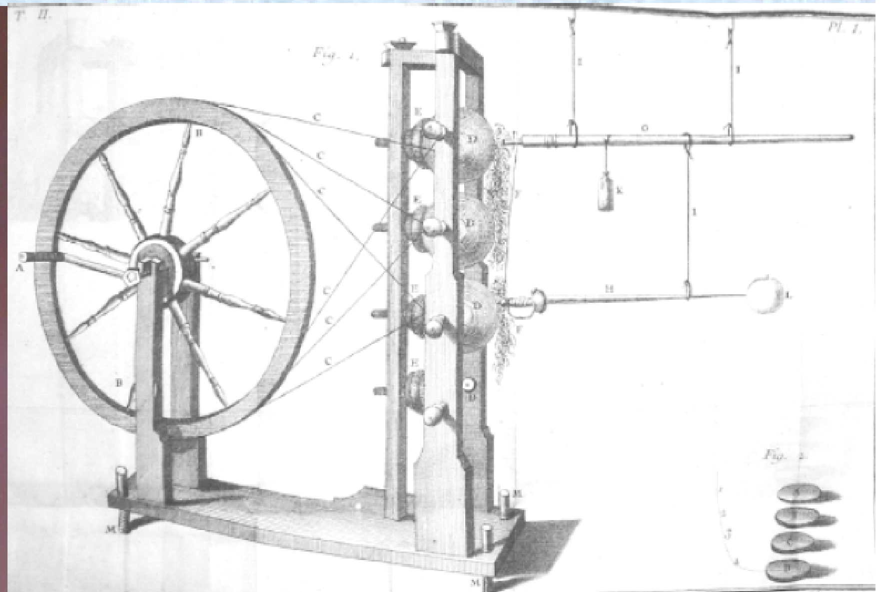
**So atmospheric plasma are more compatible with existing industrial processes**

**Moreover:**

- processes are faster (higher density of neutral radicals, if not ions)
- easily scalable to large areas
- processing region is well confined

# Atmospheric pressure plasmas in nature

***On earth: lightning, thunderbolt (storms, volcano eruptions)***



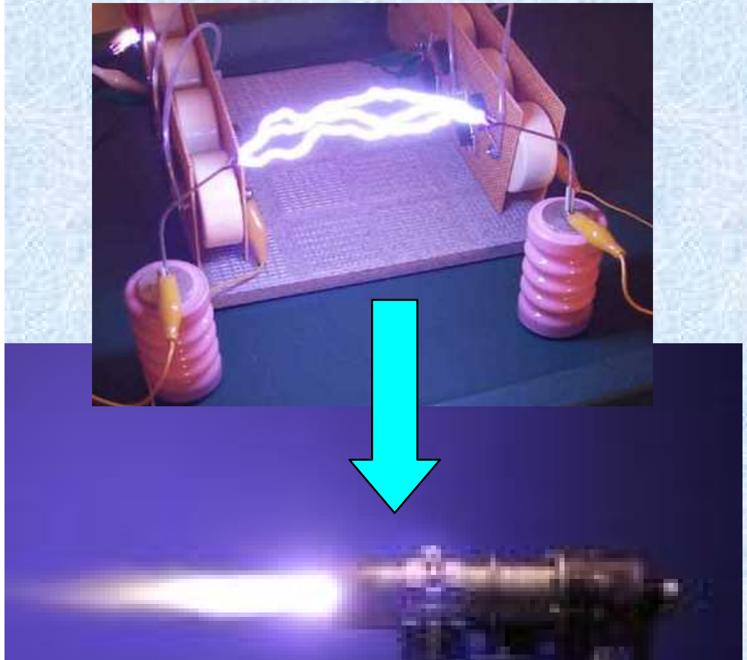
**Mankind activity:**
***Electrical discharges***
***B.Franklin (1747)***

