CPI

Coating Plasma Innovation

Optimization of atmospheric plasma for high speed industrial applications

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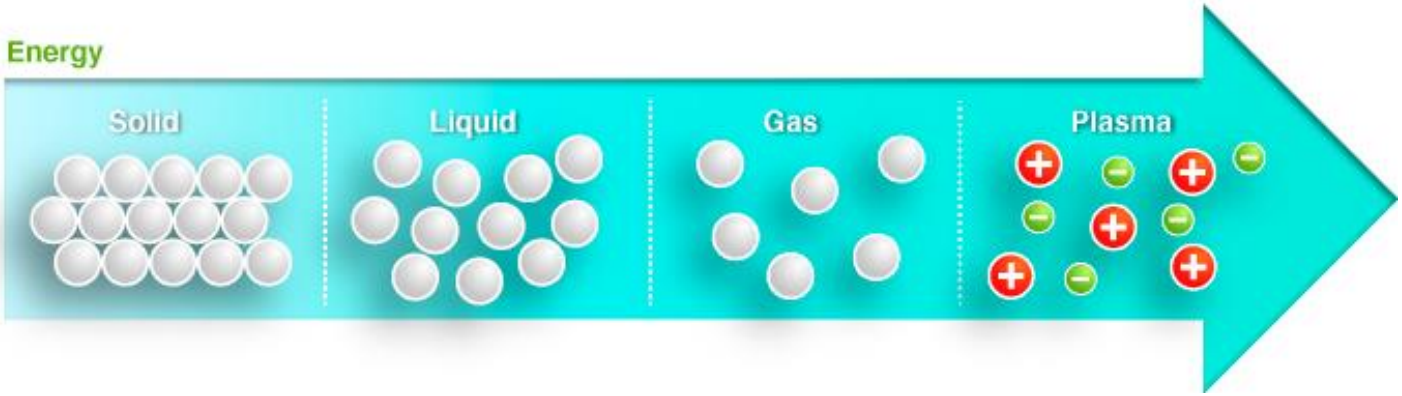
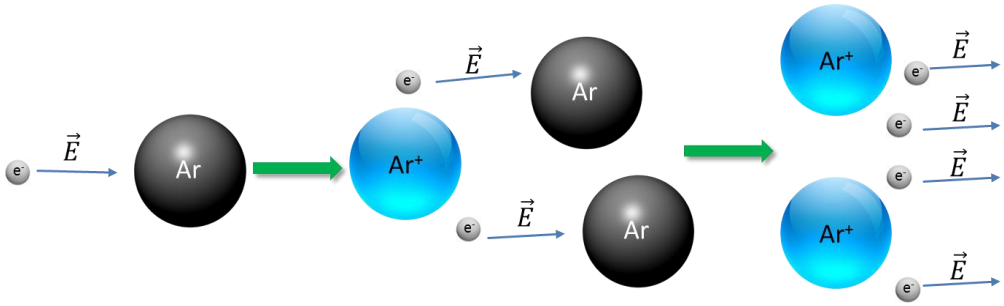
- Plasma
- Cold atmospheric plasma
- Plasma, Jet, Corona
- CPI Optimizations
- Conclusions

Plasma

4th state of matter: ionized gas





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Cold atmospheric plasma

Cold:

T_{gas} < 100 °C

$T_{ions,neutrals}$ < 100 °C

$T_{electrons}$ ≈ 10 000 °C

Hot:

$T_{gas} \approx T_{ions,neutrals} \approx T_{electrons}$

$10^4 < T < 10^8$ °C

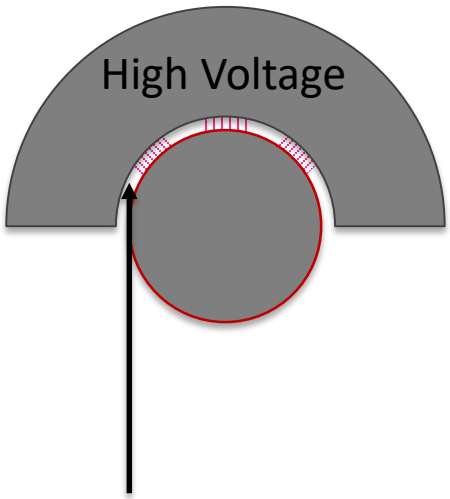
Atmospheric:

Plasma gas is at atmospheric pressure

Open reactor, high density of particles

Energetic electrons → chemistry

Corona

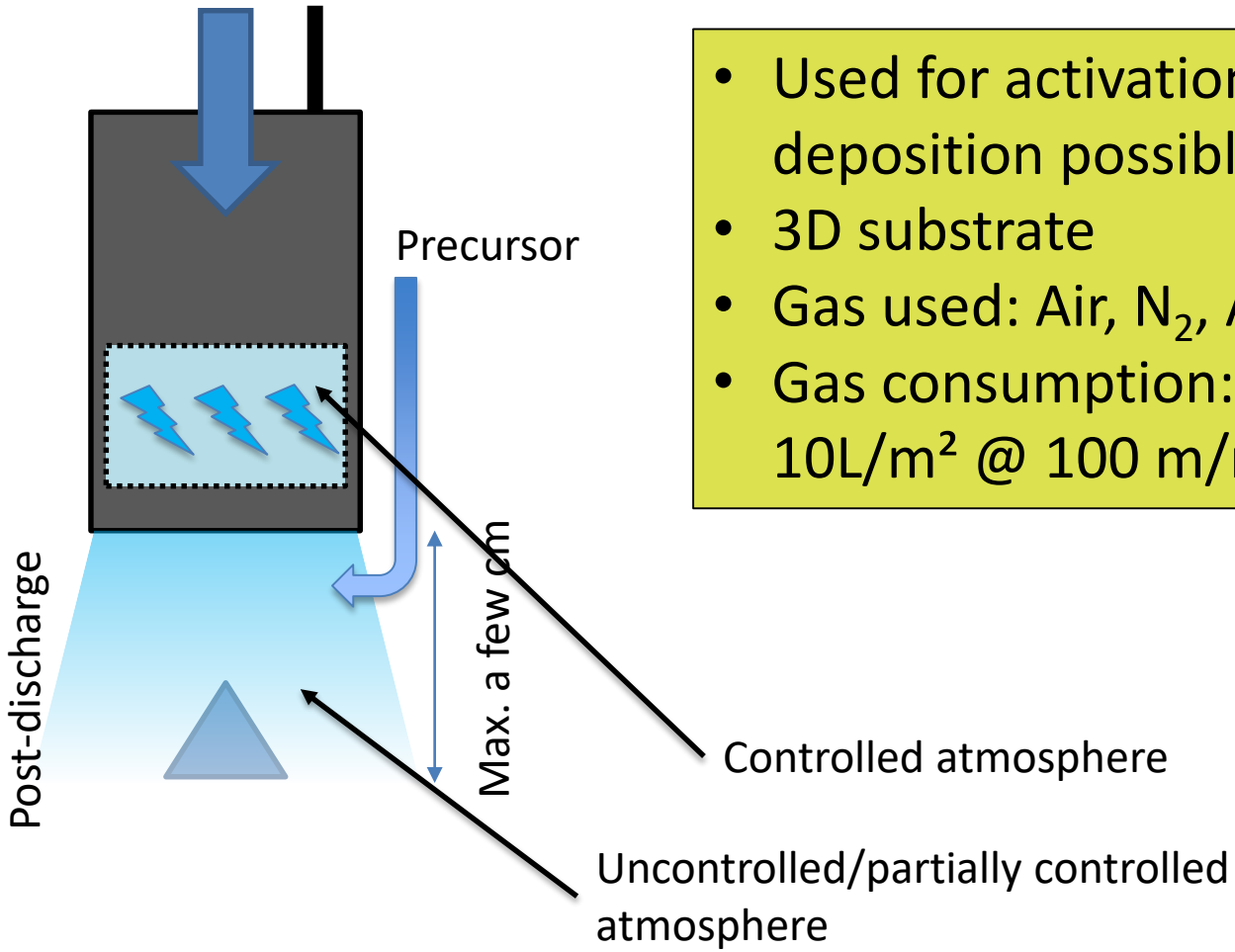


Ambient air
Filamentary discharge

- Used for activation or cleaning
- Flat substrate
- Most of the time need to be used inline with other process
- Gas used: none (ambient air)

Plasma jet (blown arc)

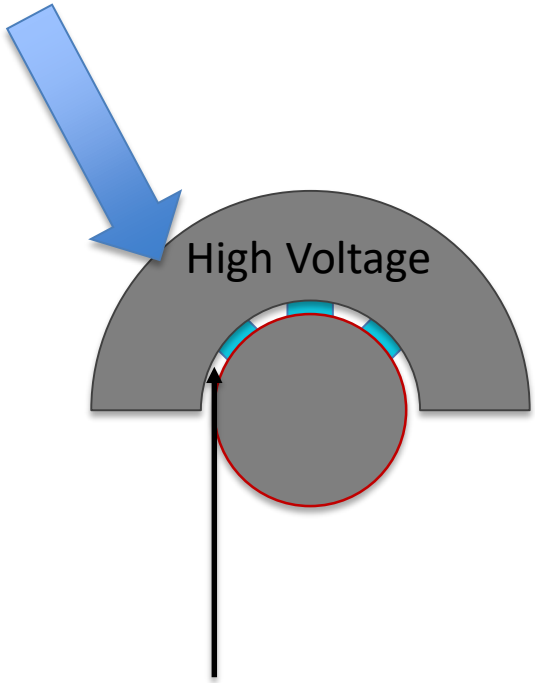
Gas injection (plasma gas + reactive gas ~~or precursor~~)



- Used for activation or cleaning, deposition possible
- 3D substrate
- Gas used: Air, N_2, Ar, He
- Gas consumption: 30 -60 l/min (➔ 10L/m² @ 100 m/min)

Plasma DBD

Gas injection (plasma gas + reactive gas or precursor)



Controlled atmosphere
Homogeneous discharge

- Used for activation or cleaning, deposition possible
- Flat substrate
- Used online or offline
- Gas used: N_2, (Ar, He)
- Gas consumption (CPI tech) < 5L/m² (50 – 500 m/min)

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Plasma vs Corona

Corona

- ✓ Very large web width
- ✓ Common technology
- ✓ Cost
- ✓ Cleaning
- ✓ Activation
- ✗ Grafting
- ✗ Coating
- ✗ Uncontrolled atmosphere
- ✗ Aggressive chemistry
- ✗ **Limited range of materials**
- ✗ Inhomogeneous treatment
- ✗ Pin holes
- ✗ Backside treatment
- ✗ Low efficiency
- ✗ **Temporary effect**

Plasma

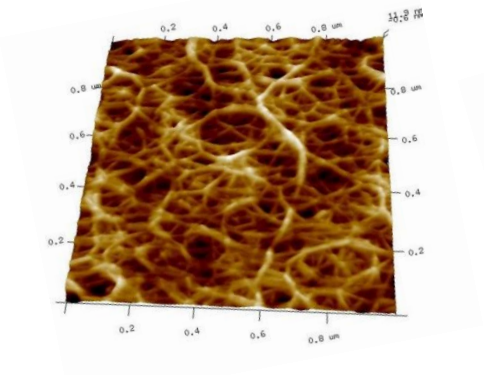
- ✓ Large web width
- ✓ Controlled atmosphere
- ✓ Homogenous treatment
- ✓ No surface damage
- ✓ No backside treatment
- ✓ High performance treatment
- ✓ **Long lasting effect**
- ✓ Cleaning
- ✓ Activation
- ✓ Grafting
- ✓ Coating
- ✓ **Wide material range**
- ✗ Common technology
- ✗ Cost

Plasma vs Corona

Microscopy (AFM) image of BOPP film

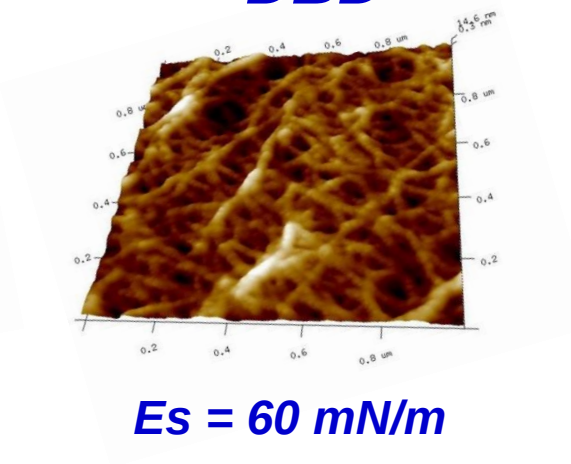
1 µm x 1 µm images (Tapping)

