Glass Performance Days 2025

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GLASS PERFORMANCE DAYS 2025

Atmospheric Plasma Pre-Treatment of Ultra-Thin Flexible Glass for Transparent Organic Coatings

Keywords: Plasma treatment
Cleaning and activation
Flexible glass
Organic conductive coatings

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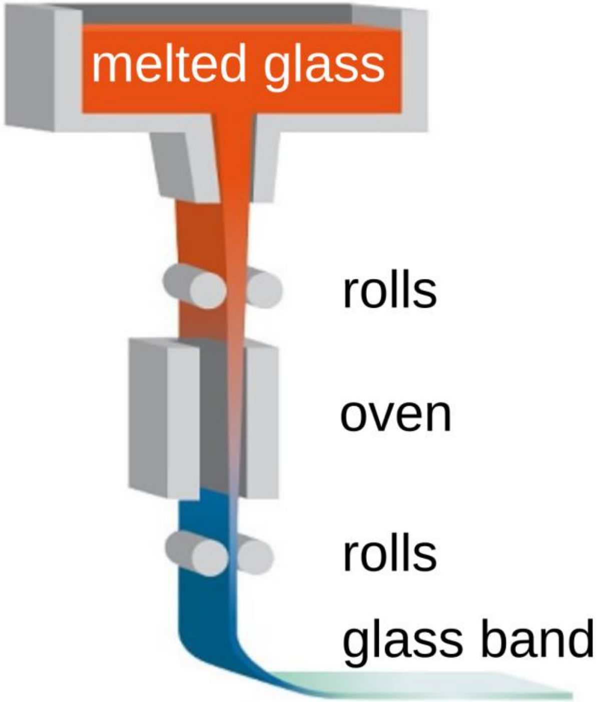
SCHOTT

Motivation:

Ultra-thin flexible glass



- Substrate
- Superstrate
- Encapsulation

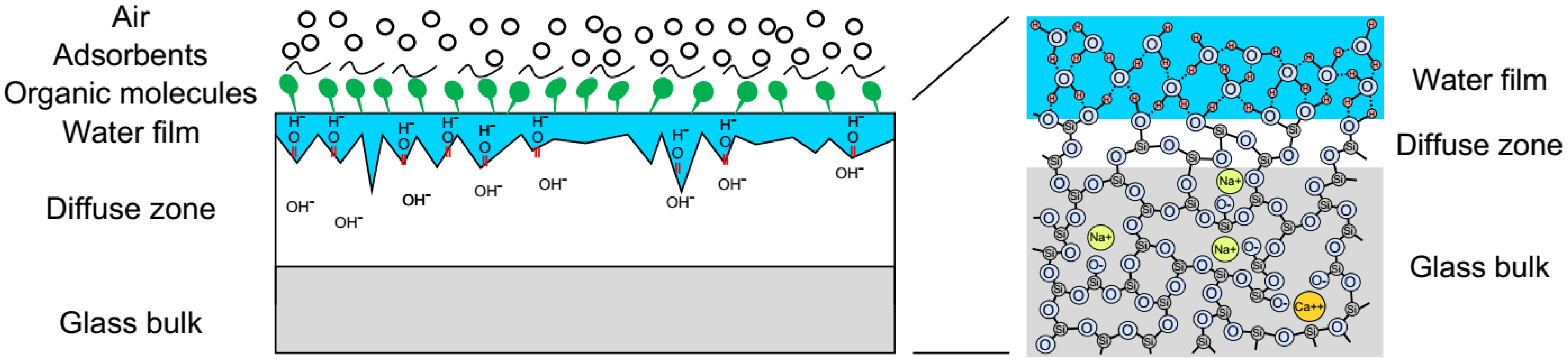
for

- Light emitting devices, displays
- Flexible photovoltaics
- Sensors, guide-wave photonics

- Areas larger than float glass

State-of-the-art:

Water film on glass surface



- Glass surface is naturally covered with adsorbed airborne contaminants
- Water and carbohydrates form a film with thickness of a few nanometers
- Bottom part of thin water film is chemically bonded to glass network

State-of-the-art:

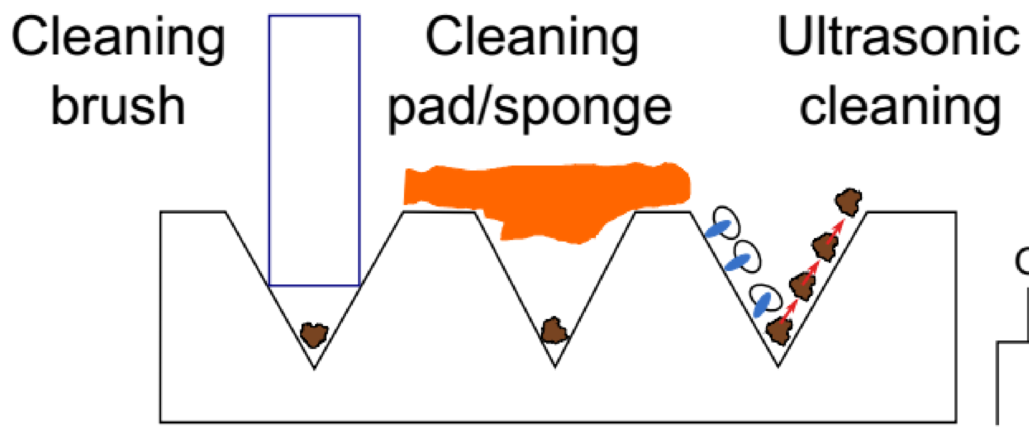
Cleaning and activation

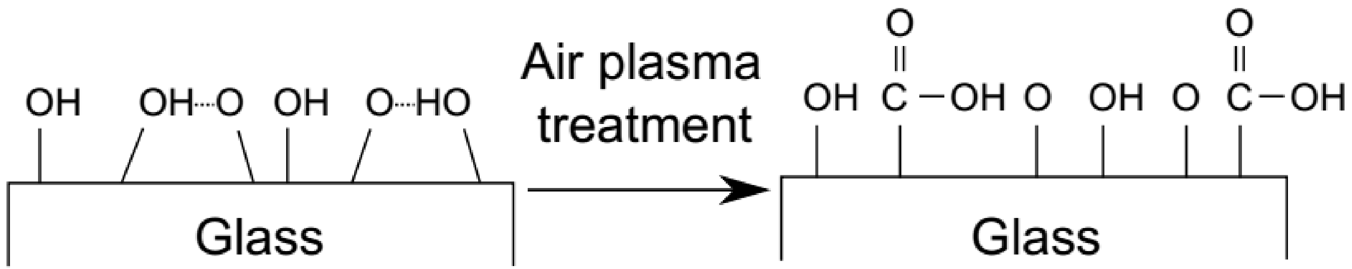
Solvent-based cleaning protocol

- Applying liquids and mechanical contact
- Duration of several tens of minutes
- Requirement of various liquids and drying

Air plasma treatment

- Generated in surrounding air
- Free of mechanical contact
- Easy to operate and control

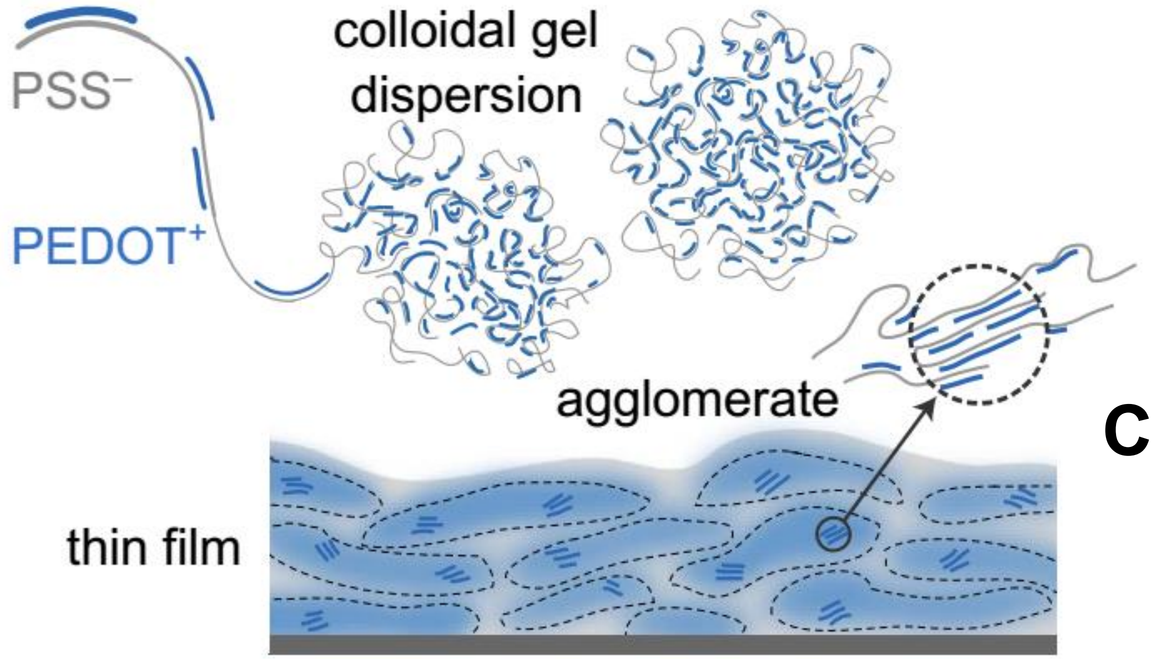


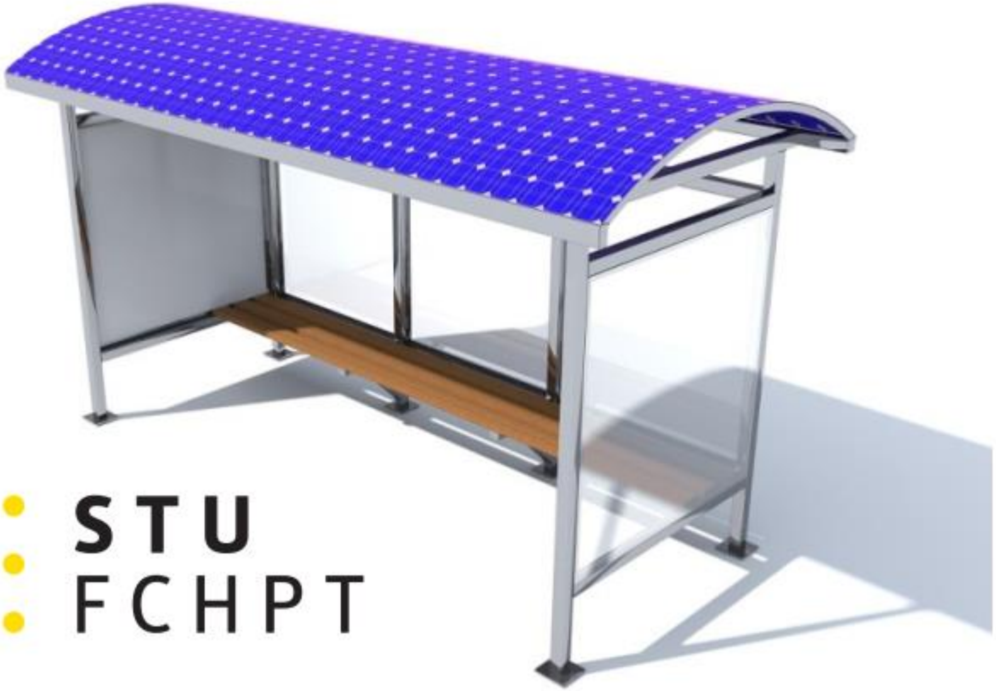


Motivation:

Organic transparent conducting electrode

- OLED, OSC, MEA, supercapacitors
- Electrochemical sensors
- Electrophysiology



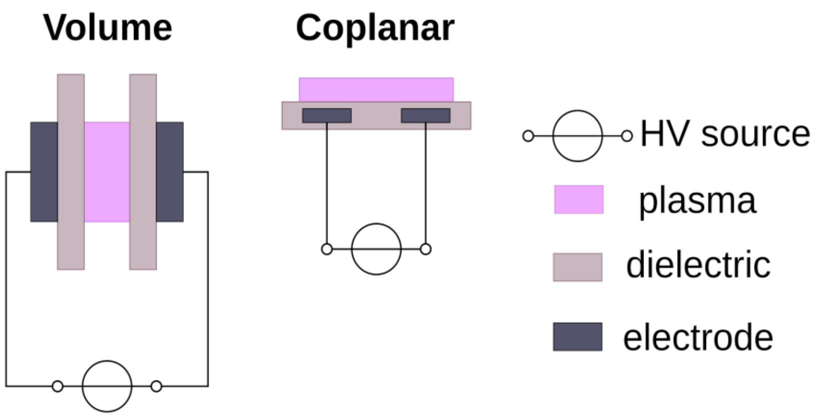


Conditioning of UTFG substrates

- Wet → detergent, acetone, IPA
- Dry → ambient air plasma

Methodology:

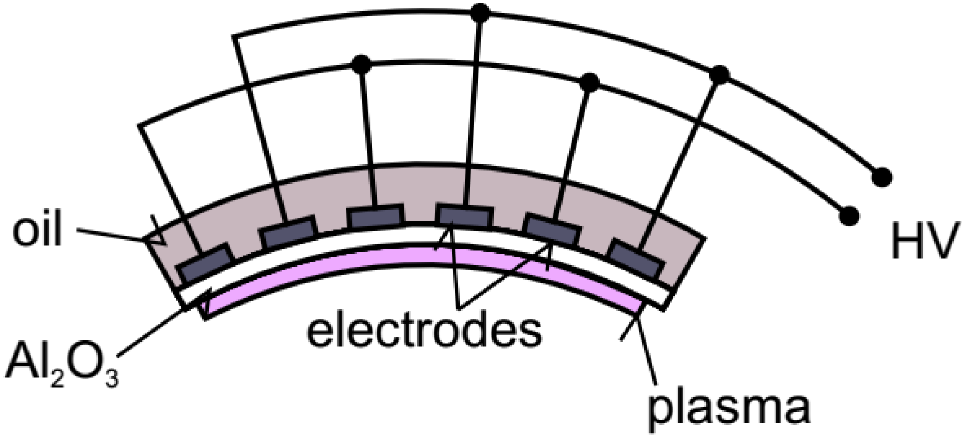
Apllied DBDs – cold plasma in ambient air

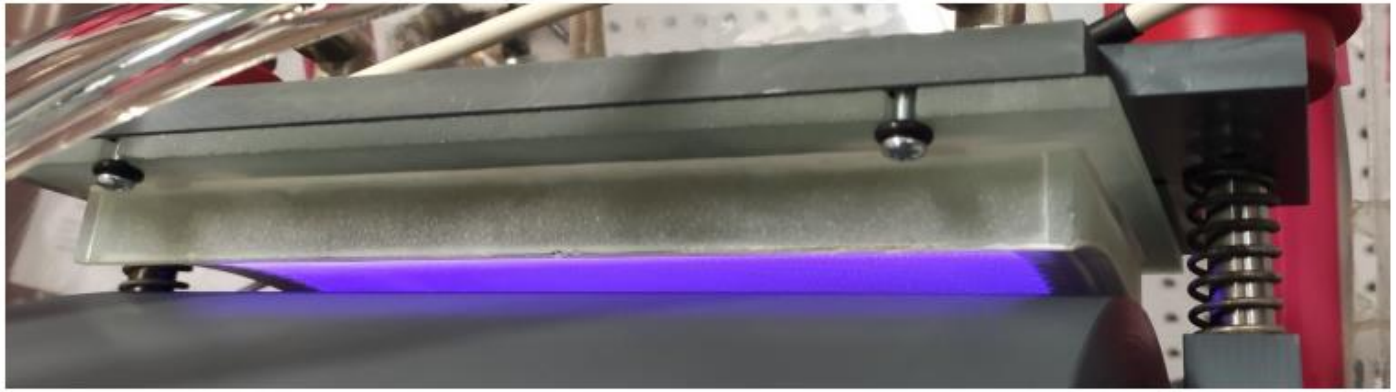


Sample distance:	0.3 mm	2 mm
Length of plasma:	80 mm	65 mm
Supply power:	350 W	416 W
Watt density (1 s exposure):	365 W.min/m^2	516 W.min/m^2

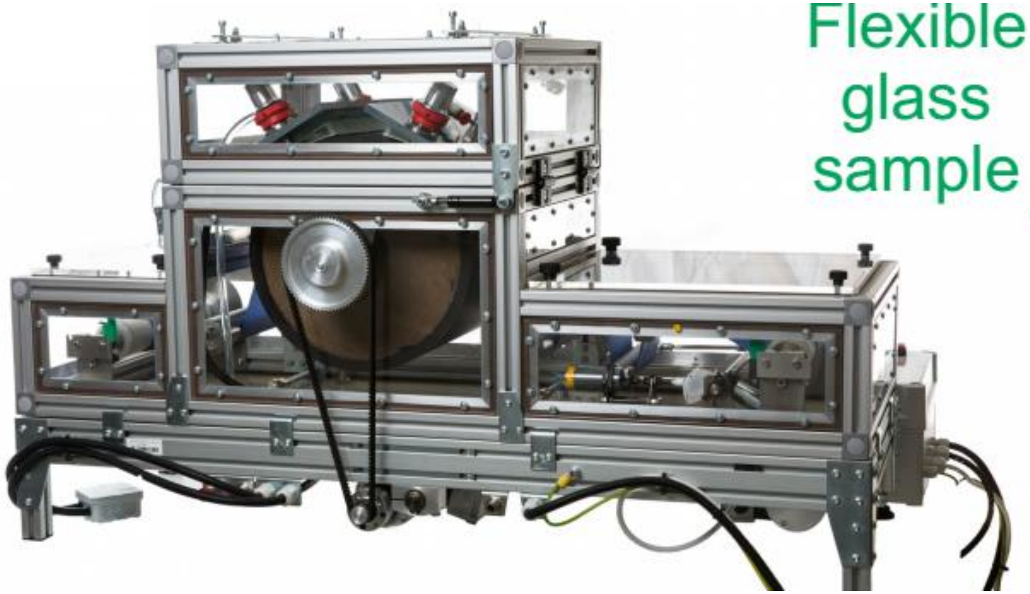
ROPLASS robust plasma systems

Methodology:
R2R DCSBD plasma system

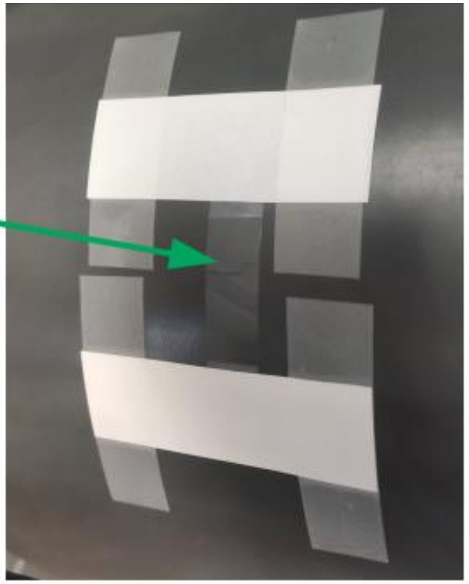




- Flexible materials
- Curved plasma units
- Unlimited thickness
- Rotary cylinders → impact on plasma



Flexible glass sample

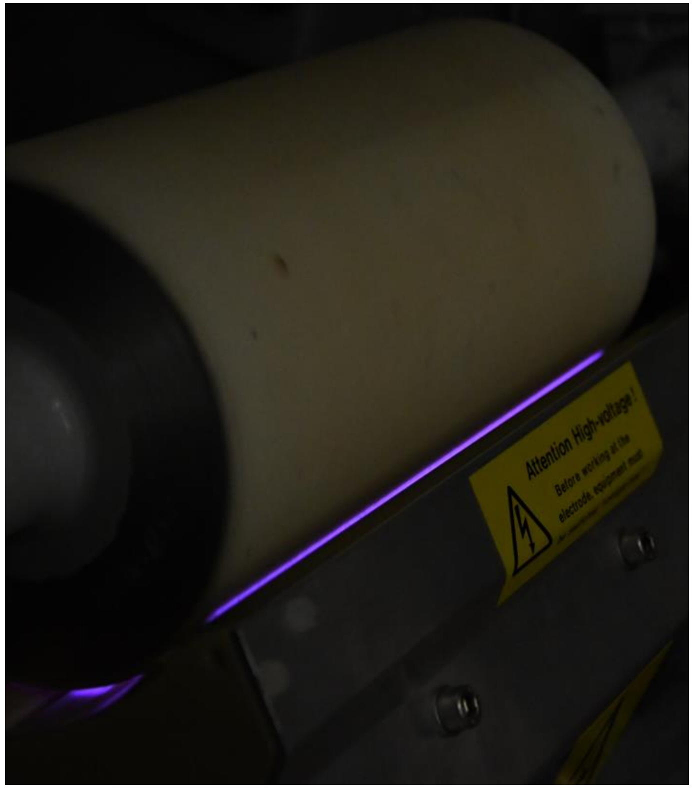


AHLBRANDT
A BALDWIN Technology Company

Methodology:

R2R VDBD plasma system

- Only thin flexible materials
- Rotary cylinder → counter electrode
- HV stripe electrodes → around cylinder

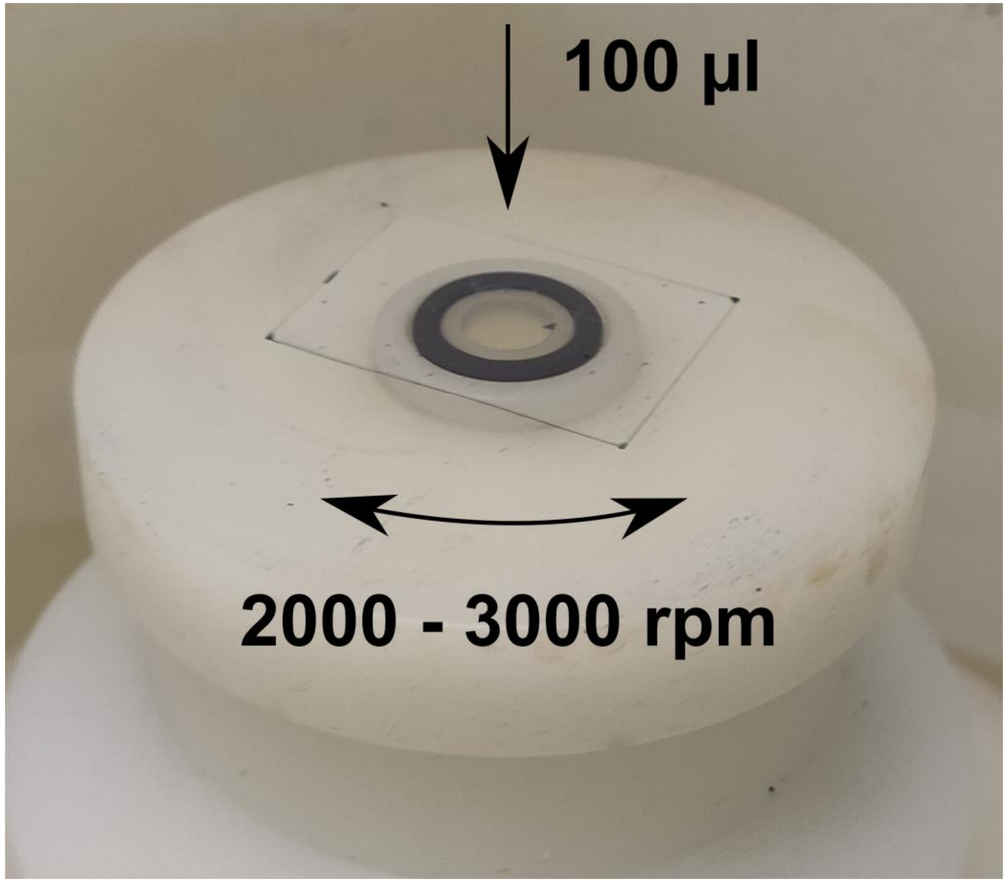


Gap distance has impact on plasma → macroscopically homogeneous < 2 mm

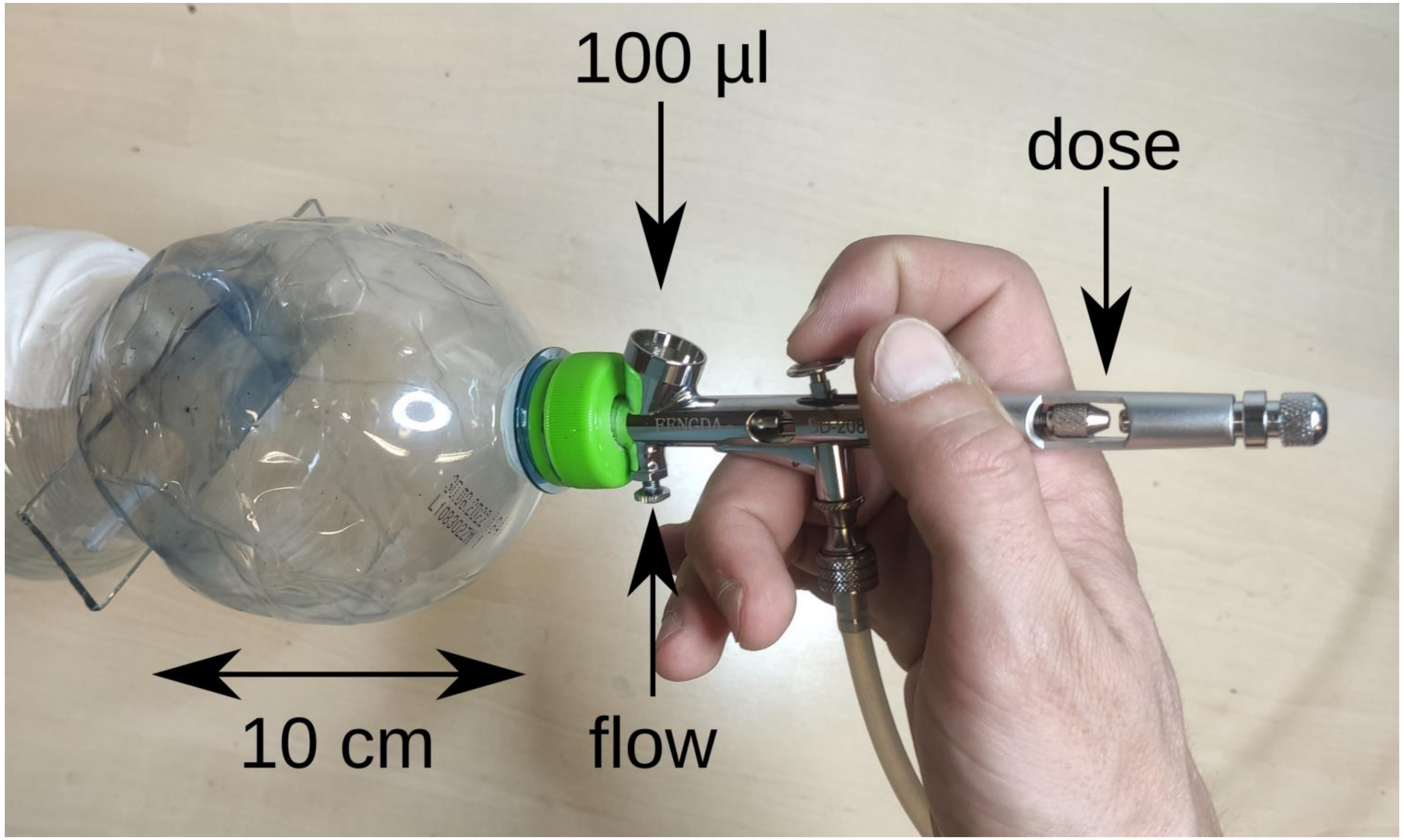
Methodology:

Coating methods – PEDOT:PPS + IPA + EG

Spin coating



Spray coating



Methodology:

Analytical methods

Cleaning and activation of UTFG

- Water contact angle
- Surface free energy
- Atomic force microscopy
- X-ray photoelectron spectrometry