# Atmospheric pressure plasmas in laboratory

**Arc discharge:**

***thermal plasma***

*($T_{gas}$~$T_e$~5-10000 K)*

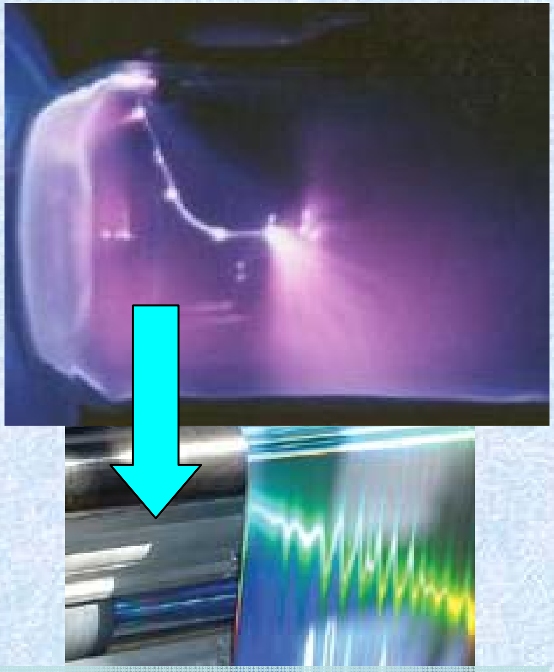


**Applications: plasma torch**

***waste, coatings, cutting***

**Corona discharge:**

***cold diffuse plasma***



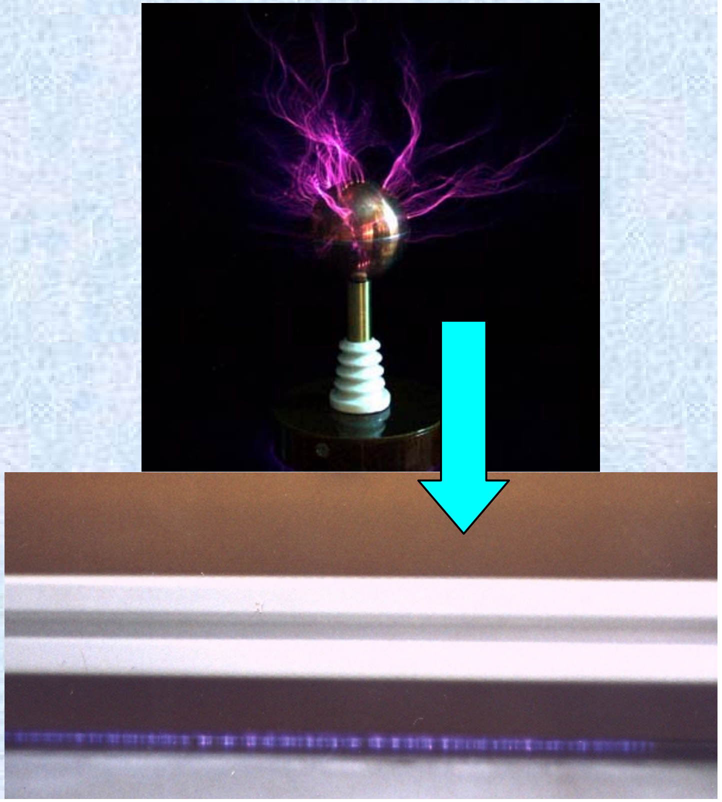
**Corona treatment:**

***Adhesion, painting***

**micro-discharges:**

***intermittent plasma***

*(streamers)*

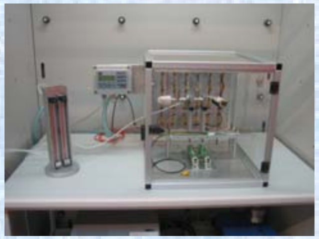


# Laboratory and experimental setup

## PlasmaPrometeo Center (2004)

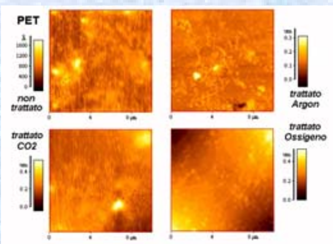
### Plasma sources and diagnostics

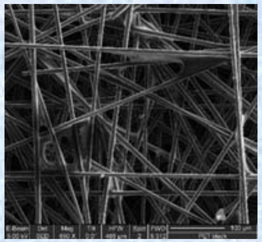
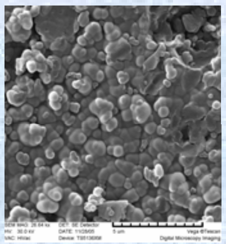