Untreated



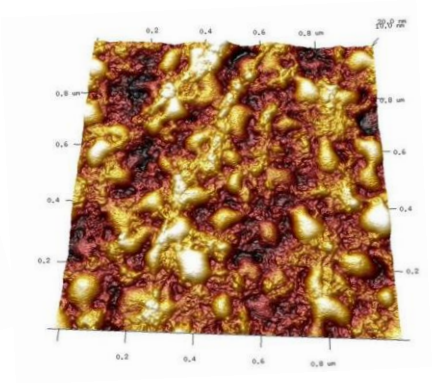
Es ≤ 30 mN/m

Plasma DBD



Es = 60 mN/m

Corona



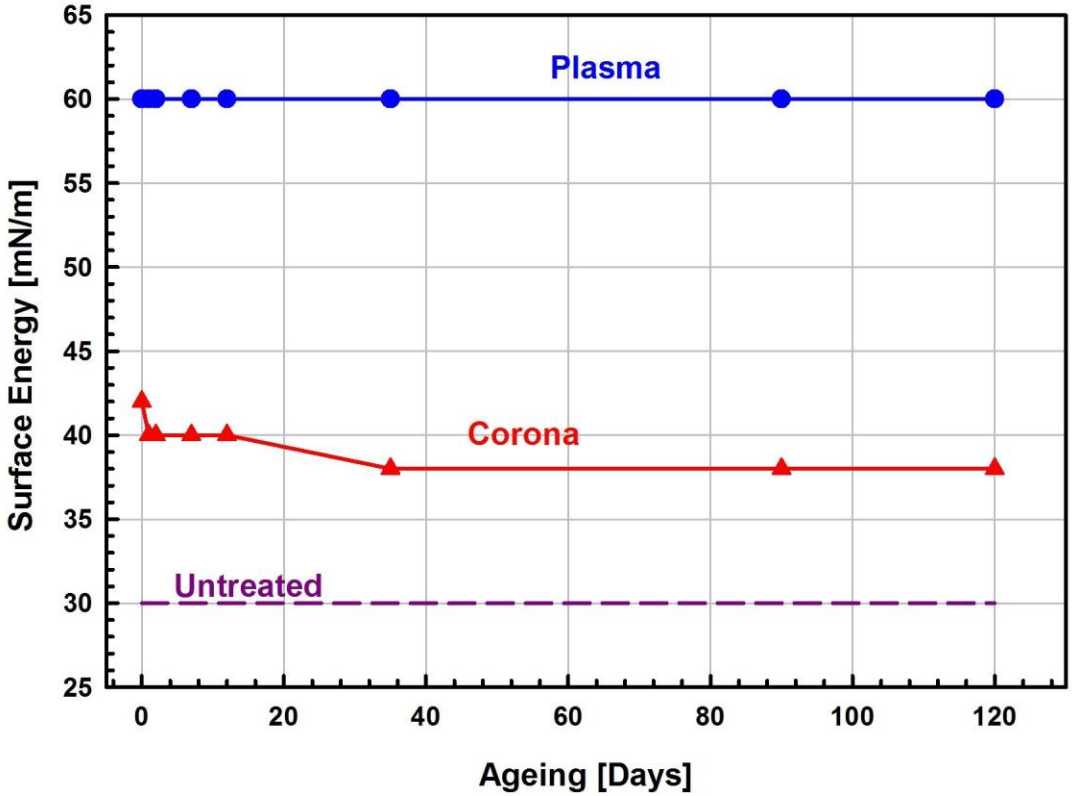
Es = 38 mN/m

Identical discharge power

Controlled chemistry, homogenous discharge ➔ no surface damage

Plasma vs Corona

Surface energy measurements on BOPP film



Controlled chemistry ➔ Long lasting treatment, higher surface energy

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DBD vs Jet/torch

Torch/Jet

- Localized treatment (max width ≈10 cm)
- Indirect plasma exposure (post discharge)
- Medium speed treatment (10's m/min)
- 3D and complexes shape substrate
- Partially controlled atmosphere
- Cleaning, Activation, Grafting, Coating

DBD

- Up to several meters web width
- Direct plasma exposure
- High speed treatment (100's of m/min)
- Thin flat substrate
- Controlled atmosphere
- Cleaning, Activation, Grafting, Coating

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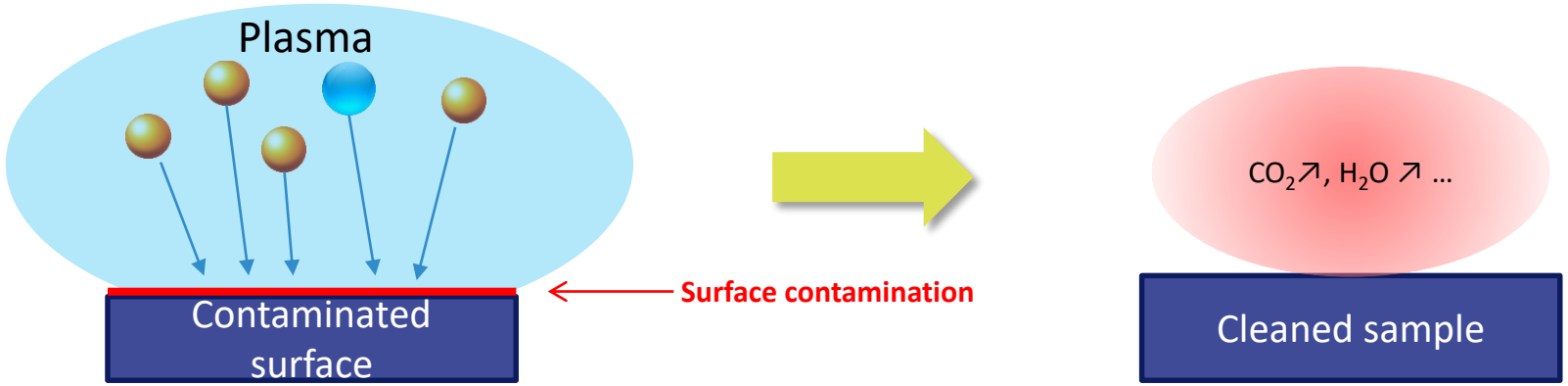
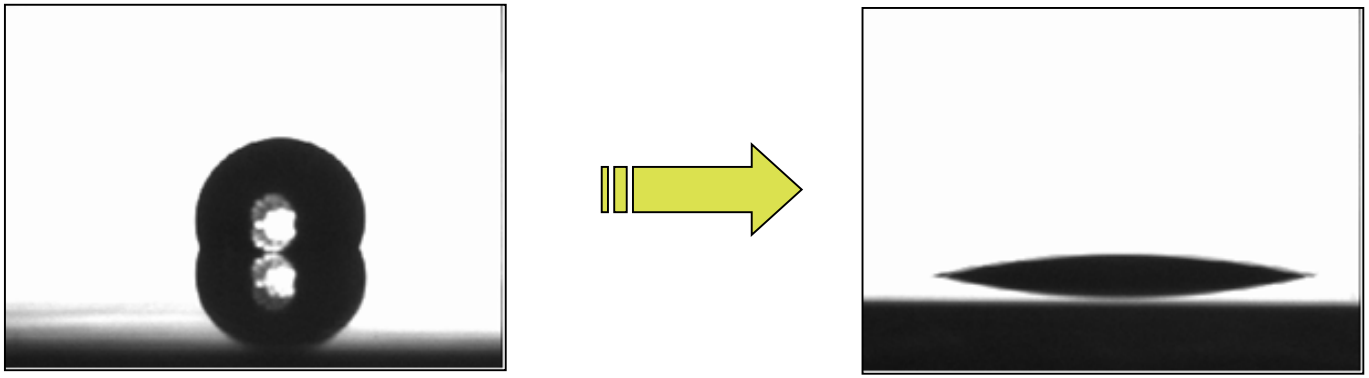
Cleaning - Grafting - Coating





