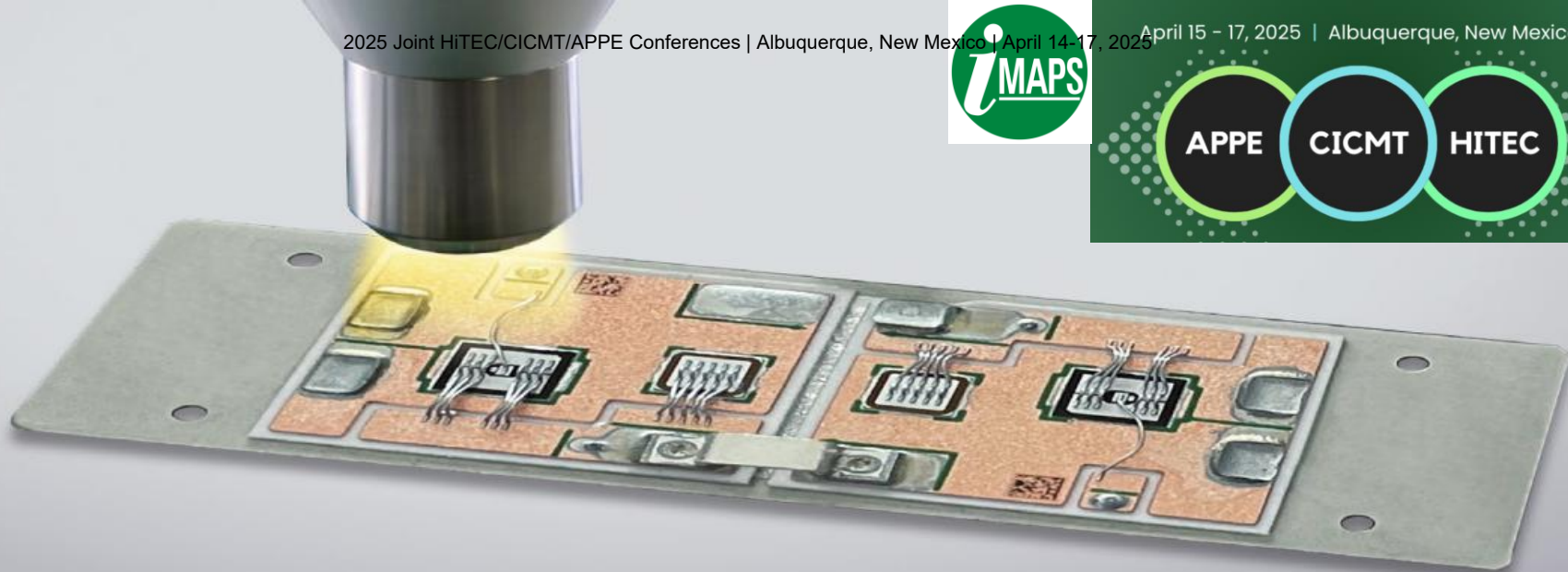


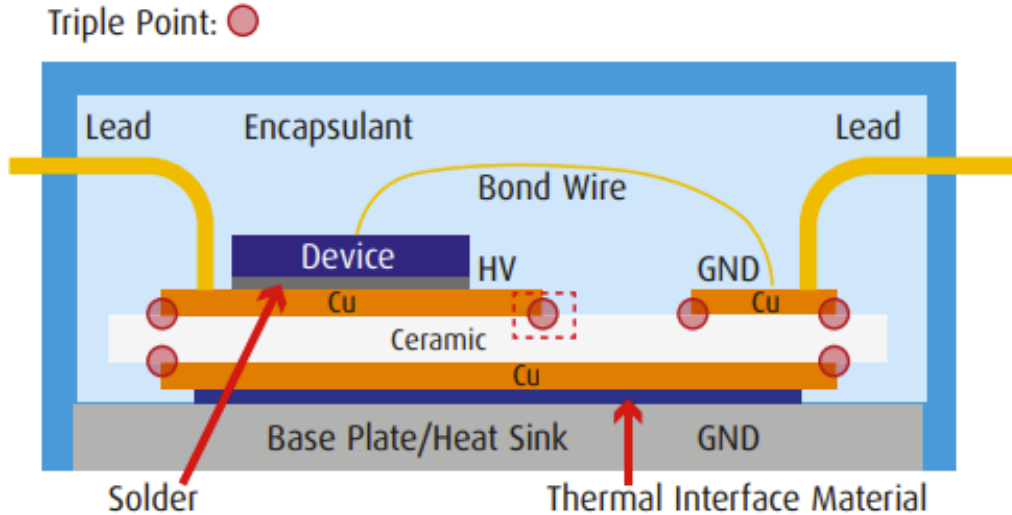


Plasma Engineering of Materials for Power Electronics Packaging

**Daphne Pappas, Ryan Robinson, Terry Dunbar, Yaser Hamedi, Nico Coenen, and
Dhia Bensalem**

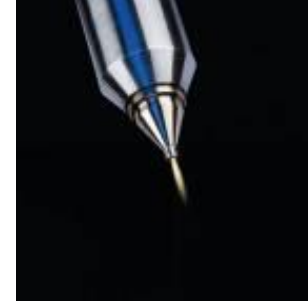


Power Module – Material Challenges



- Dissimilar materials: adhesion, thermal and electrical properties of each layer are critical