### Surface Diagnostics:

***AFM, FIB/SEM , FT-IR***



## Controlled gas-phase DBD reactor

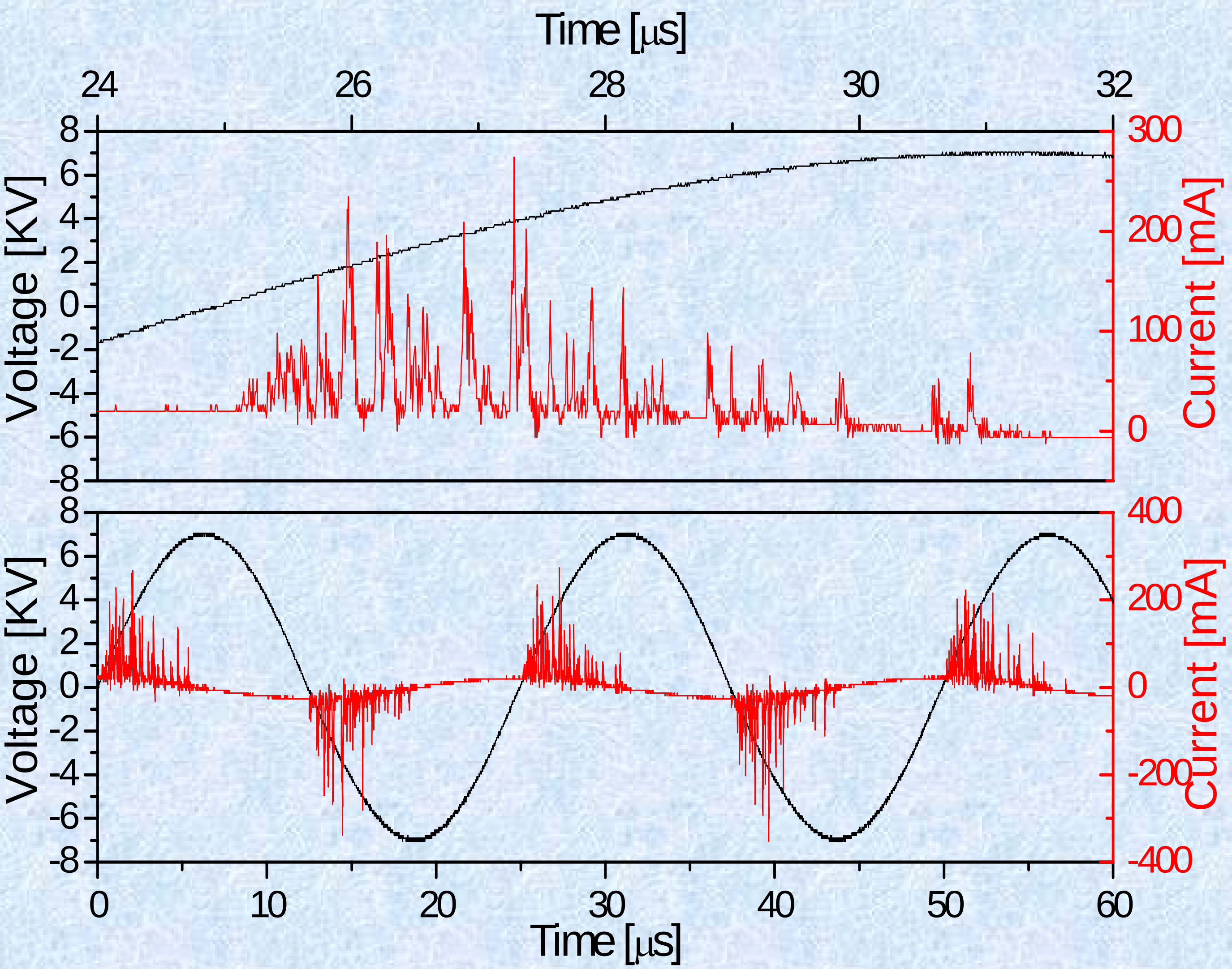
***Evacuated chamber***

# Diagnostics

## Electrical characteristics:

**Voltage across the gap:**
*HV probes, large bandwidth*
*(PS-6015A, 75 MHz)*

**microdischarge current**
***Large bandwidth,***
***high sensitivity***
*(home-made Rogoski coils)*

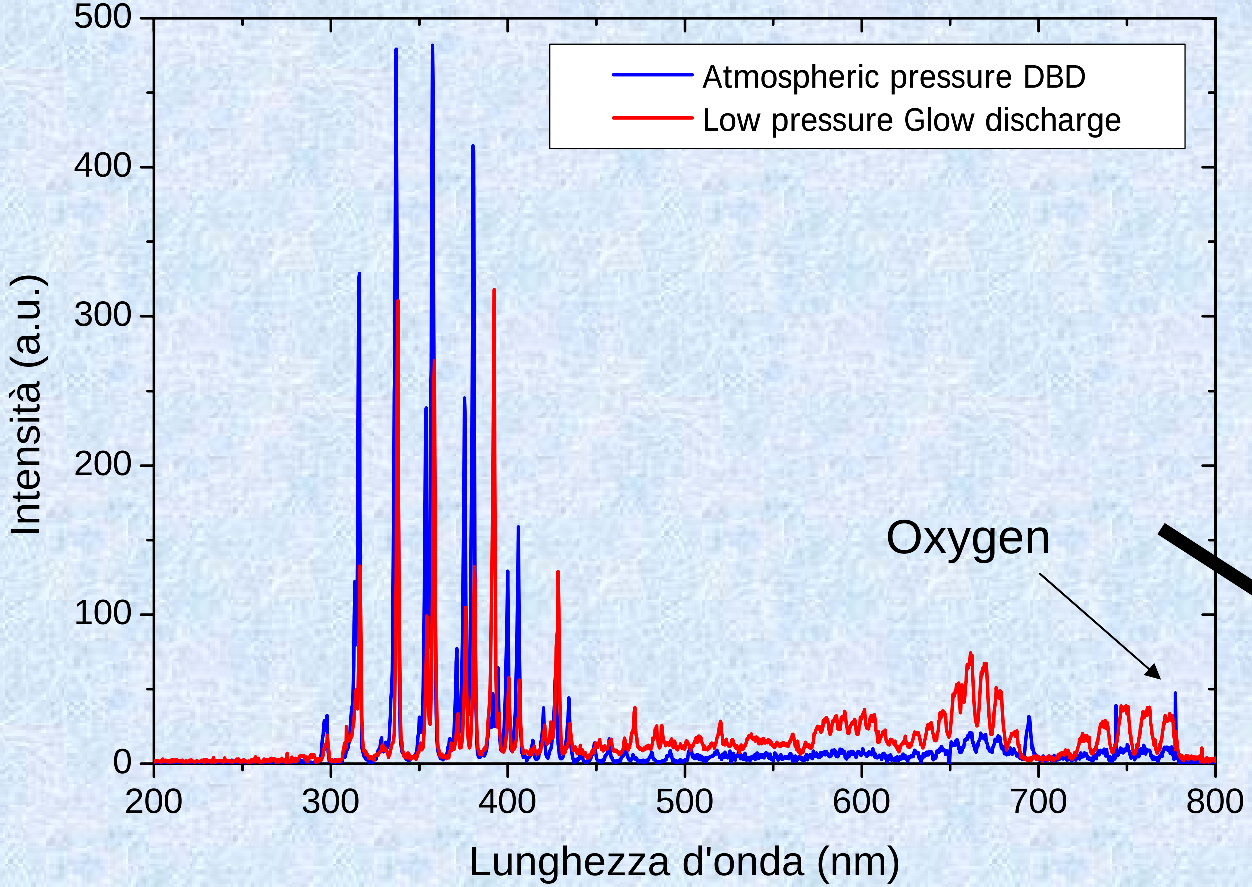


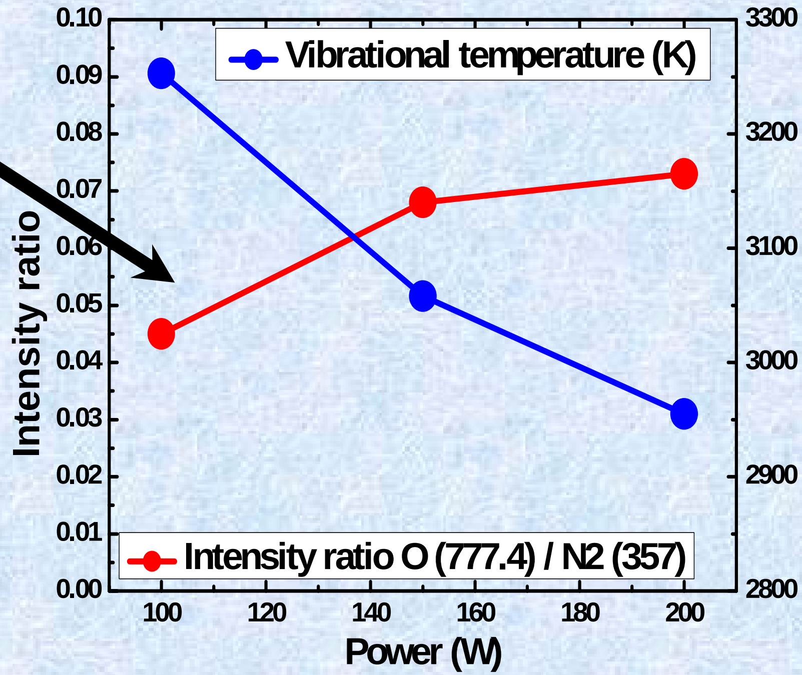
# Diagnostics

## Optical tecniques:

**Emission spectra**
*radical identification*

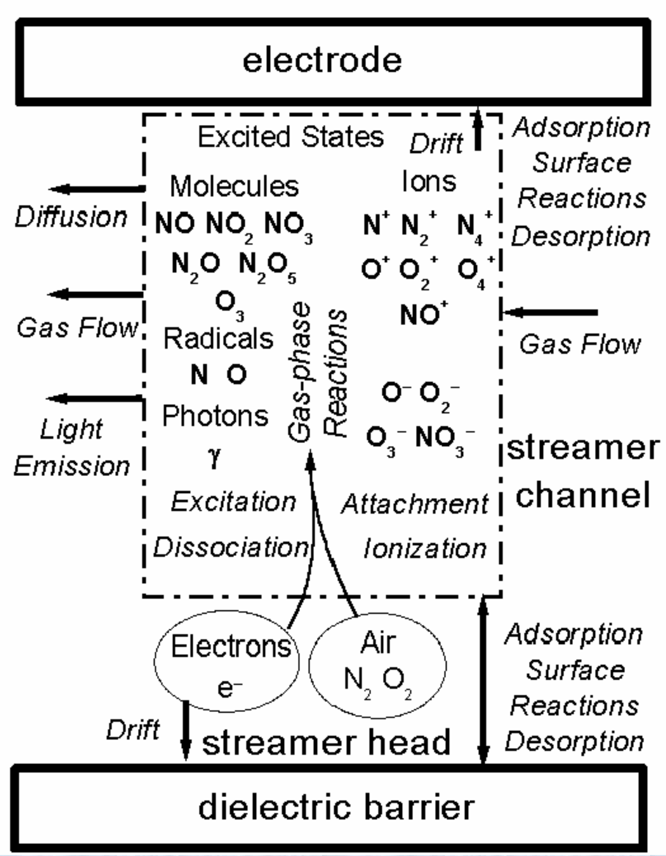
**Advanced tools**
*LIF, Stark, fast cameras*