Torch, Corona, Plasma

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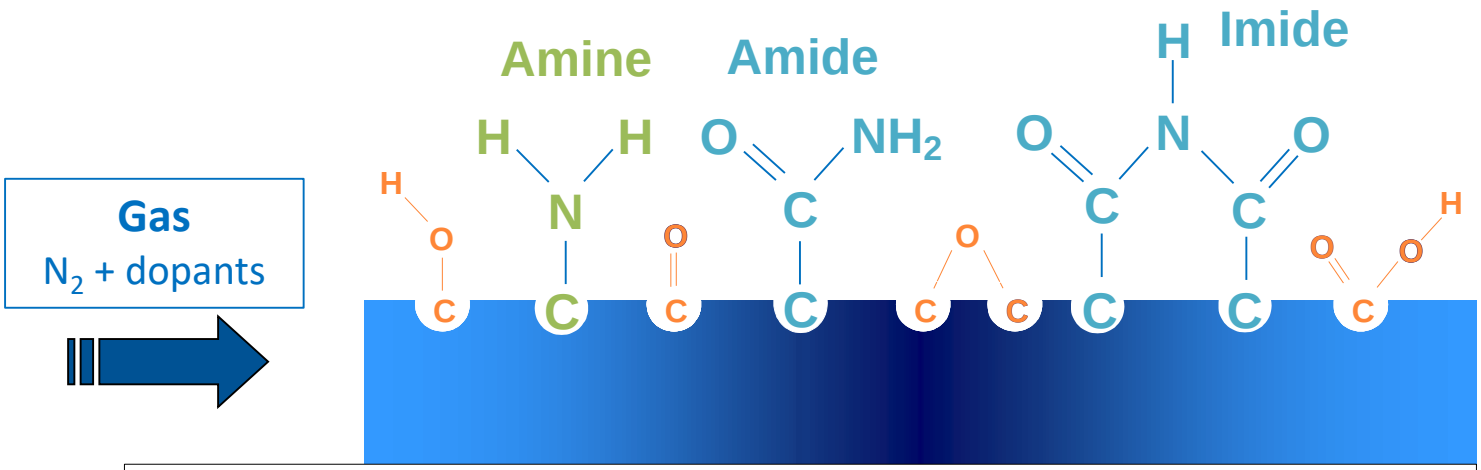
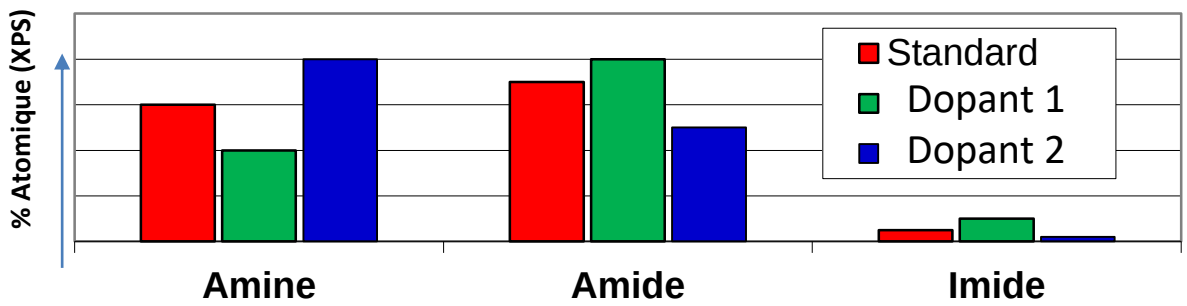
Cleaning - **Grafting** - Coating





Grafting of nitrogen containing groups

Torch, Corona, **Plasma**

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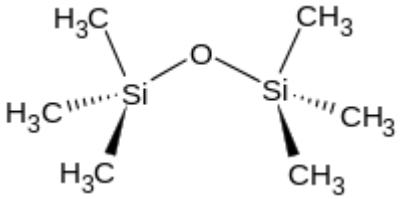
Cleaning - Grafting - **Coating**

Specific molecules (precursor) are added to the plasma gas. Those molecules are activated ( ) by the plasma and react with the sample surface to form a thin film.

HMDSO precursor



SiO_x hydrophilic

SiC_yO_x hydrophobic

Torch, ~~Corona~~, **Plasma**

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Conclusions

- Corona is adapted for basic treatment of low value materials
  Limited performance regarding surface energy, durability of treatment and range of materials treatable

- Plasma jet are adapted to localized treatment and 3D shaped objects
  Cost and technical issues for large scale treatment

- Plasma DBD is adapted to high performance applications and/or high performance materials.
  Not competitive if corona can achieve the same goal

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COATING PLASMA INDUSTRIE

- Plasma
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- **CPI Optimizations**
- Conclusions

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Needed Improvement in atmospheric plasma technology

1st generation of atmospheric plasma issues:

- Treatment speed was too slow
- Gas consumption was too high
- Some materials could not be treated
- Coating was difficult

  ➔ Cost was too high in regard of the performances

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Optimizations

Improvements in electrode design

- Homogenous plasma at high power density
- Longer exposure time with similar footprint

Improvements in gas dynamics:

- Controlled Chemistry even at high web speed
- Reduction in gas consumption

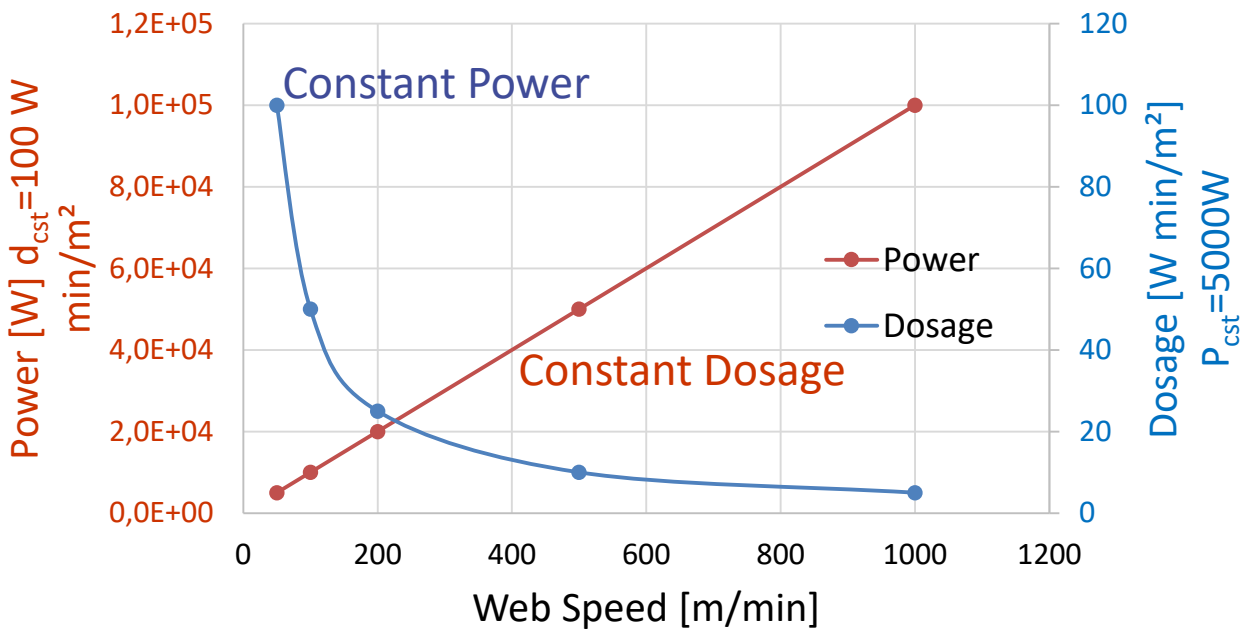
➢ High power density, longer exposure time:
  - ✓ High speed treatment
  - ✓ Inert material treatment such as fluorinated polymers