Plasma Jets - Localized vs Large Area Treatment

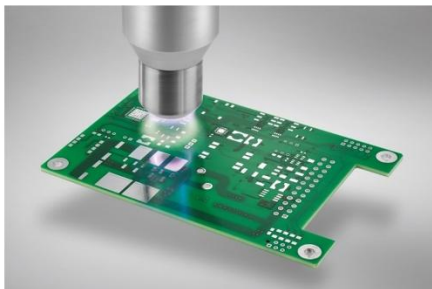


4mm to 120mm treatment width

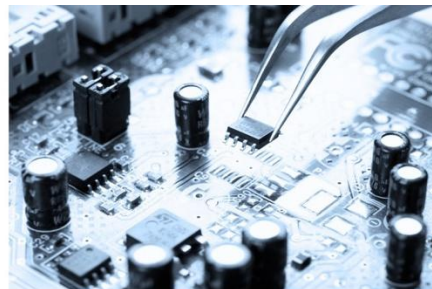
Atmospheric Pressure Plasmas for Electronics Manufacturing



Cell Phone Manufacturing



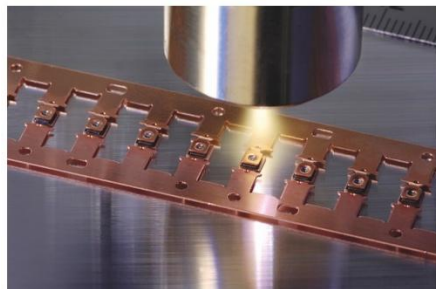
PCB Manufacturing



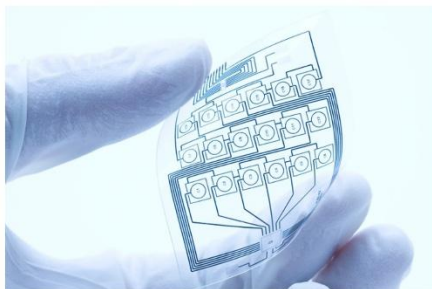
PCB Assembly



LED Manufacturing



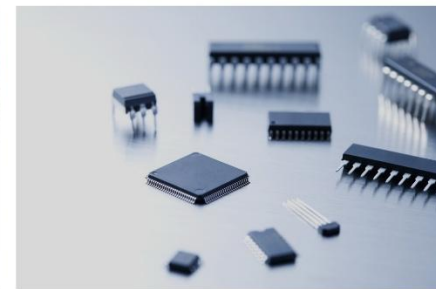
Semi & Packaging



Flex Circuits



Display Manufacturing

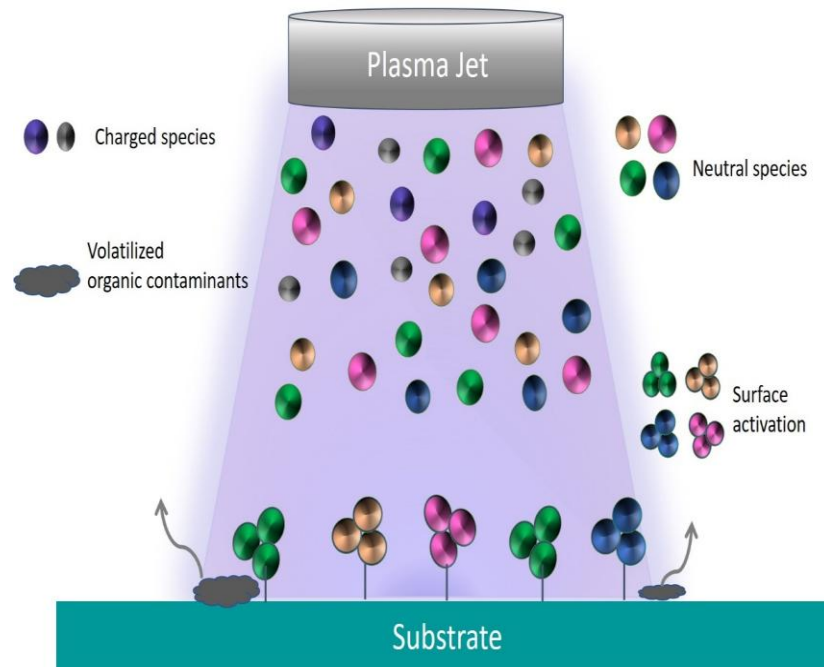
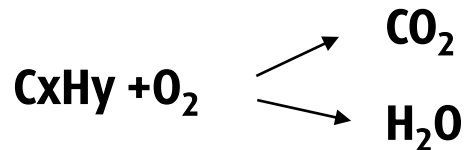


Component Assembly

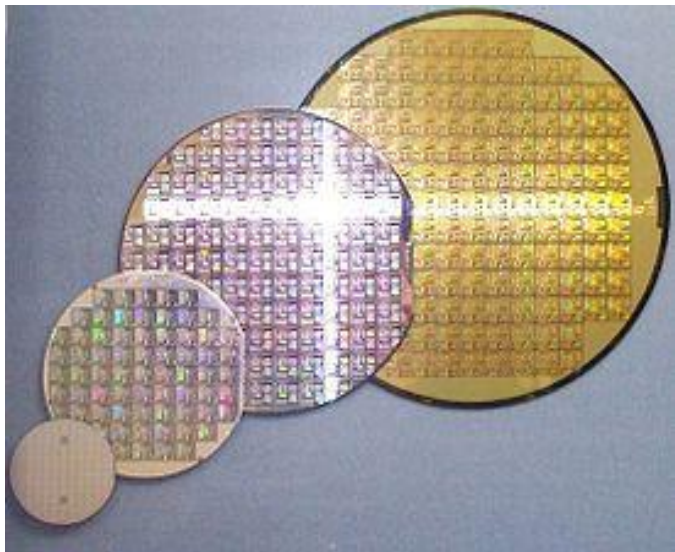
Openair®-based Plasmas for Cleaning

Removal of Contaminants:

Flux residue, organic layers, epoxy
overmold materials



Packaging Materials Cleaning

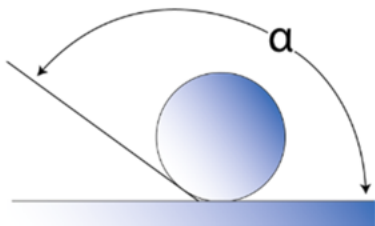
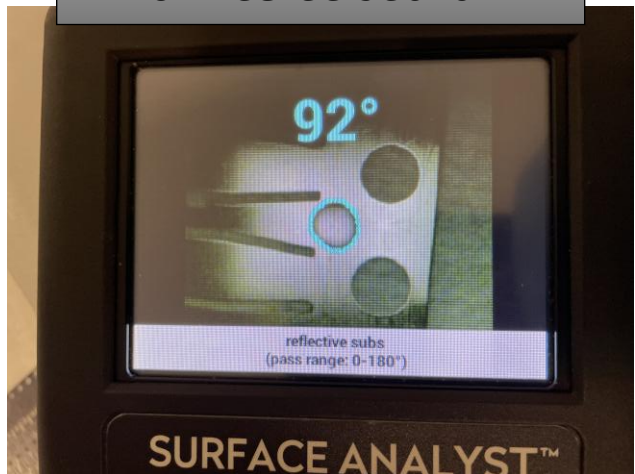


➤ Materials

- Si wafers
- Dies
- Metals: leadframes, wire pads and wires
- PCBAs
- Solder resist/FR4 boards

Leadframe Cleaning With Openair® Plasmas

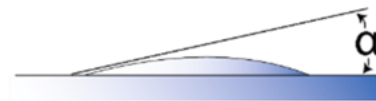
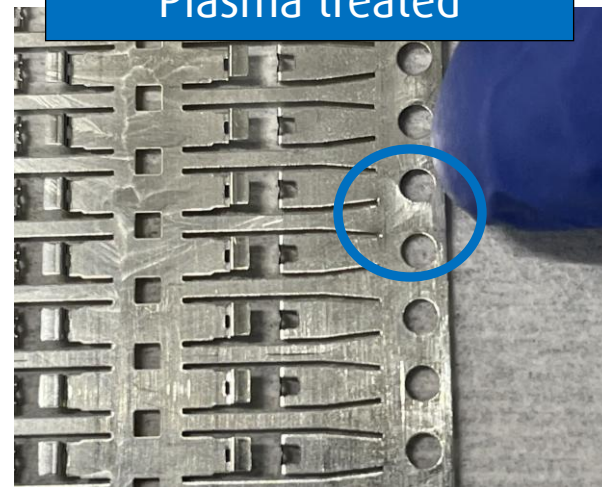
Untreated section