# Modeling

## Chemical kinetics of the gas-phase in a microdischarge




## Chemical reactor model

- **cylindrical** channel ($R_s$, L)
- **radial** diffusion
- longitudinal **uniform** (n, T)
- slow flowrate -> mixing along the channel (**well-mixed reactor**)

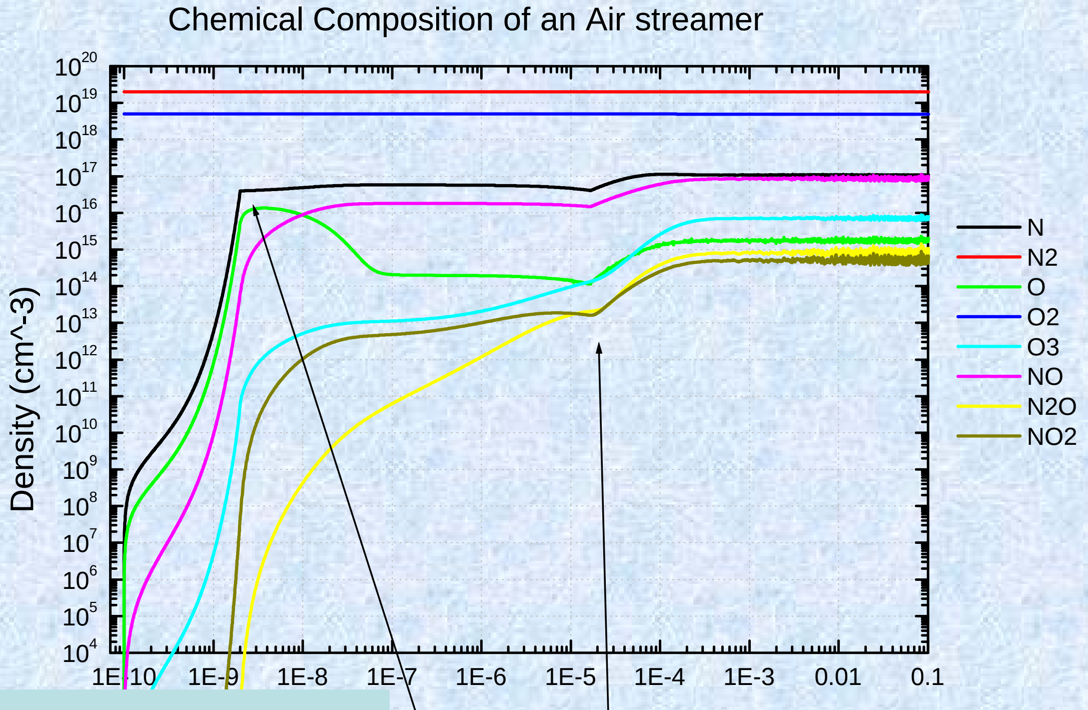
## Density balance equations

- 22 species (10 neutral, 12 ions)
- 194 reactions rates
- 15 wall recombination processes

$$\frac{dn_k}{dt} = \sum_{i,j} K_{i+j\to k} \cdot n_i \, n_j - \sum_{i,j} K_{i+k\to j} \cdot n_i \, n_k - \frac{D_k}{\Lambda^2} \cdot n_k + \sum_i \frac{D_i}{\Lambda^2} \cdot (1-S_i) \cdot B_{i(w)\to k} n_i$$