➢ Homogenous discharge, controlled chemistry:
  - ✓ No hot spots, no damage of films (LMWOF)
  - ✓ Stable atmosphere allow to add controlled amount of dopant gas (vapors)
  - ✓ Treatment of sensitive or difficult materials (PTFE, ECTFE, PEEK, PLA…)

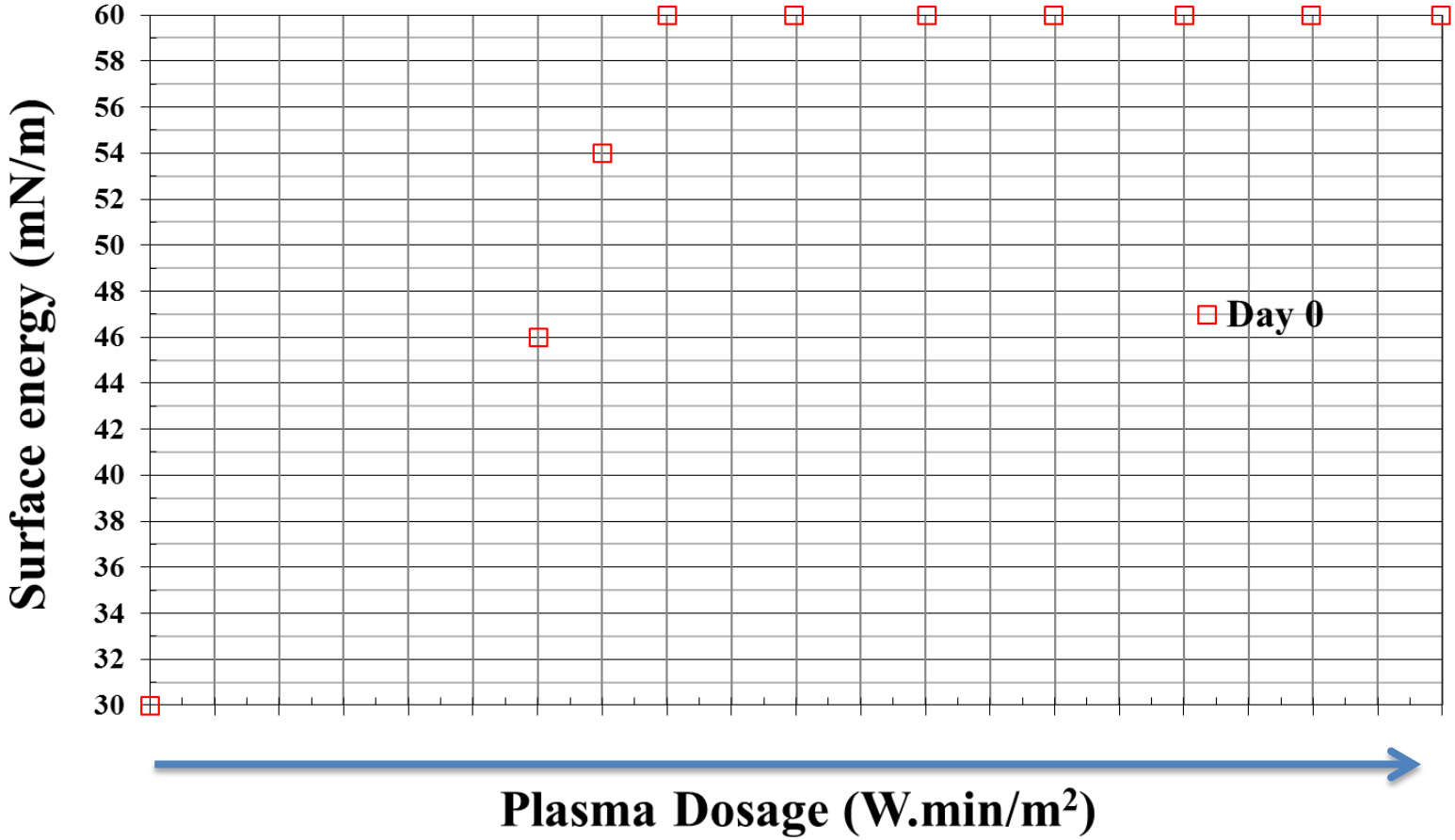
Dosage

The plasma dosage (d) represents the amount of electrical energy applied the material during the treatment

$$d = \frac{Plasma\ power}{Web\ widht\ \times\ Web\ speed} = \frac{[W]}{[m]\ \times \left[\frac{m}{min}\right]} = \frac{[W \cdot min]}{[m^2]}$$