PEDOT:PSS-based coating

- Four point probe
- Profilometry
- SEM imaging

Surface properties

Wetting, uniformity, ageing recovery

Physical and chemical interaction

Morphology and roughness

Chemical composition

Layer properties

Sheet resistance

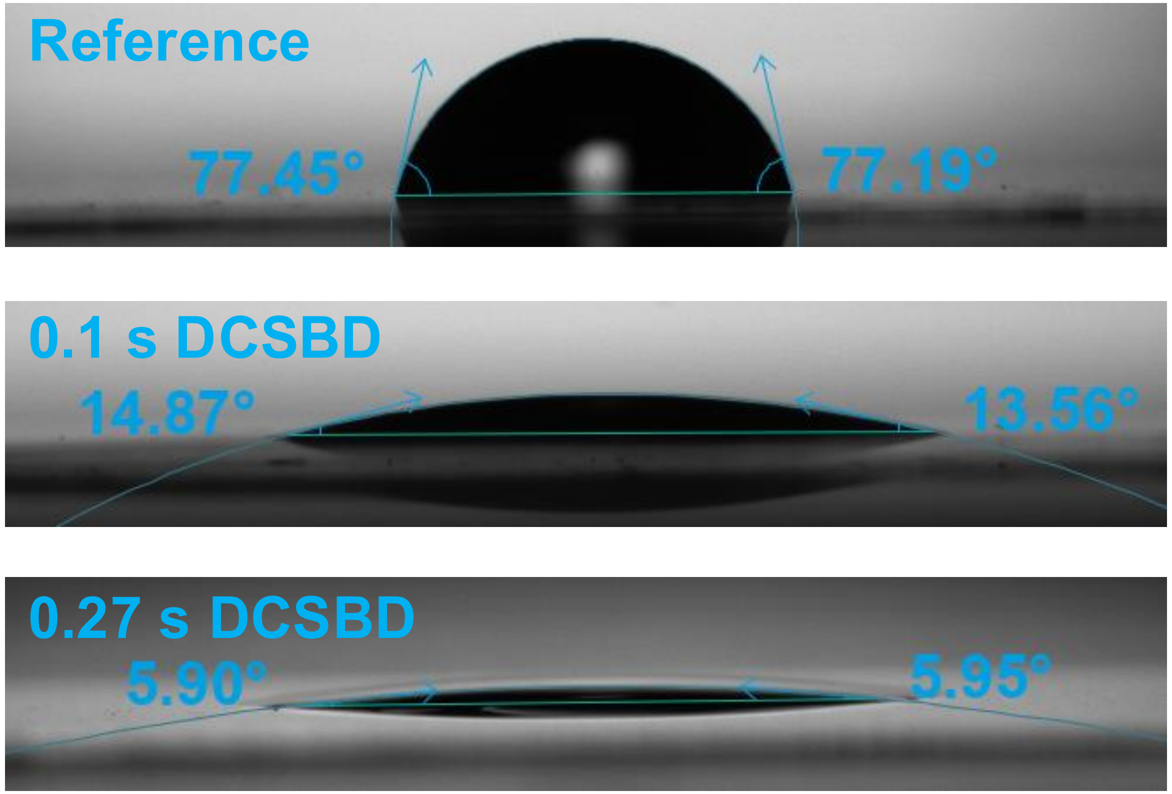
Thickness

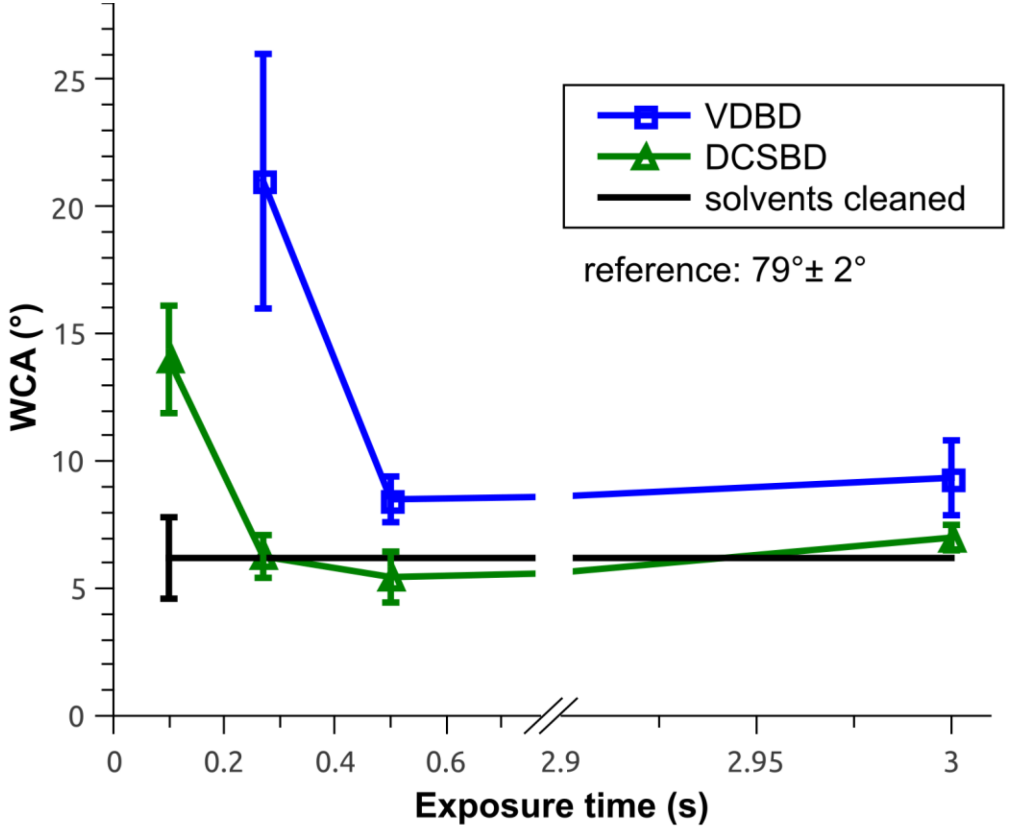
Uniformity

Conductivity

Results:

Water contact angle – hydrophilisation

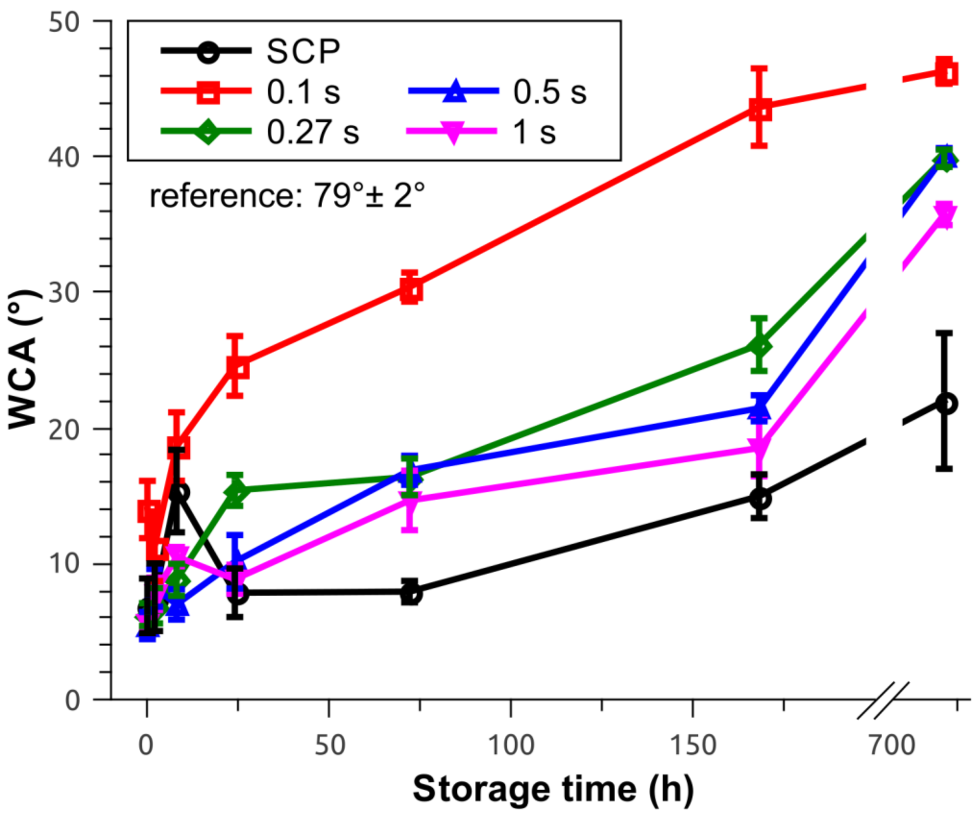


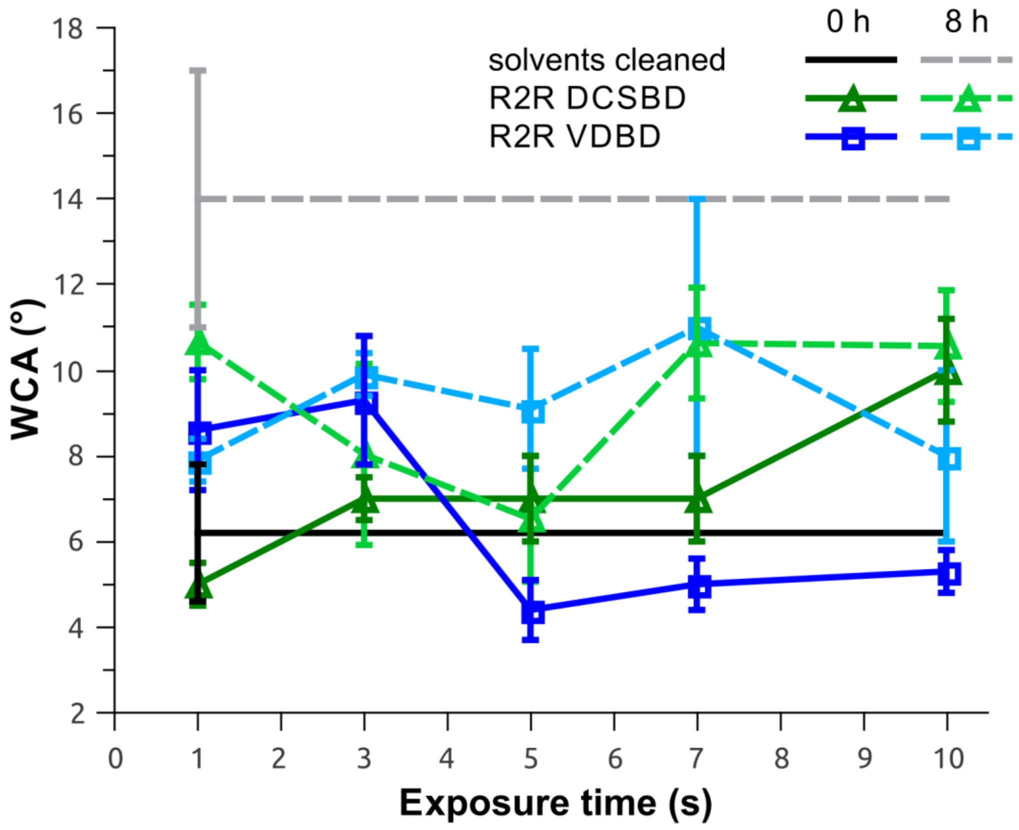


- Only 0.27-s exposure to R2R DCSBD plasma induced 92 % reduction in WCA to 6.3° ± 0.8°, which is similar to the 45 mins SCP incorporating surfactants

Results:

Water contact angle – hydrophobic recovery





Plasma treatment	8 h	7 days	30 days
0.27 s R2R DCSBD	15.4° ± 1.1° **+ 145 %**	26° ± 2° **+ 313 %**	39.9° ± 0.6° **+ 552 %**

Results:

Surface free energy – hydrophobic recovery

Total SFE:

Uncleaned reference: 35.1 mJ/m^2

DCSBD plasma 0.5 s: 74.4 mJ/m^2

Components of SFE:

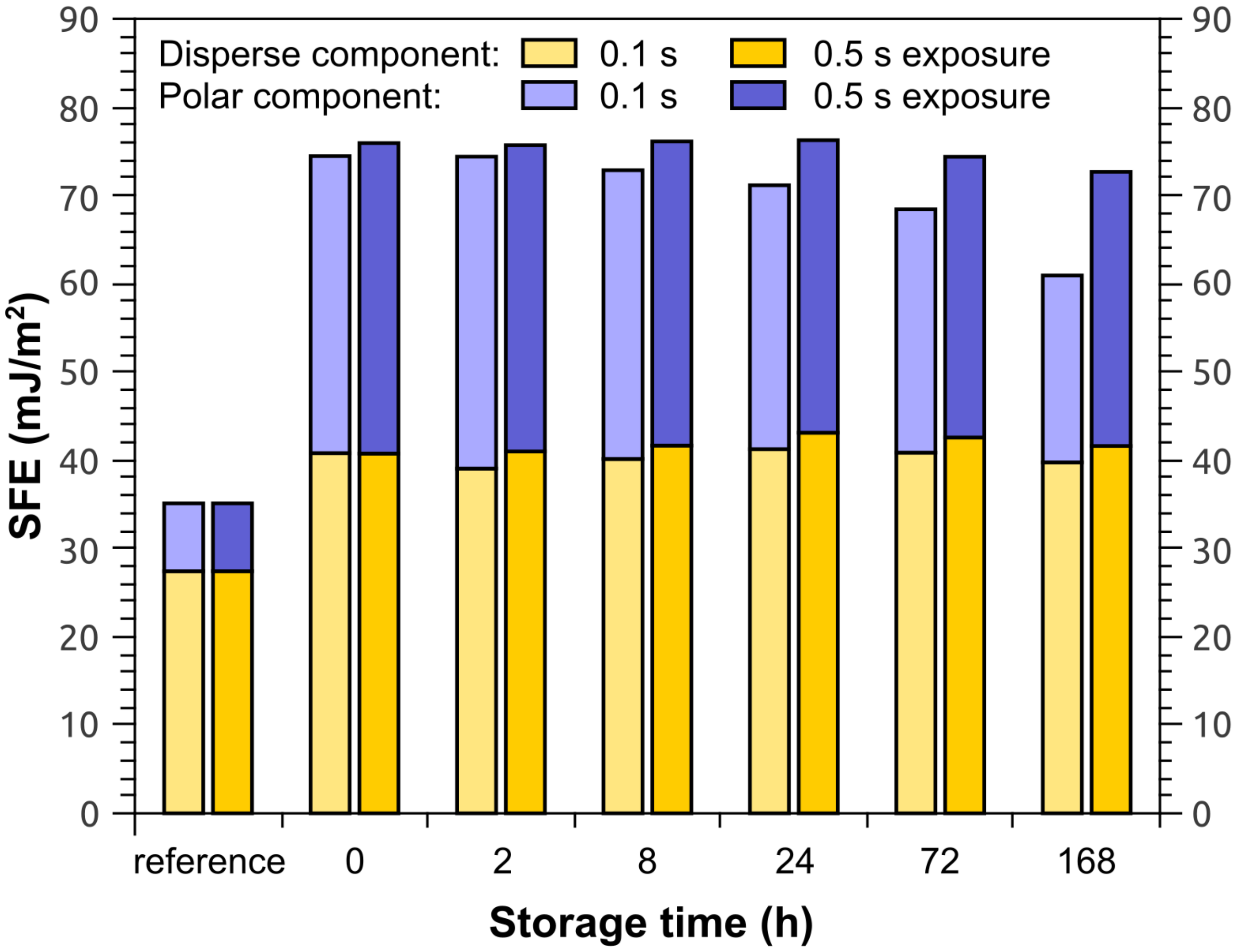
Disperse – London-Waals interactions

– physical surface modification

Polar – polar interactions (H-bond, dipole)

– functional groups (– OH, – COOH)

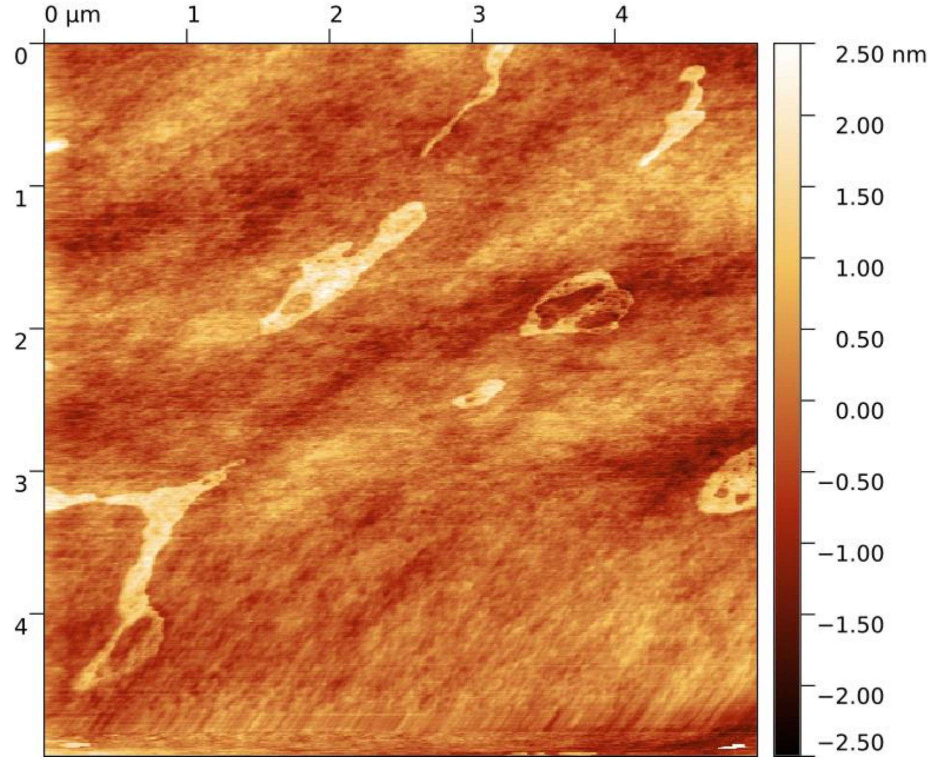
– chemical surface functionalisation



Results:

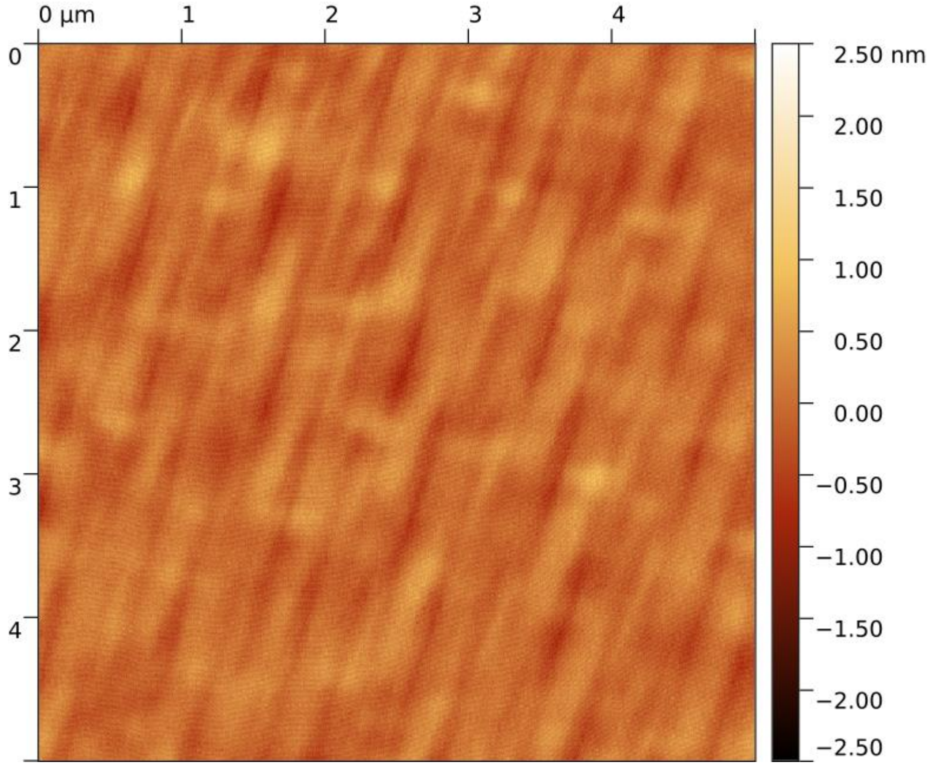
AFM – surface morphology and roughness

Uncleaned reference



Sq = 0.39 nm

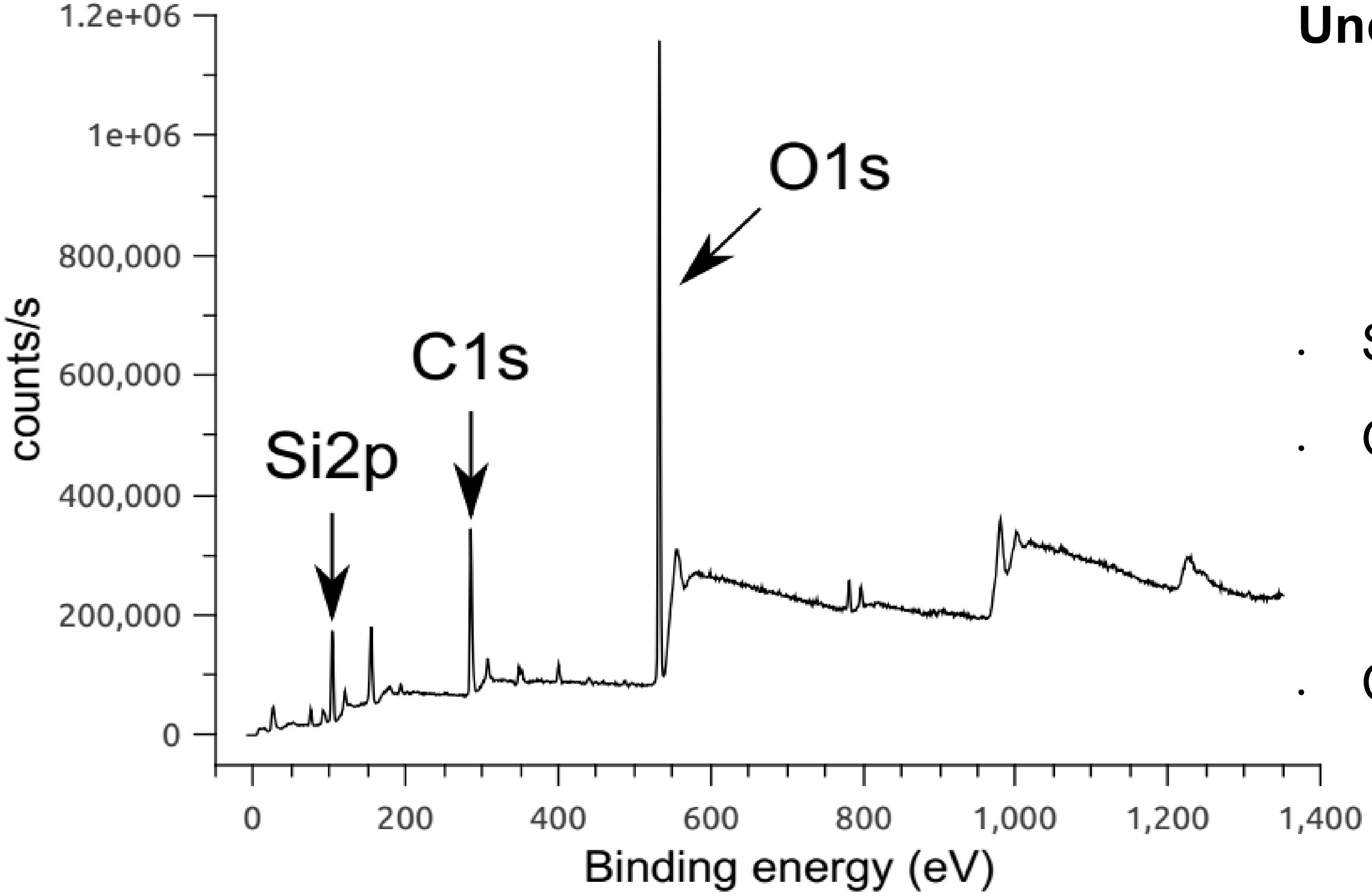
3 s R2R DCSBD



Sq = 0.38 nm

Results:

XPS – survey spectra



Uncleaned reference:

– silicon: 16 %

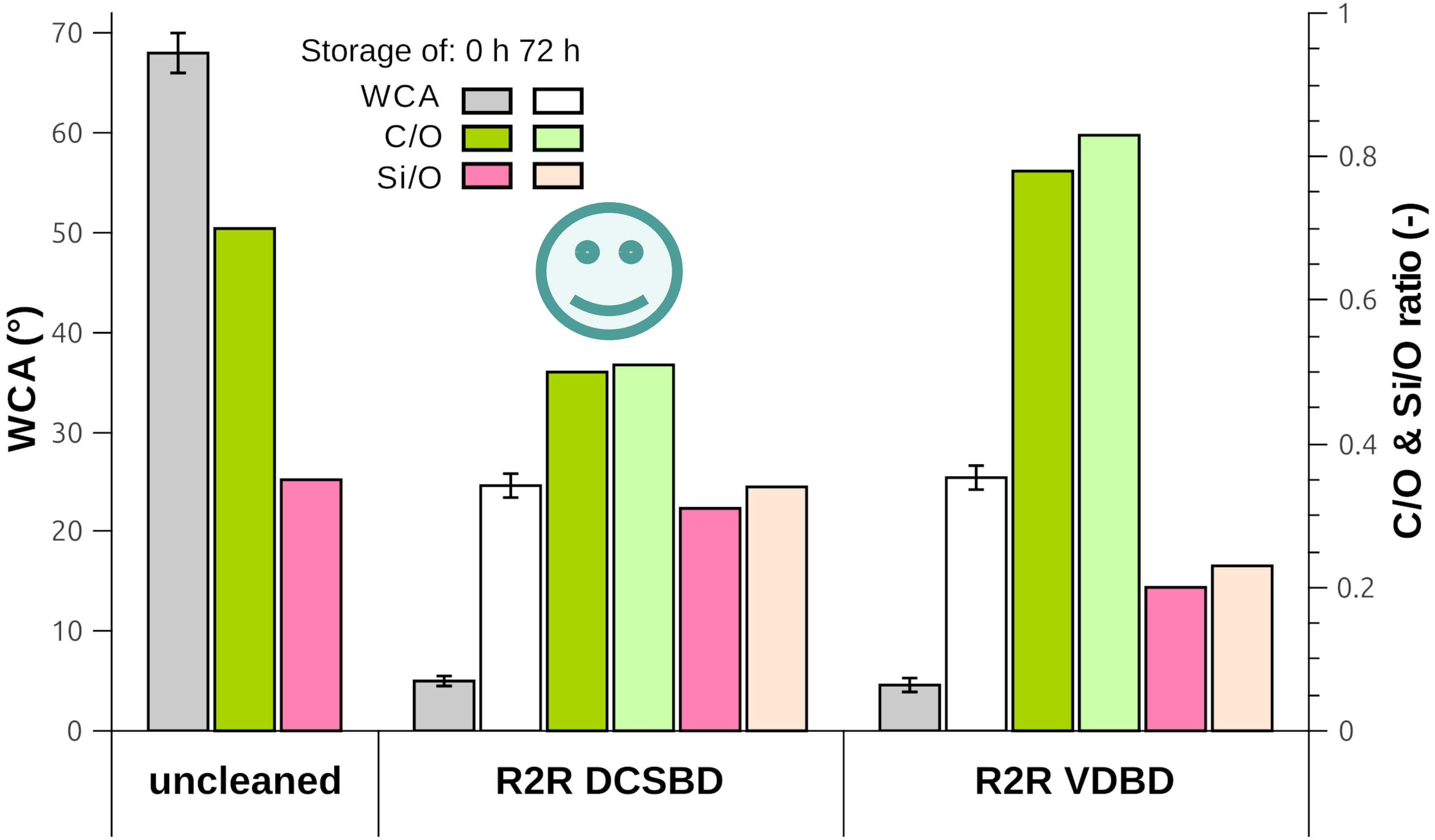
– oxygen: 45 %

– carbon: 31 %

- Silicon – glass matter
- Oxygen – bulk material
  – polar groups
  – airborne contaminants
- Carbon – polar groups
  – airborne contaminants

Results:

XPS & WCA – 1 s exposure to plasma



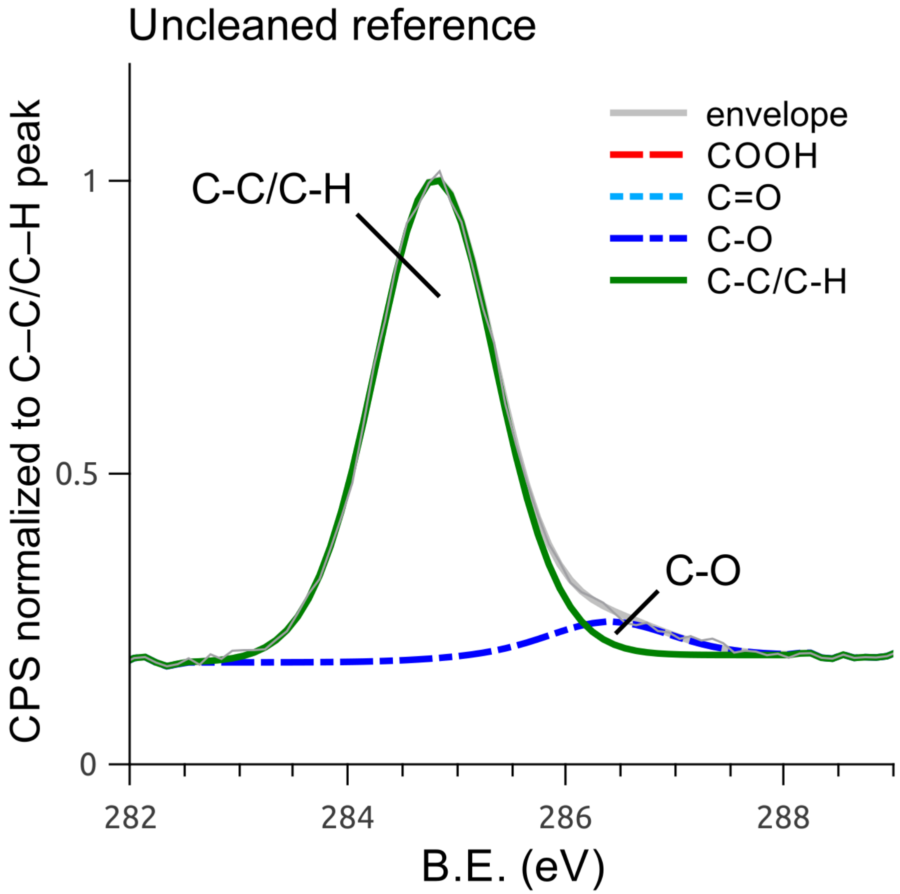
C/O increase

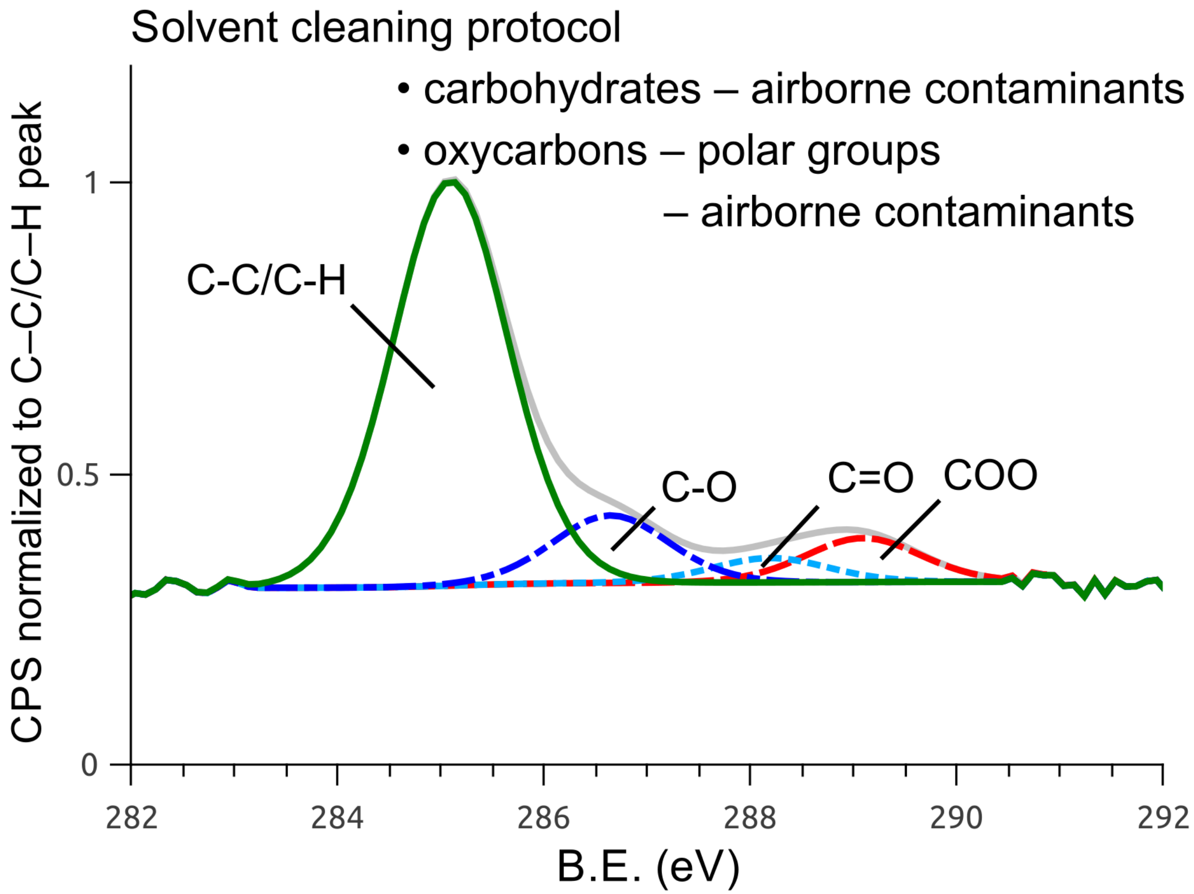
imbalance

Si/O decrease

Results:

XPS – C1s bonds – standard cleaning protocol

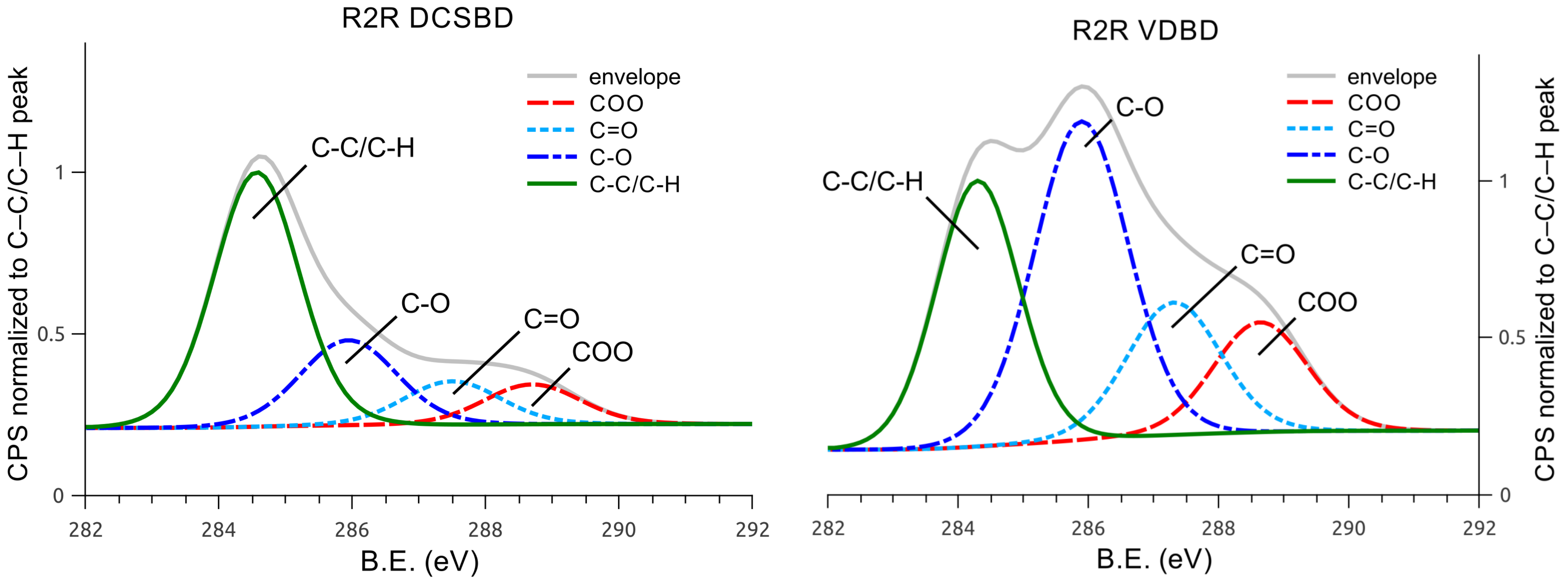




- SCP reduced carbohydrates and introduced oxycarbon bonds, while WCA dropped by 92 %

Results:

XPS – C1s bonds – 1 s exposure to plasma

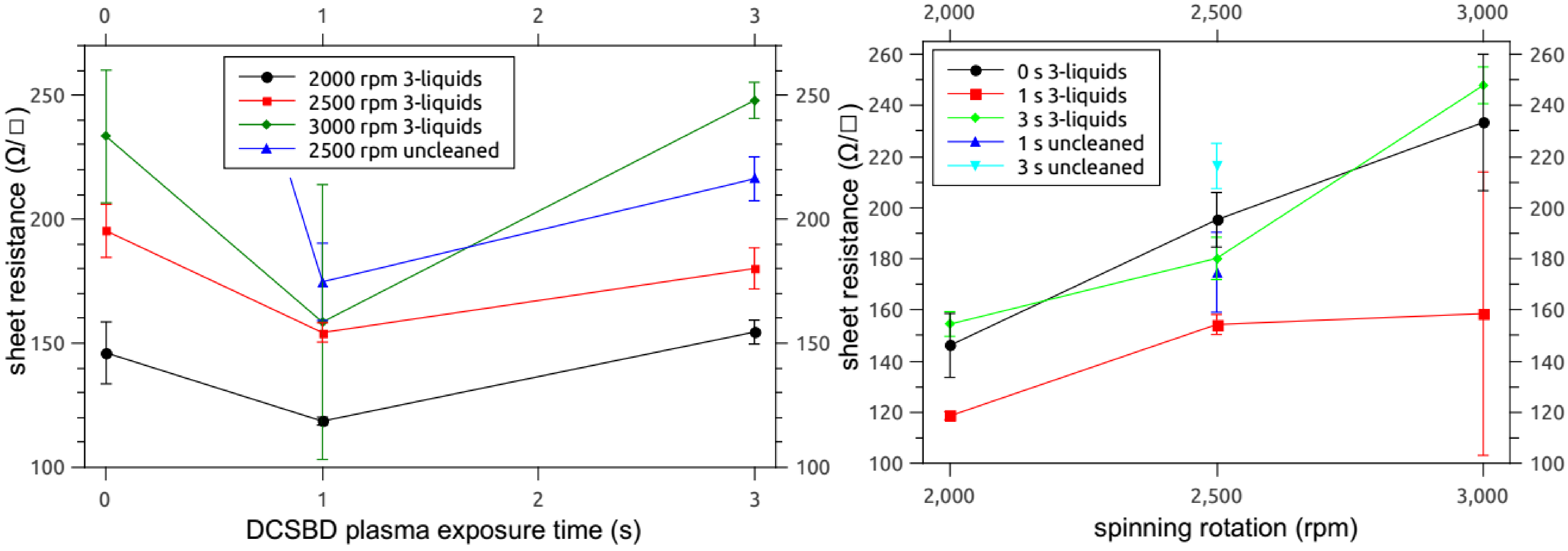


- R2R DCSBD showed a similar distribution of C1s components as the most stable SCP

Results:

Spin-coated layers – sheet resistance

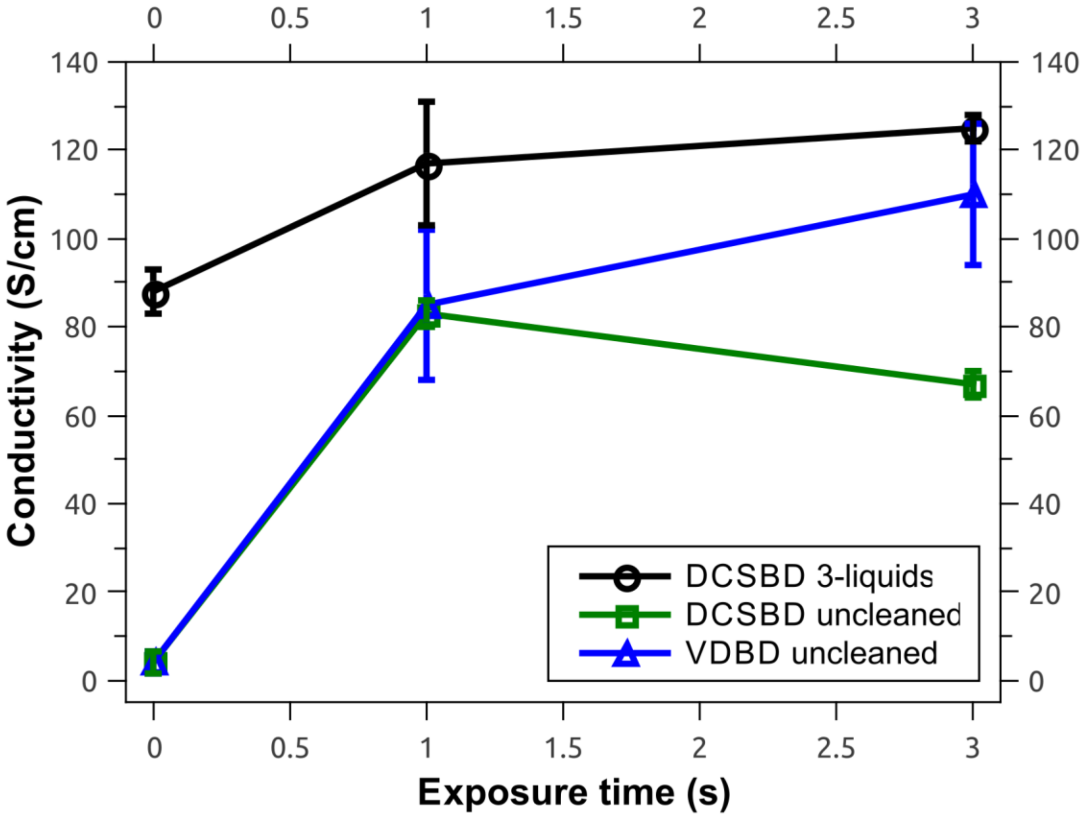
PEDOT:PSS + EG + IPA on DCSBD plasma treated UTFG

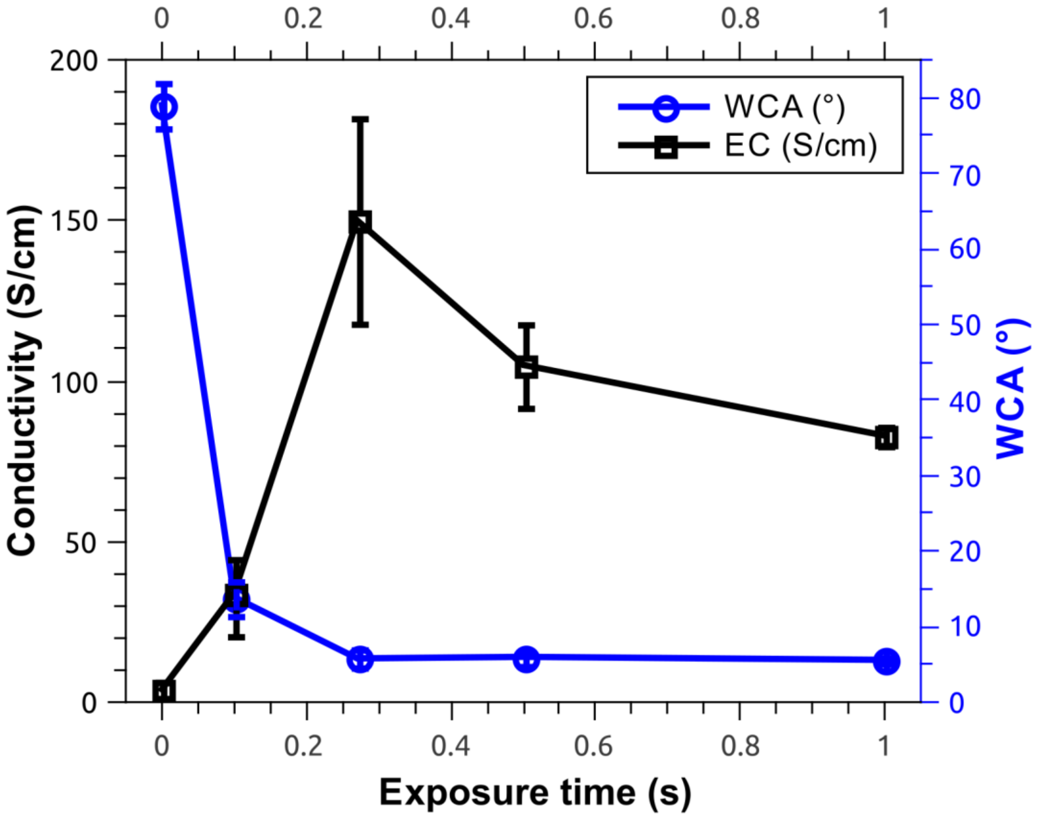


- The lowest sheet resistances were measured on layers treated 1 s with DCSBD plasma