# Modeling

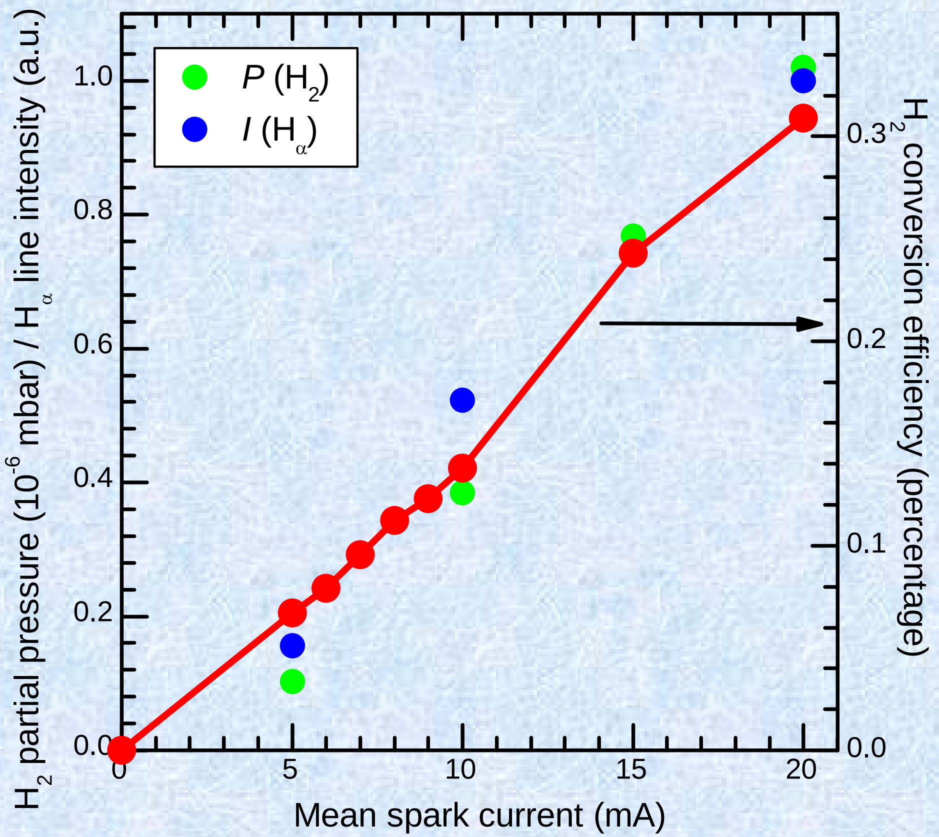
## Chemical kinetics of a dbd in air
*(streamer regime)*




Streamer development

Repetition rate
$\nu = 2\ \nu_{AC}$

## Chemical kinetics of a spark discharge in Ar/CH4

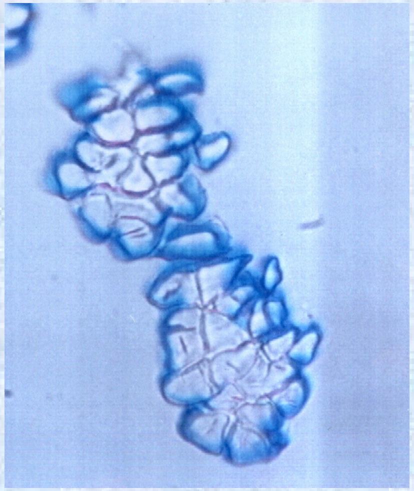


# Applications:

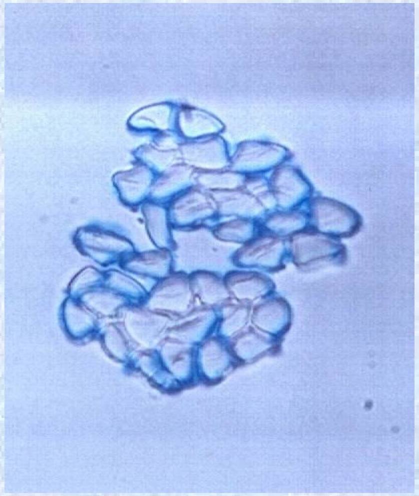
**Silk:** technology goal → remove sericin

**Process:** selective removal → pure fibroin fibres

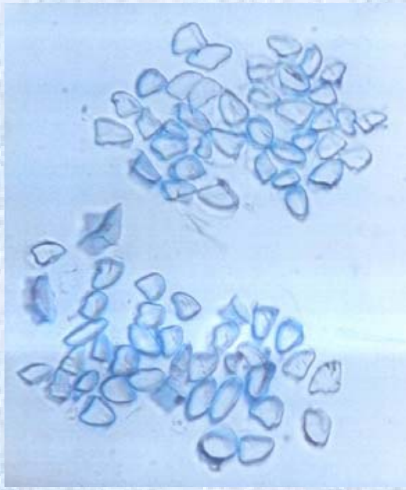
**Plasma:** etching $O_2$ → remove / crack sericin



Untreated



Plasma treated



Chemical degumming

# Applications:

**Leathers:** technology goal → obtain printability

**Process:** modify wettability → dye fixed on surface

**Plasma:** dbd in air / helium → -OH,-COOH grafting

Untreated

Plasma treated

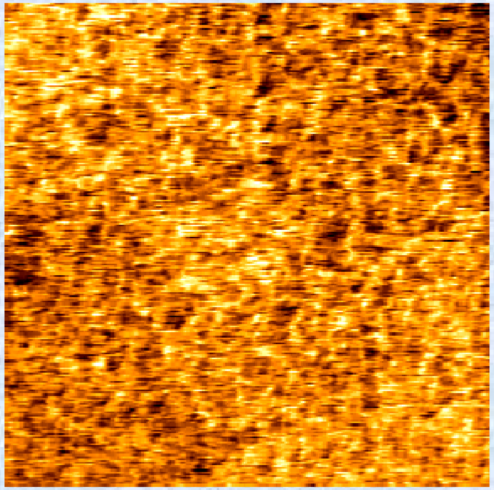
Photographic film

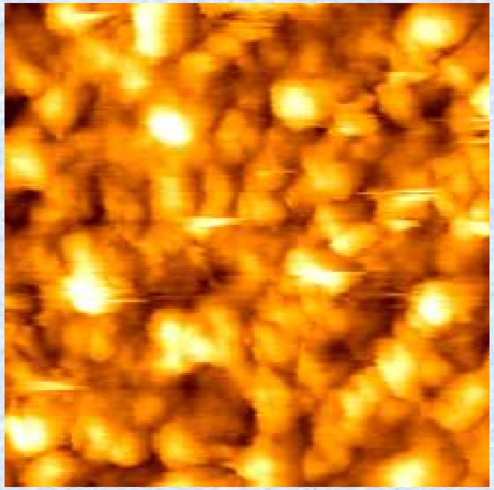
# Applications:

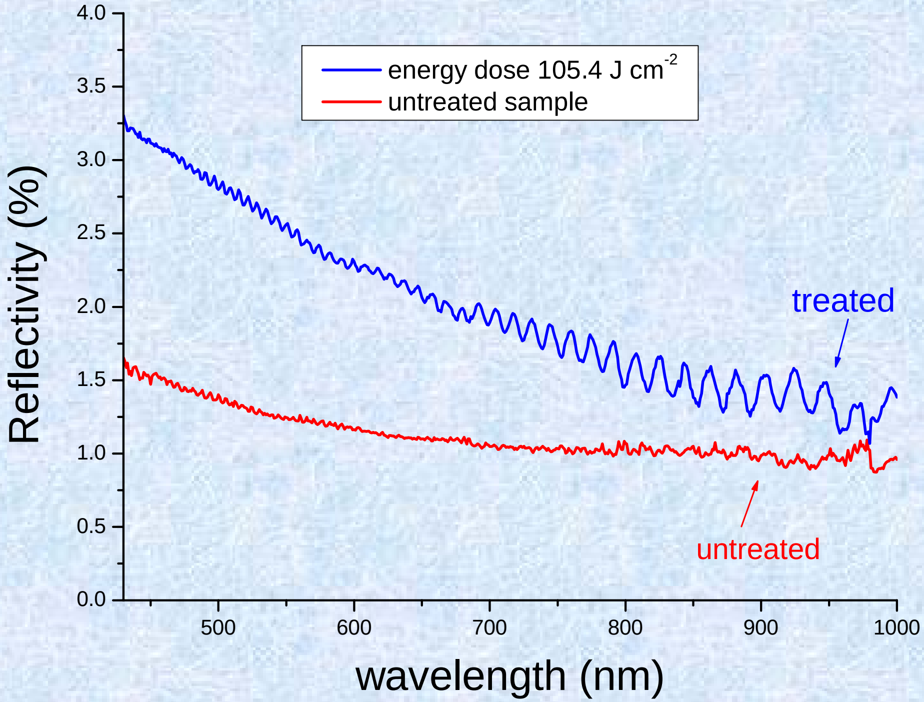
**PET films:** technology goal → optical properties