Electrode design



High power density ➔ High Dosage at high speed

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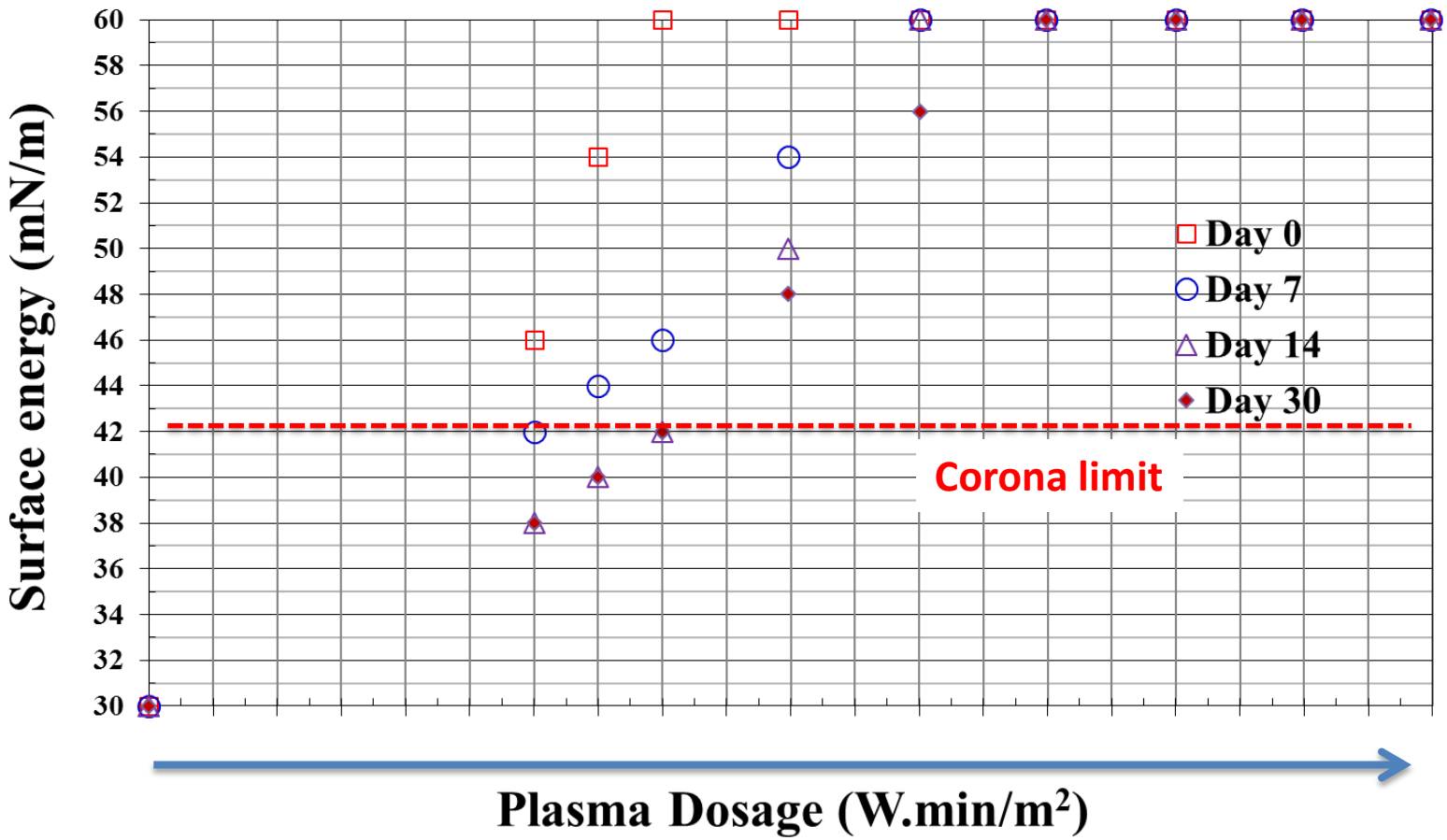
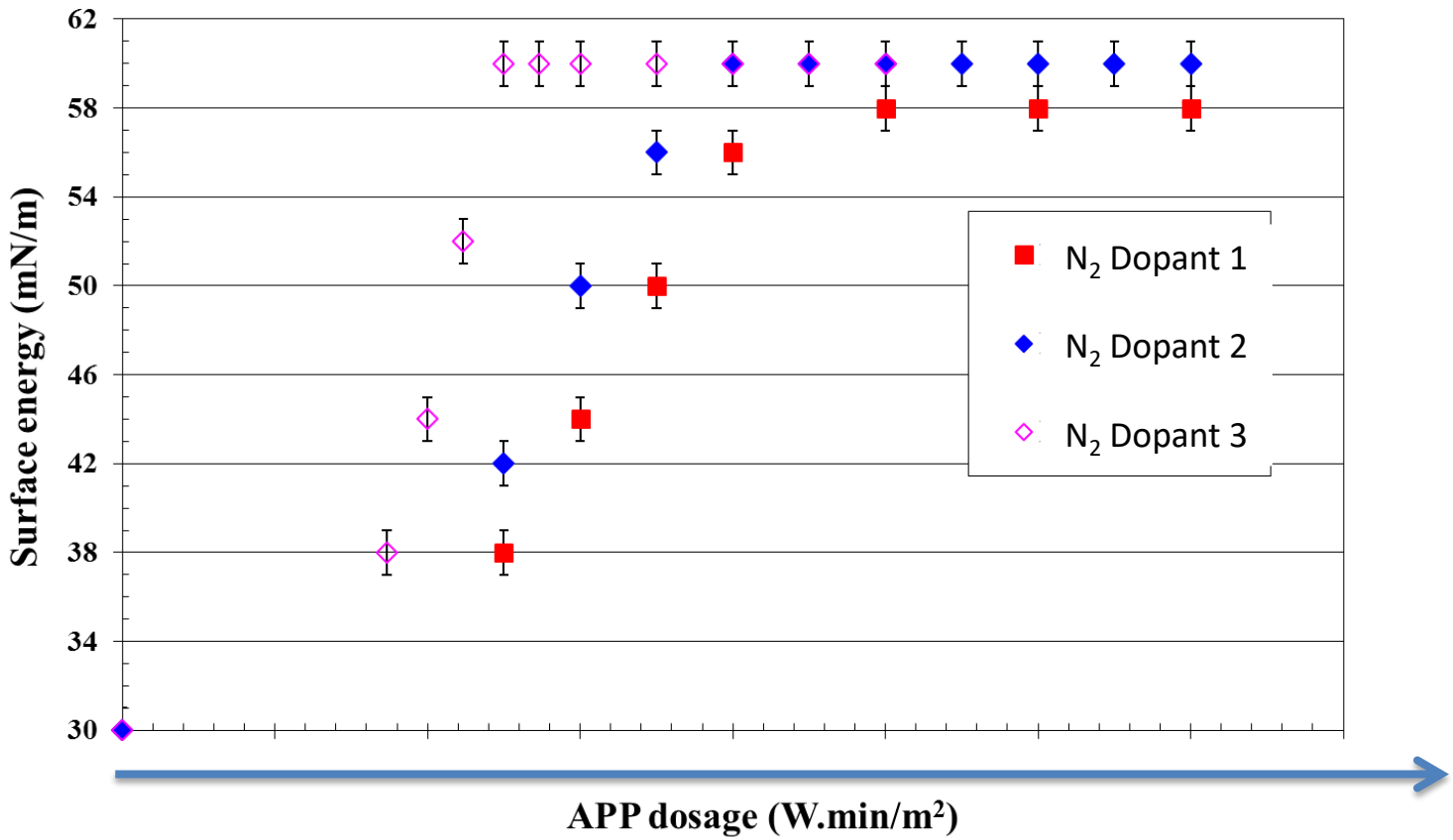
Electrode design