Low surface energy,
higher contact angle ($\alpha > 140^\circ$)
- Hydrophobic -



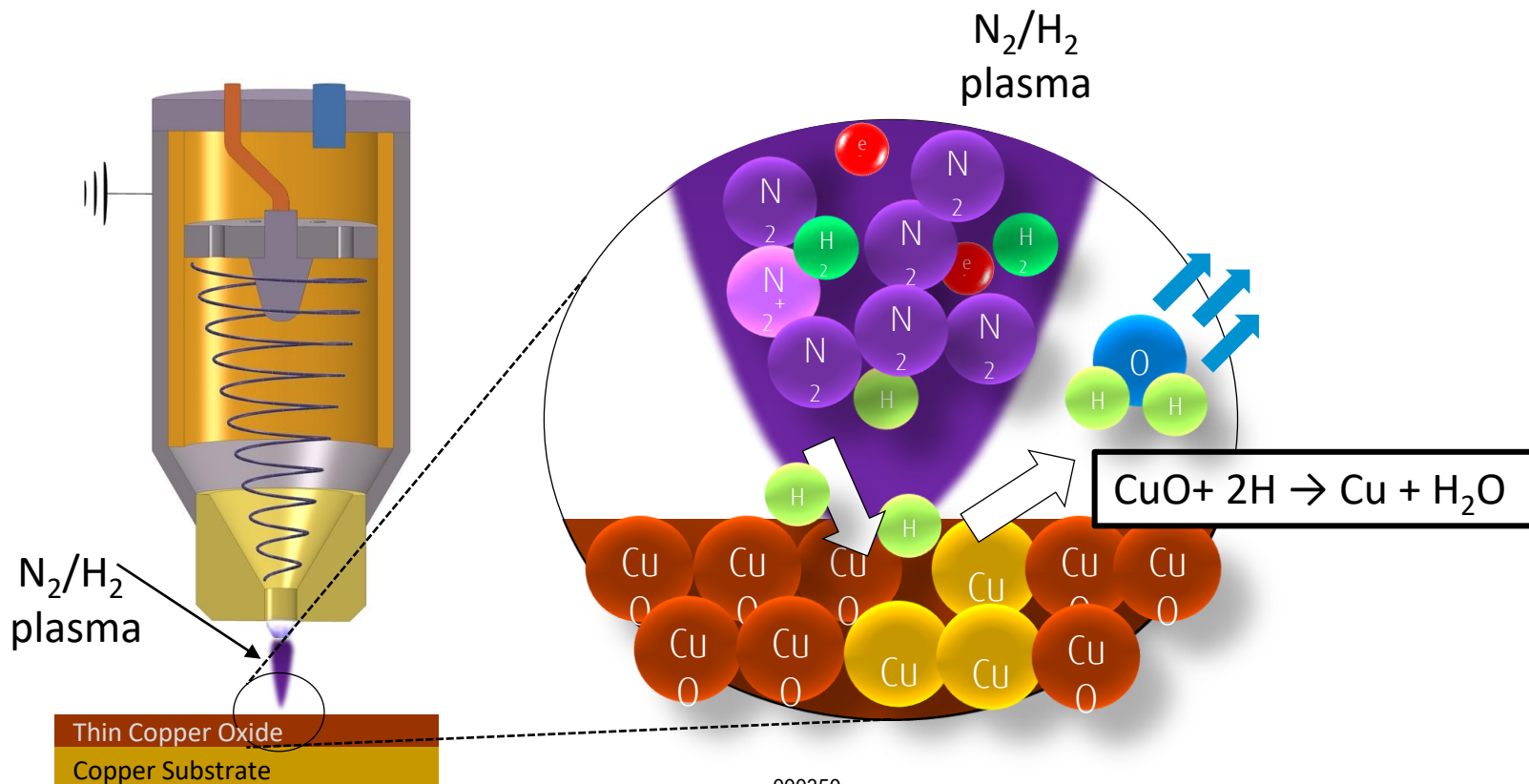
Plasma treated



Higher surface energy,
low contact angle ($\alpha < 40^\circ$)
- Hydrophilic -