**Process:** modify roughness → reflectivity changes

**Plasma:** dbd in air → surface etching


Untreated


Plasma treated

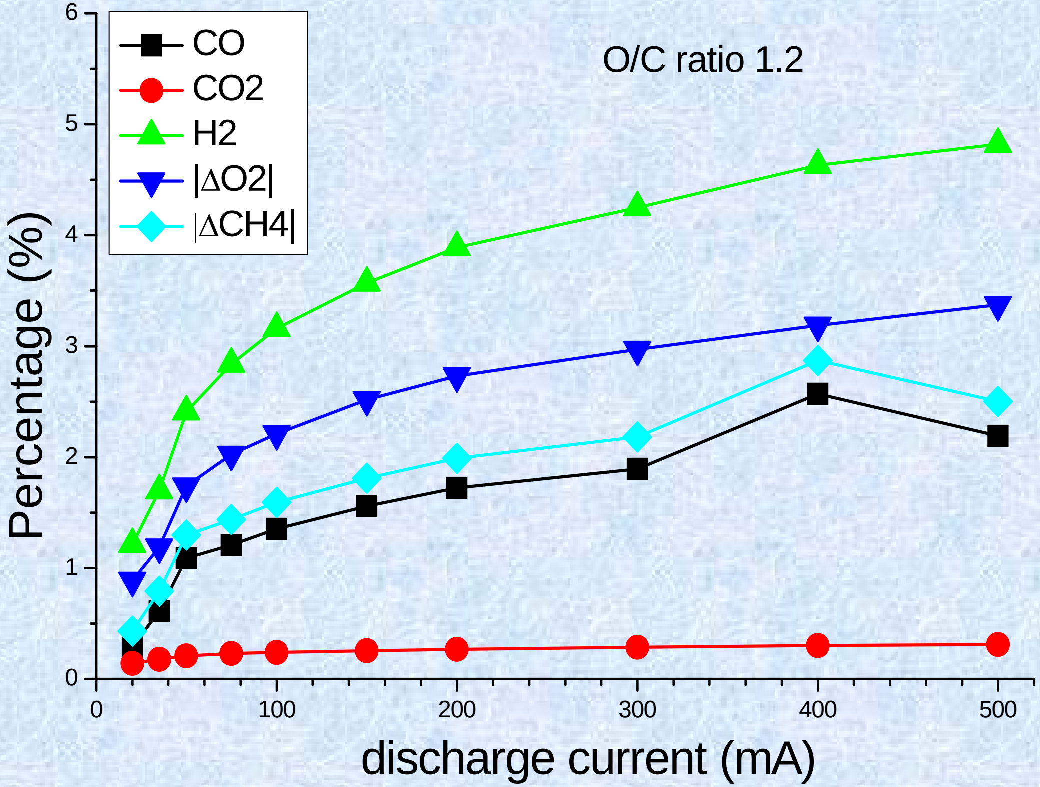


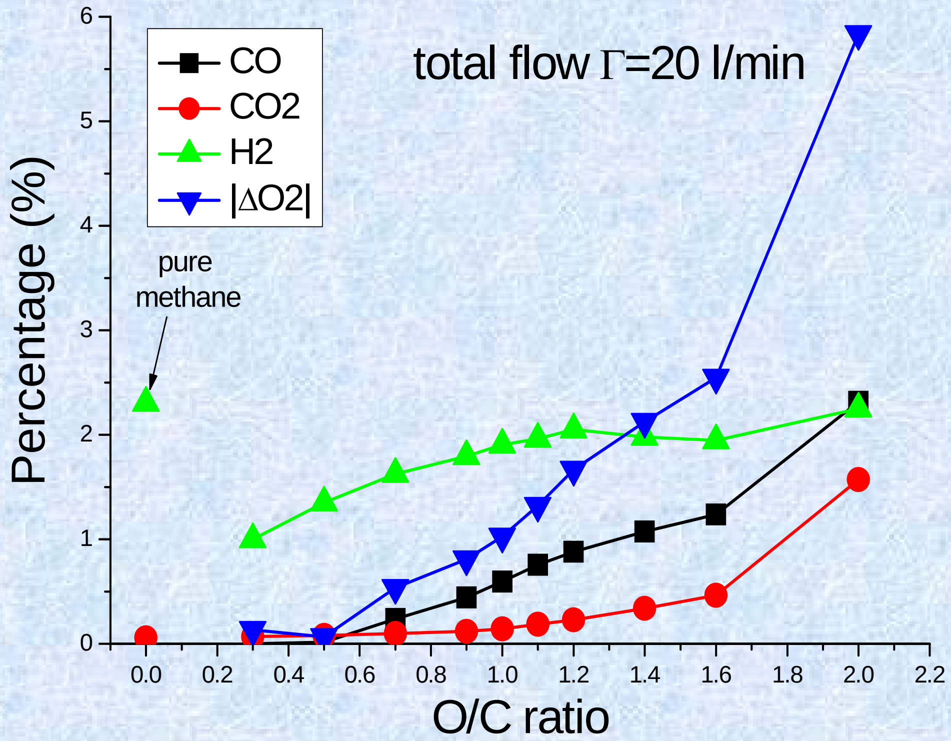
# Applications:

**Energy:** technology goal → hydrogen production

**Process:** fuel reformer → $H_2$ rich mixtures

**Plasma:** spark in $CH_4$ / air → $H_2$ production



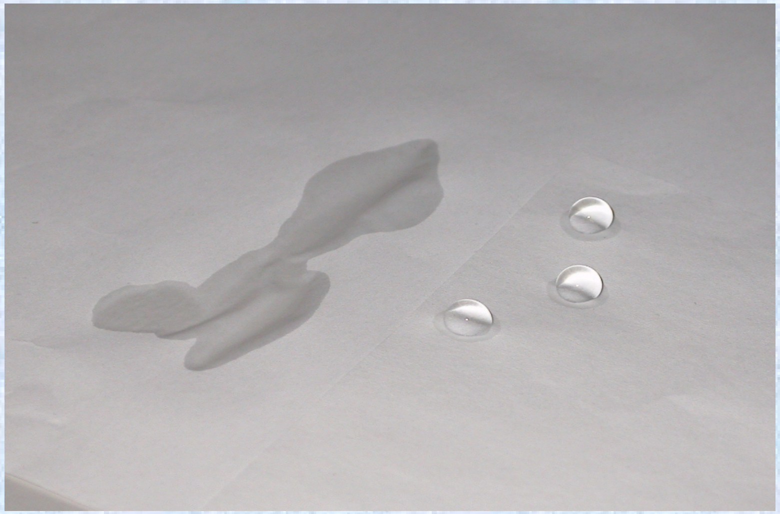



# Applications:

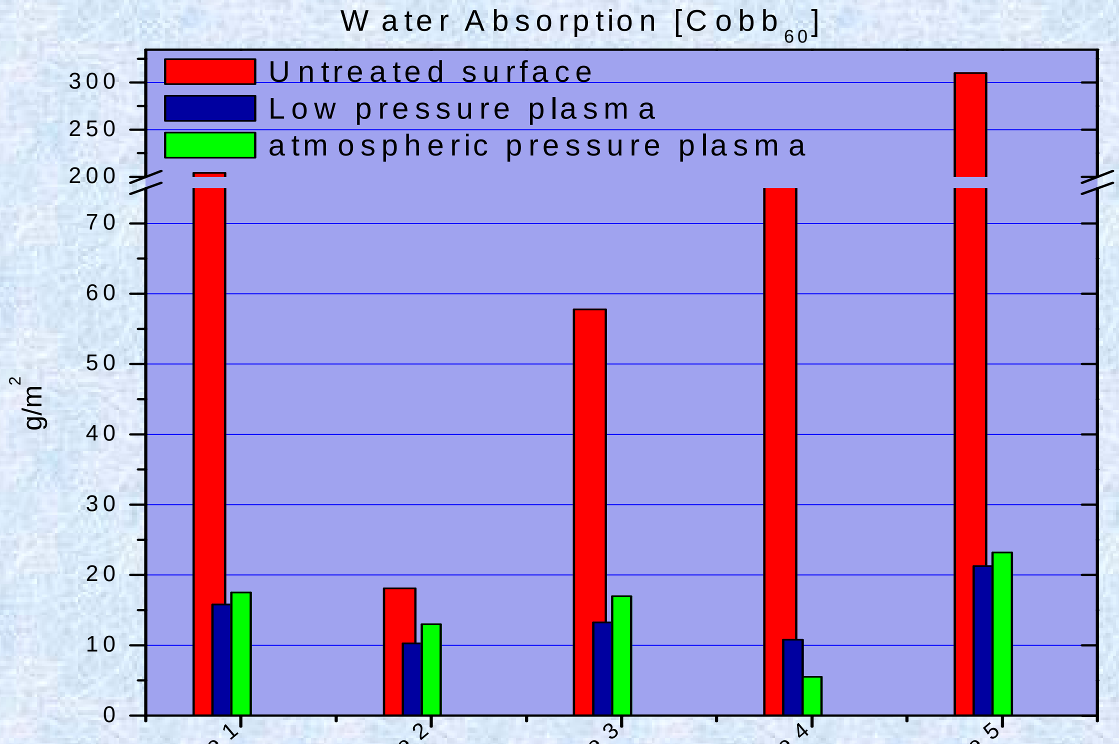
**Paper:** technology goal → improve packaging