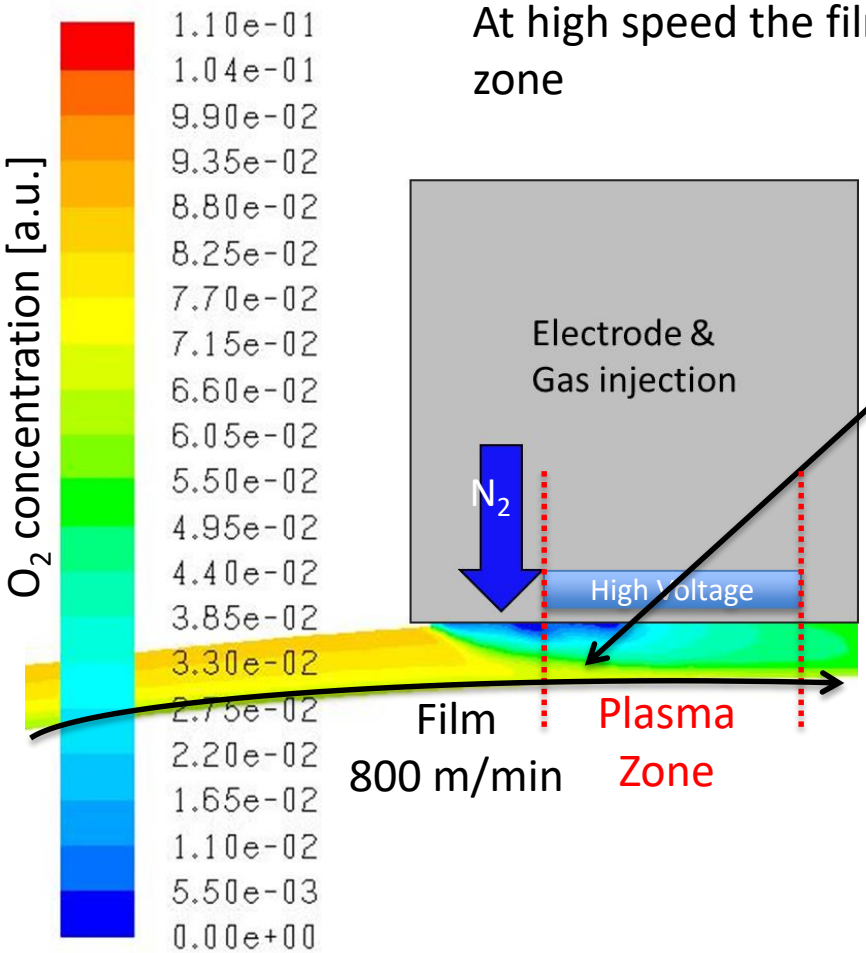
High Dosage without damage ➔ Long lasting treatment

Controlled atmosphere - dopant



Dopant → same performance at lower dosage

Gas dynamics



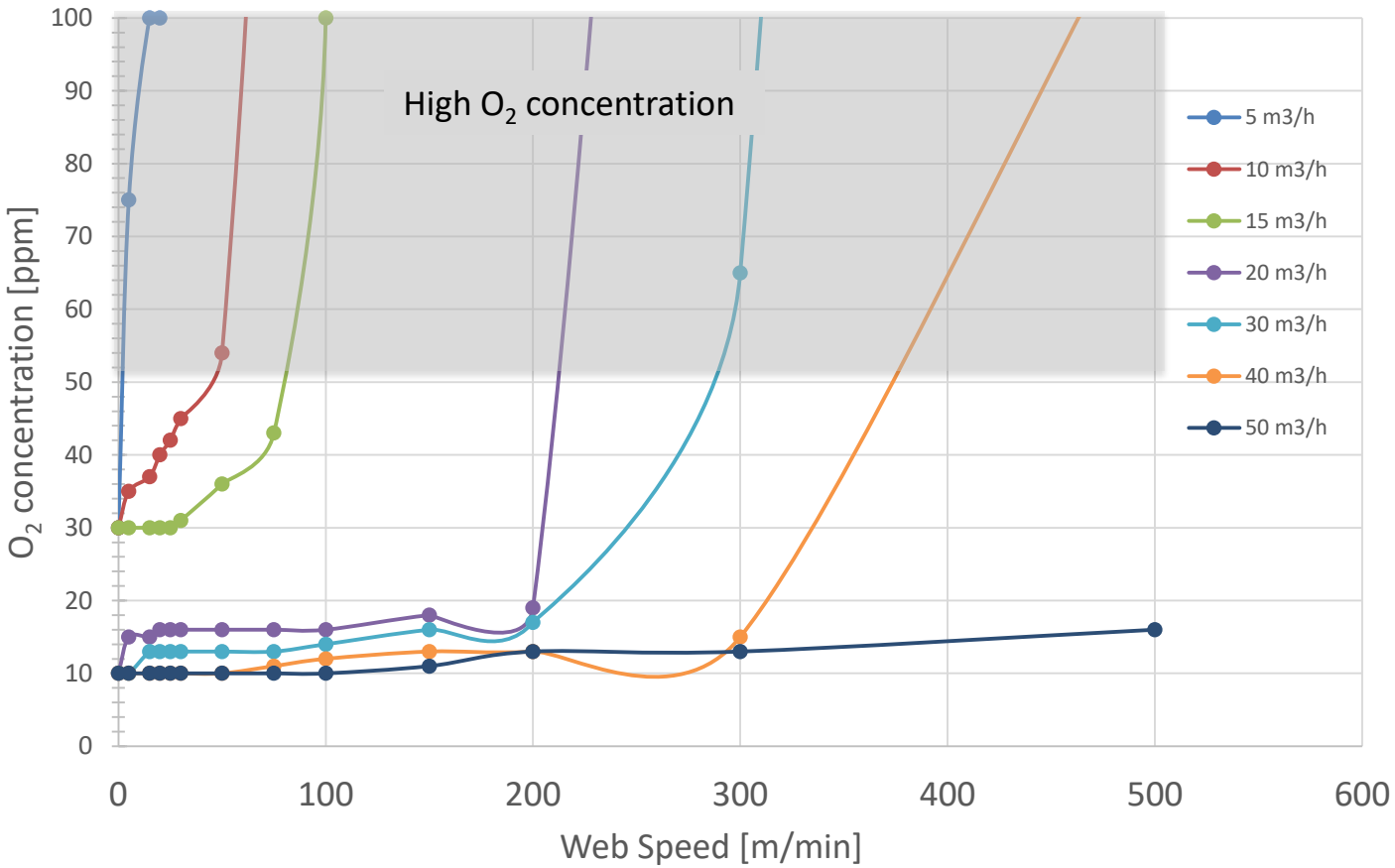
At high speed the film carries an air boundary layer in the plasma zone

Air (Oxygen) is introduced in the plasma
Chemistry of the plasma is not controlled