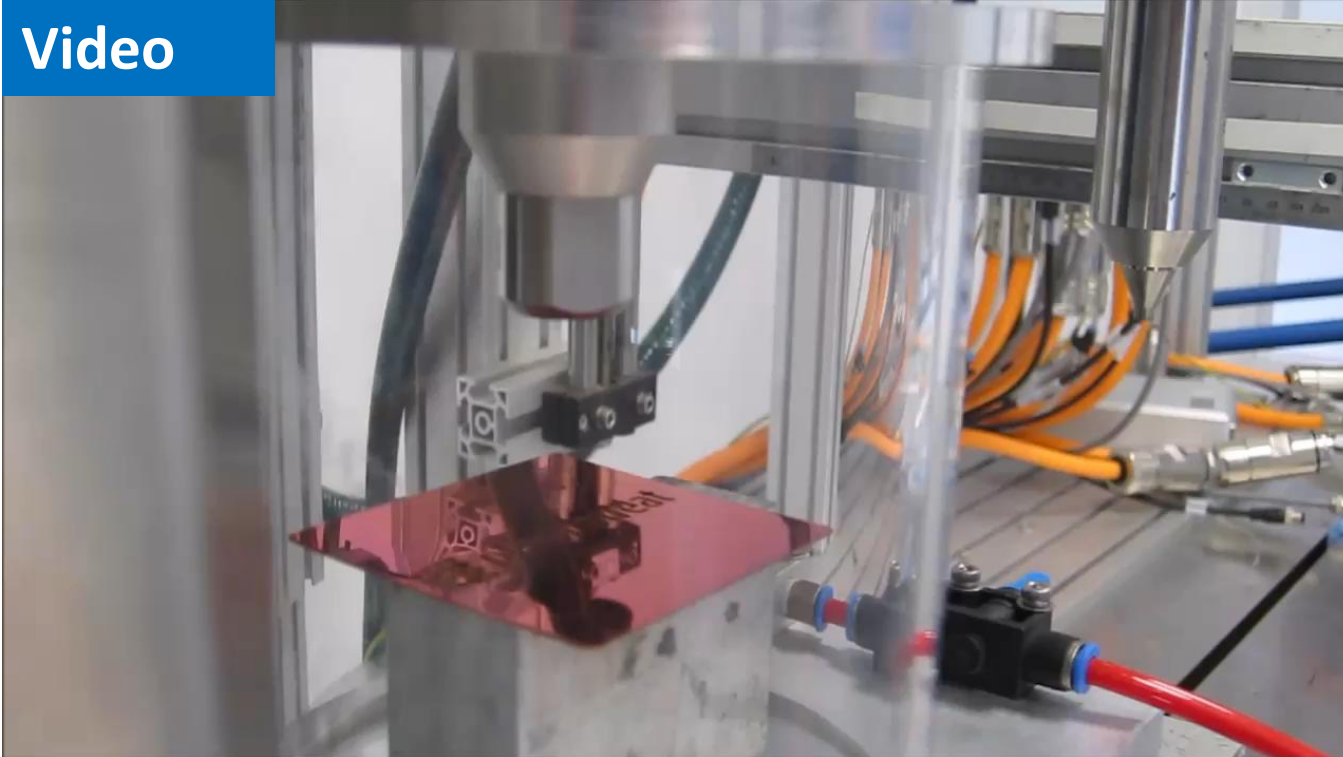
Plasma-Induced Metal Oxide Reduction

Example: Cu

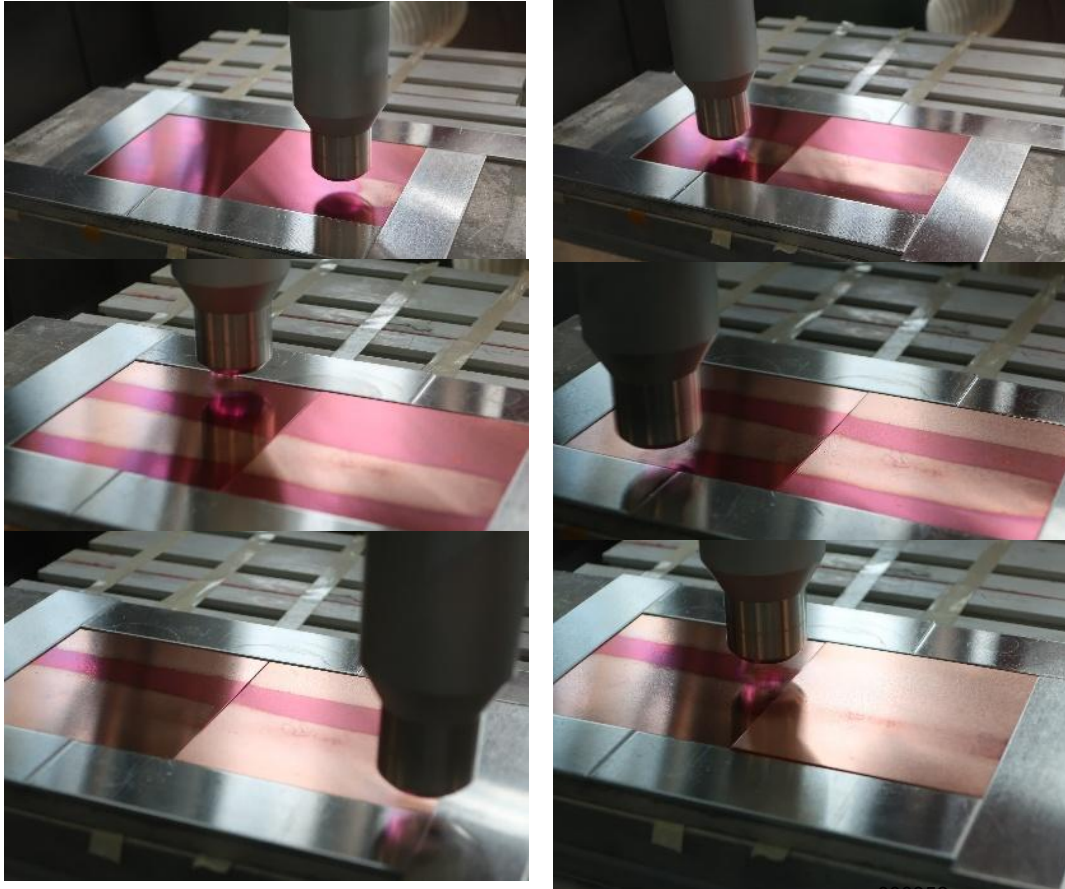


Small Scale Copper Oxide Reduction

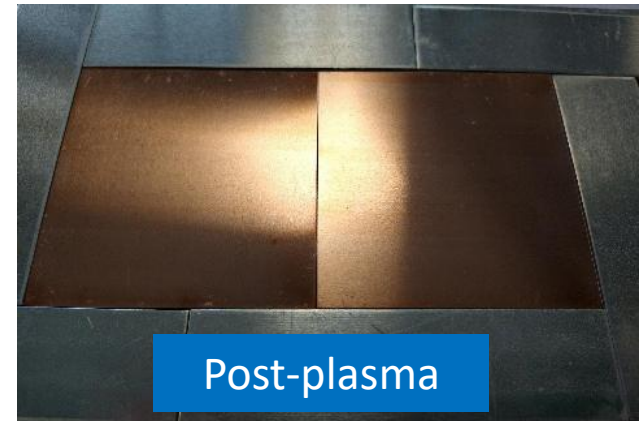
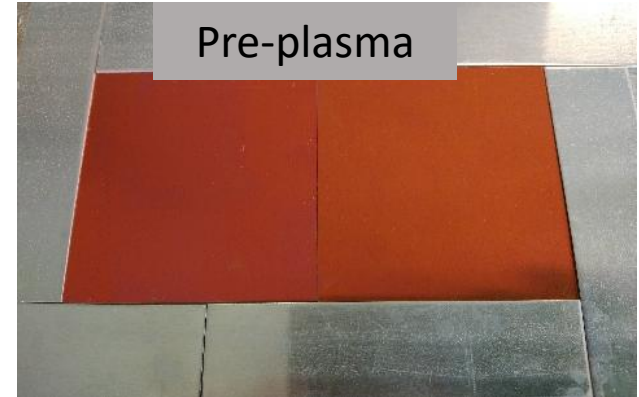
Video