**Process:** modify wettability → hydrorepellncy

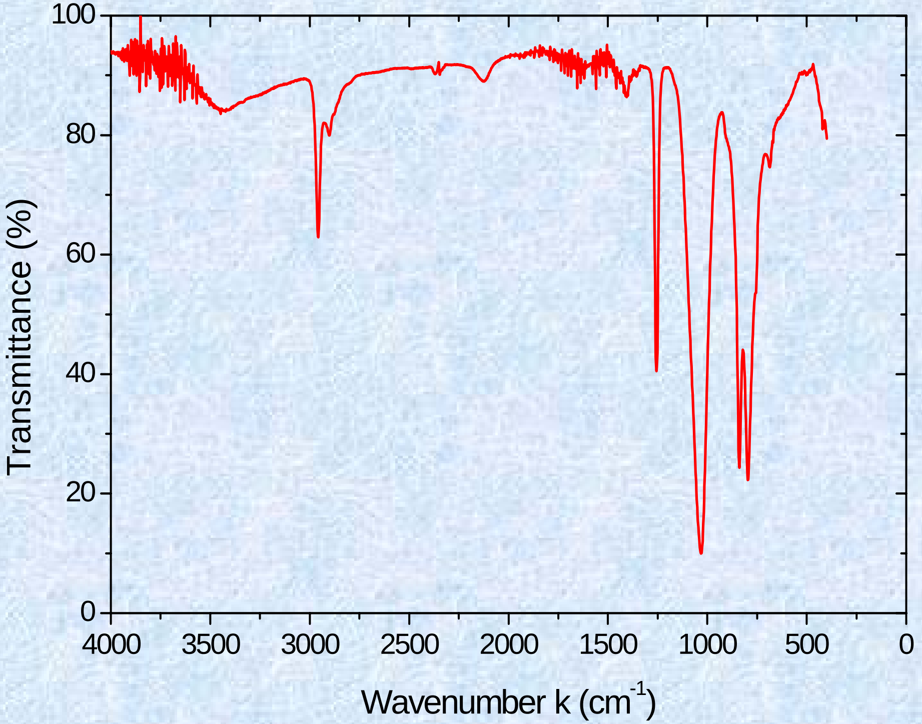
**Plasma:** $N_2$ / HMDSO dbd → siloxane film



Untreated Plasma treated

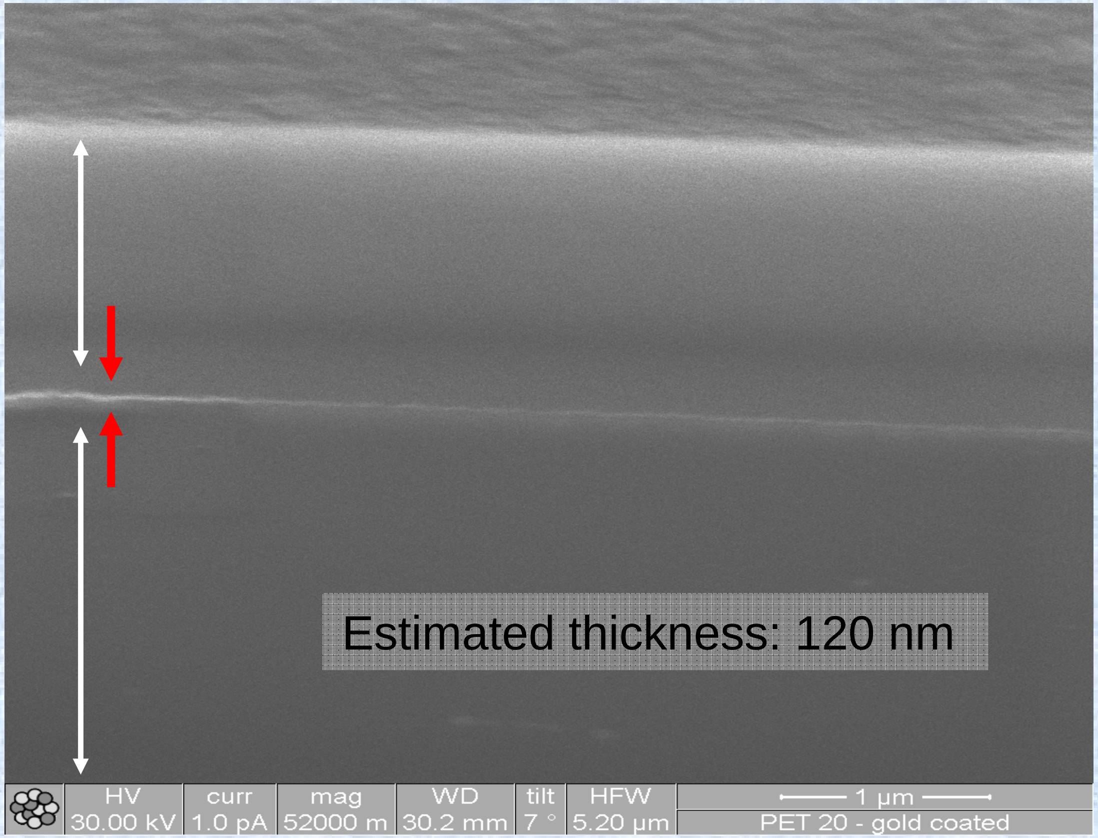


# Applications:




**FT-IR spectra**
**of HMDSO film on PET**
*(Si-O-Si, Si-CH3, CHx)*

**FIB section and imaging**



# Conclusions

**Plasma processing:**

- is a dry and eco-friendly technology *(deserve spreading)*
- atmospheric pressure discharges widen application field of plasmas
- processes should be brought at atmospheric pressure
  *(polymerization, pattern, nanopowder)*

**Contribution from basic plasma physics research:**

- development of advanced diagnostics
  *(electrical, optical)*
- modeling of the discharge processes
  *(breakdown, sustainement, regimes, chemistry)*