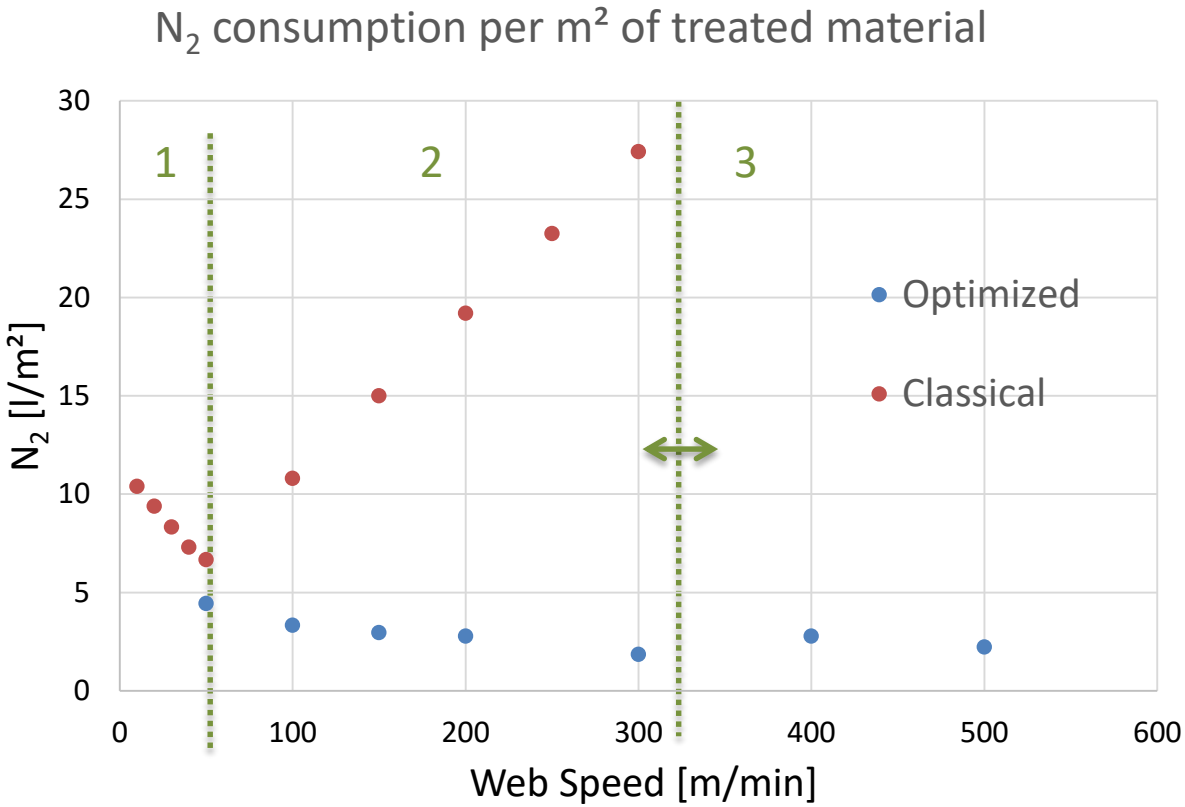
Air boundary layer must be removed:

- **High N_2 flow rate**
- **Optimized gas diffusor geometry**
- **Low power corona**
- **Physical barrier**
- **…**

Gas dynamics - Controlled atmosphere



Gas dynamics - Controlled atmosphere



Electrode-gas diffusor assembly optimization ➔ running cost ↘↘

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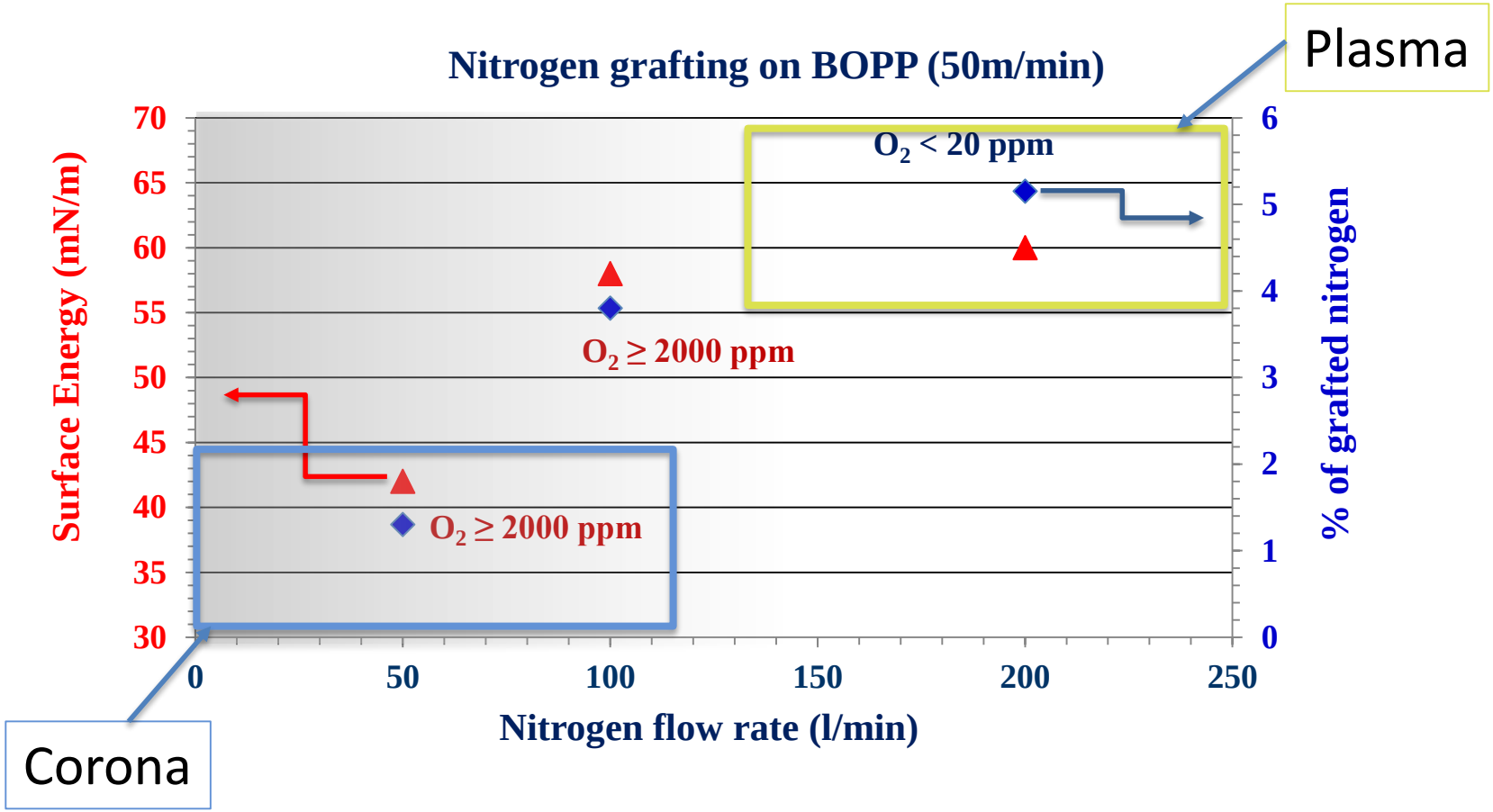
Controlled atmosphere



Good inerting ➔ Higher surface energy

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Thin film Coating

Coating by atmospheric plasma pressure was/is hindered by:

- ❖ Powder formation in the gas phase
  - ➔ low adherence to substrate
  - ➔ low quality powdery film
- ❖ Powder formation on the electrode
  - ➔ high maintenance
- ✓ **Optimized electrode gas diffusor assembly solves those issues**

Remaining issue: high density film at high speed

- ✓ Dense film at 10th m/min ➔ slow for industrial use
- ✓ Deposition at 100th m/min ➔ low density film

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Conclusions

Improvements in electrode design and gas dynamics allowed to overcome most of the previous atmospheric plasma limitations.

- Treatment speed are very high (hundreds of m/min)
- Running cost are becoming competitive
- Chemistry of the plasma can be controlled

Plasma is adapted to high performance materials and/or high performance applications

Thank you