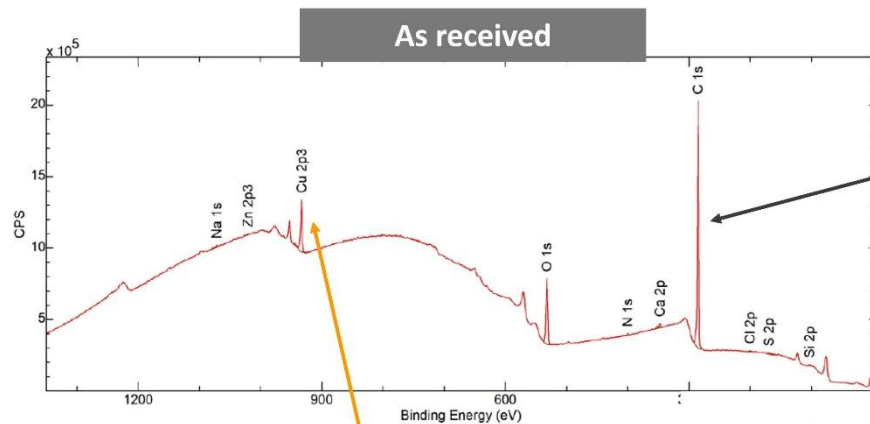


Inline Copper Oxide Reduction



000352

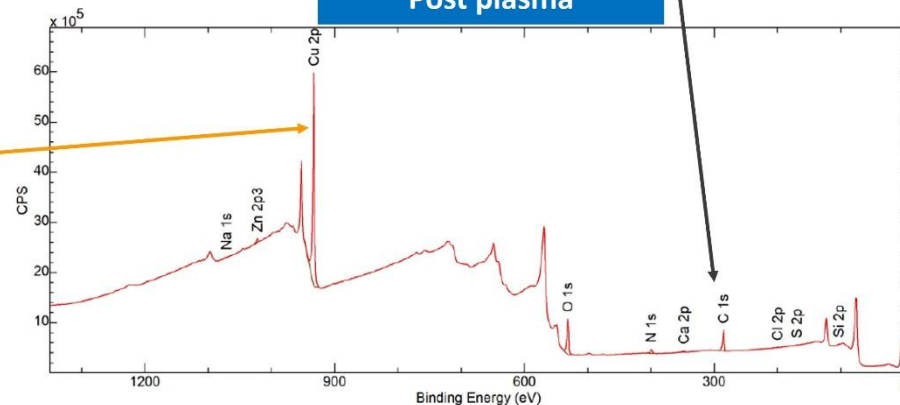




**Removal of carbon
contaminants**

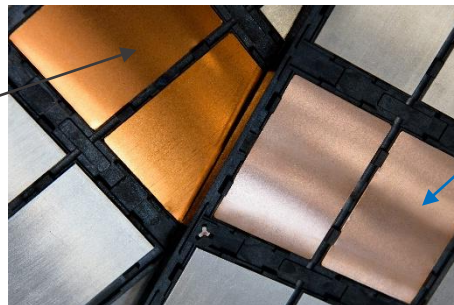
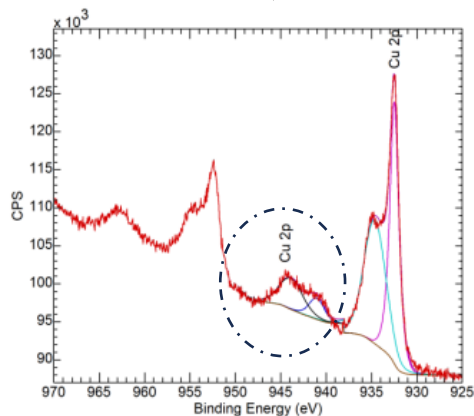
Increase of surface Cu