Results:

Spray-coated layers – conductivity

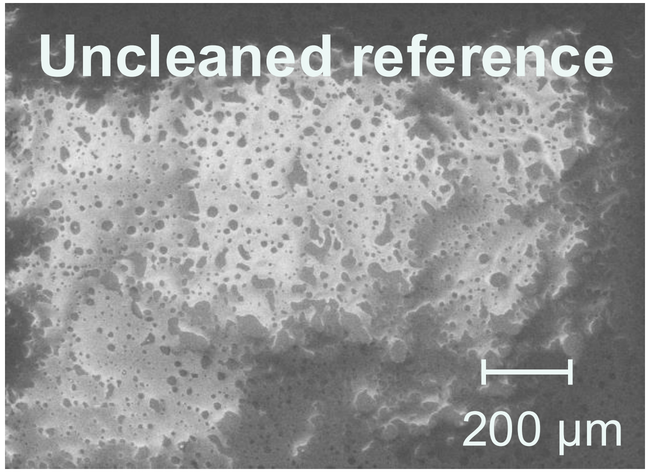


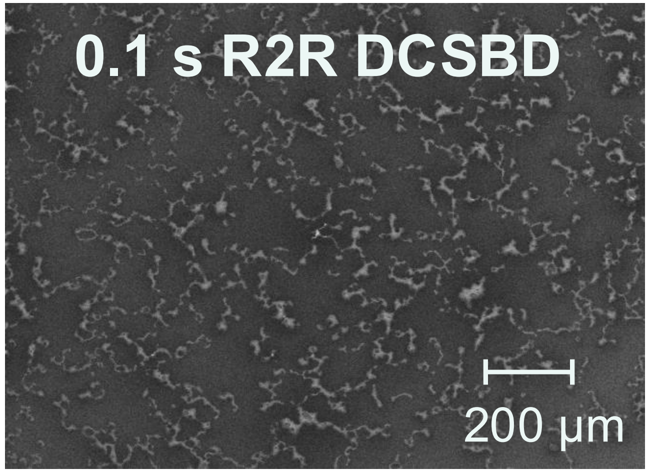


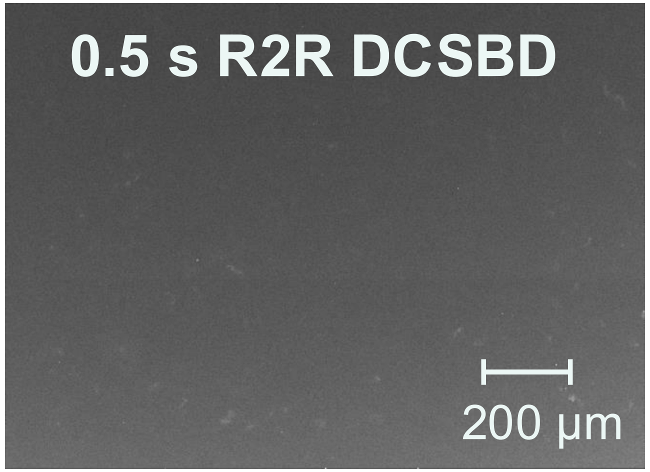
- Only 0.27-s exposure of UTFG to R2R DCSBD air plasma allowed to produce coatings with similar electrical parameters to 45-min SCP using ultrasound and 3 liquids

Results:

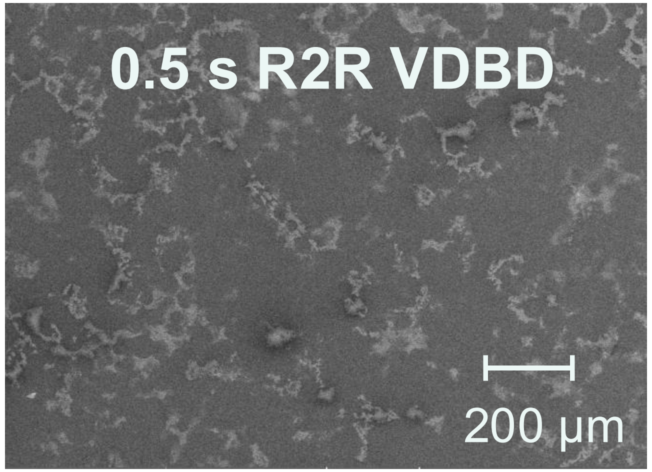
Spray-coated layers – SEM







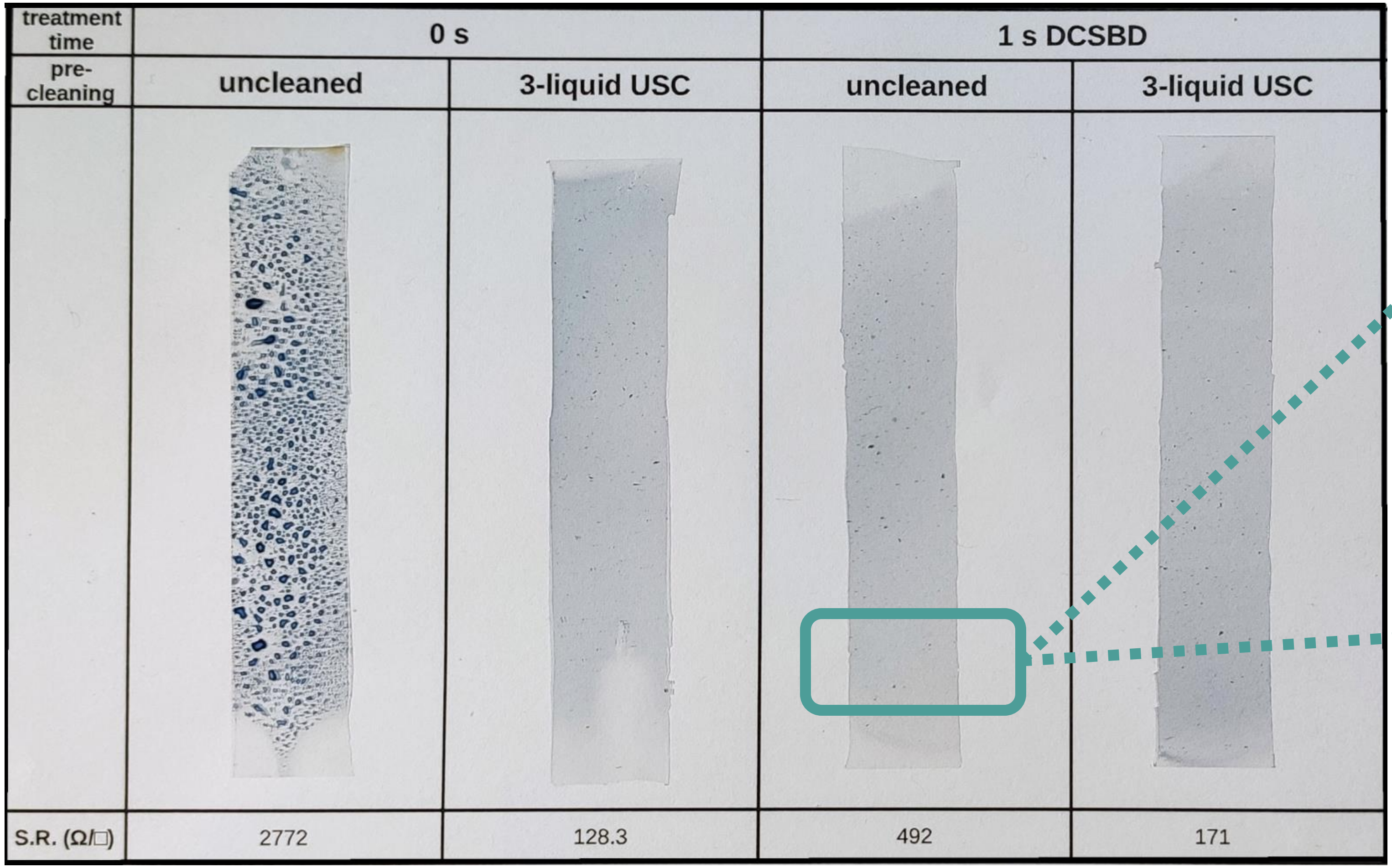
- Uniformity of PEDOT:PSS layers plays key role in their electrical performance
- Prolonging exposure time to plasma prior to coating indicates improvment of uniformity
- 0.5 s R2R DCSBD → EC = 105 ± 13 S/cm



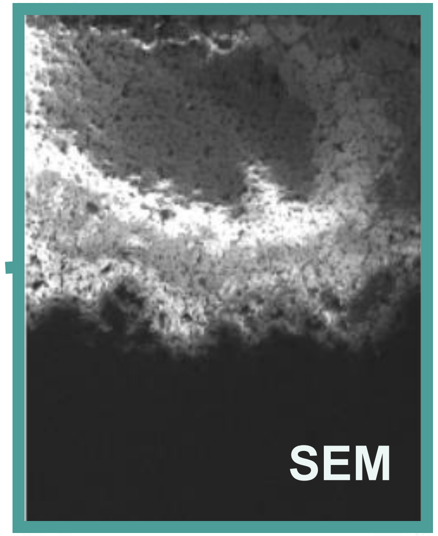
Results:

Spray-coated layers

Boundary of plasma-treated area



treatment time	0 s		1 s DCSBD	
pre-cleaning	uncleaned	3-liquid USC	uncleaned	3-liquid USC
S.R. (Ω/□)	2772	128.3	492	171



Summary:

Conclusions

- R2R DCSBD plasma approved as an effective and gentle tool for cleaning and activation of UTFG without deterioration of its smooth surface
- R2R VDBD plasma induced increasing of oxygen-based functional groups in differrent way than treatment with R2R DCSBD or solvent cleaning protocol incorporating surfactants
- The short exposure time (~ 0.5 s) to R2R DCSBD plasma is optimal for pretreatment of UTFG prior to deposition of thin (~ 50-150 nm) uniform PEDOT:PSS-based layers, which is perspective for replacing solvent cleaning in the fabrication of flexible optoelectronics on glass