Post plasma

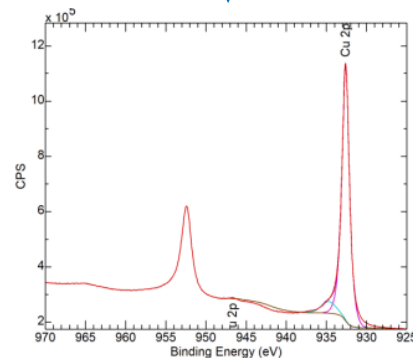


Oxide Levels Remain Low After Plasma Treatment

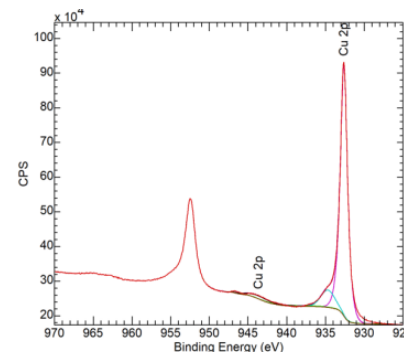
As received



Post plasma



At t=0



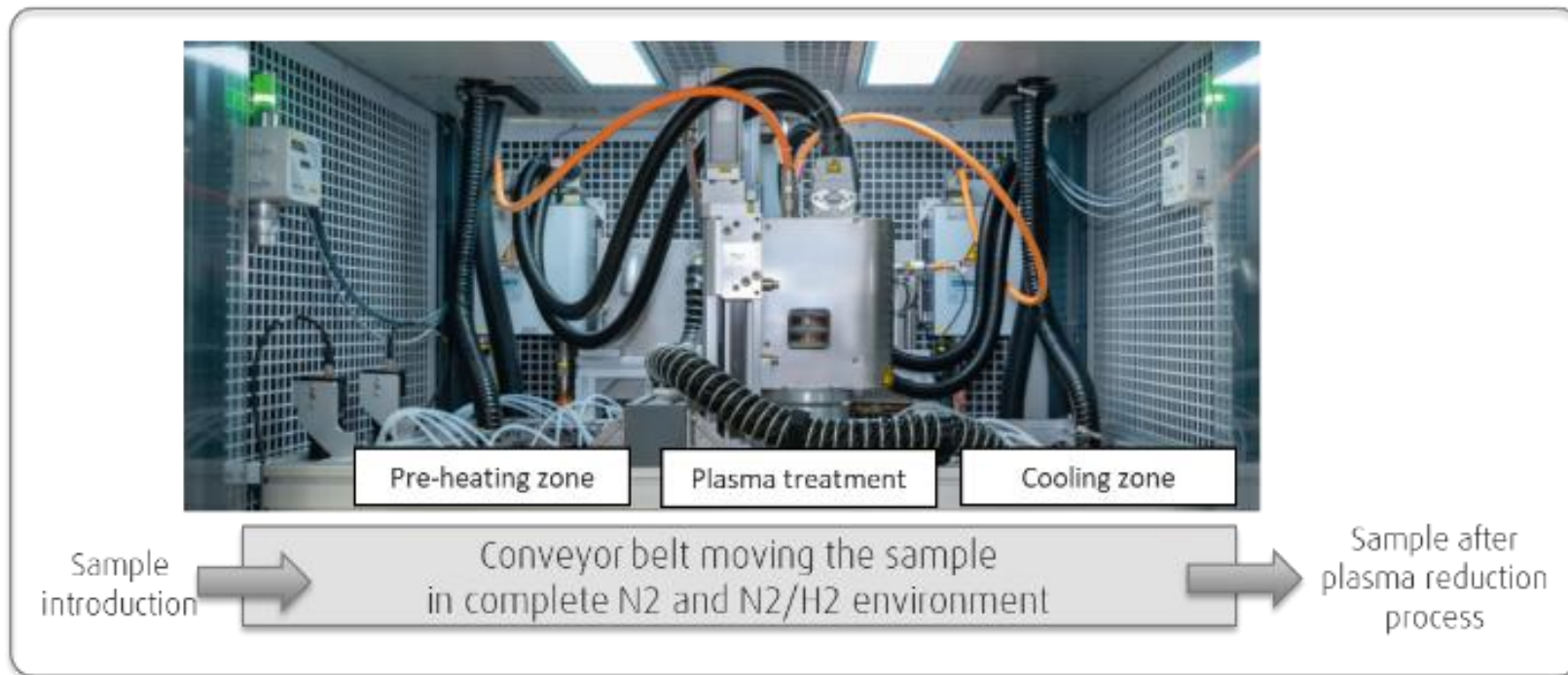
After 3 days

Cu(0) - metallic Cu: ↑ 47 at%

Cu(I) - Cu₂O: ↓ 25 at%

Cu(II) - CuO: drops down to 0 at%

Industrial Scale System for Metal Oxide Reduction



Optimized process for high processing speed
Mitigation of re-oxidation

Other Metals

➤ Silver oxide reduction

	Ag	O
As-received	15.0%	24.1%
Plasma treated	57.5%	9.9%

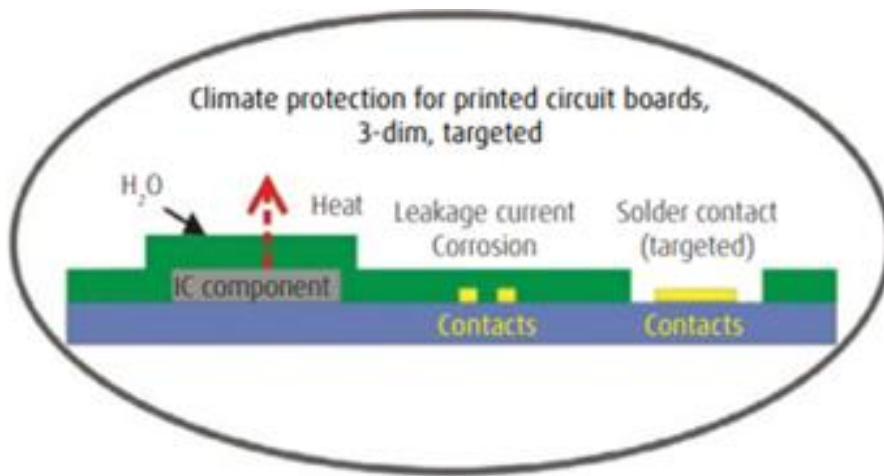
➤ Nickel oxide reduction

	Ni (M)	Ni (Ox)
As-received	0.2%	99.8%
Plasma treated	21.7%	78.3%

➤ Tin oxide reduction

	Sn (M)	Sn (Ox)
As-received	3.6%	96.4%
Plasma treated	48.0%	52.0%

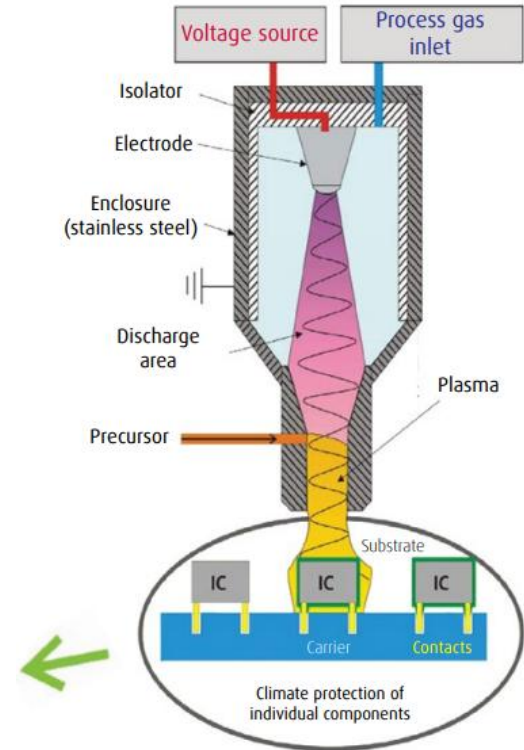
Dielectric/Barrier Layers in Packaging



- Provide electrical insulation, thermal stability, and protection against physical and chemical damage

Atmospheric Pressure Chemical Vapor Deposition

- **Negates the need for vacuum**
- **Utilizes Clean Dry Air (CDA) and not Ar, He, etc, for plasma generation**
- **Liquid precursors can be vaporized for the deposition of functional nanocoatings (<2 μm)**
- **Selective area treatment**
- **Treatment of ceramic, metals and polymers**
- **Industrially scalable for inline processing**
- **Treatment of 3D, unique geometry parts**



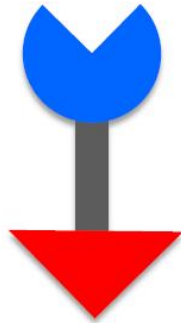
Discover the fascinating new possibilities of this technology and benefit from the extensive knowledge of our experts.

Deposition of Organosilicon Nanocoatings

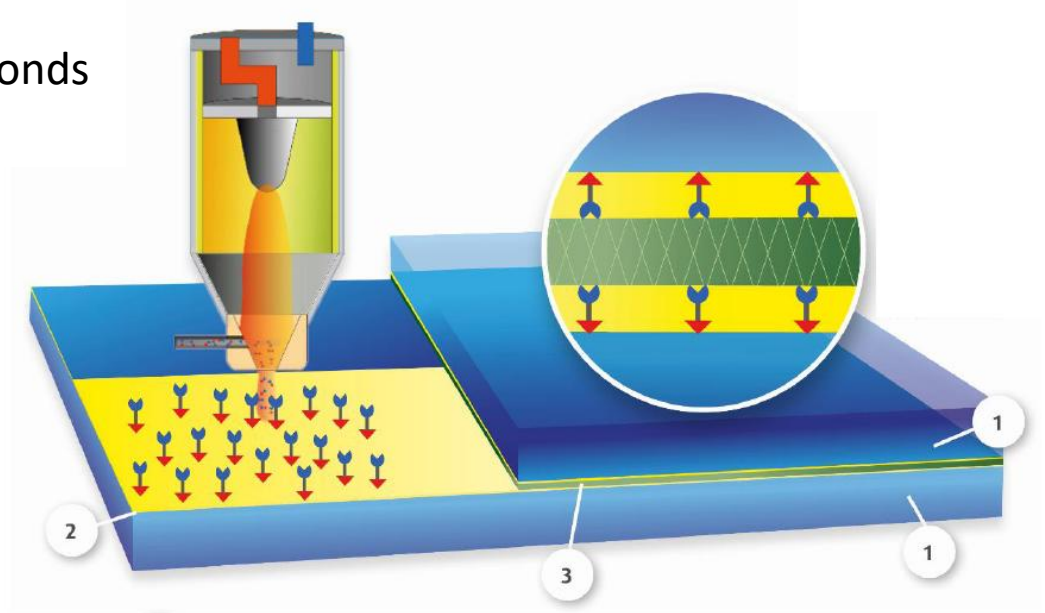
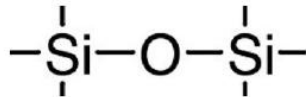
Plasma Polymer/Ceramic Coating:

- Bi-functional layer
- Formation of strong covalent bonds
- Dry process

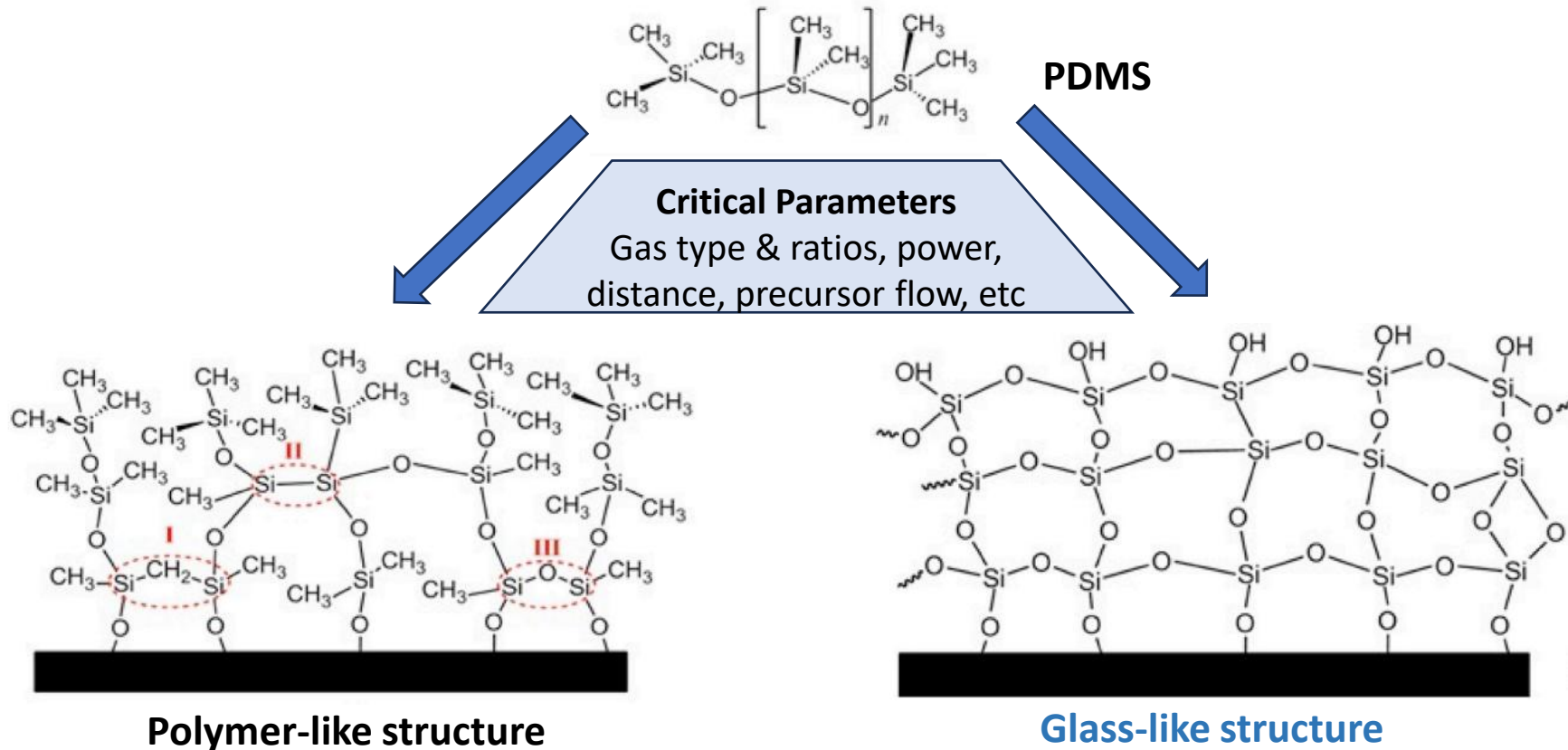
Functional group:
amine, epoxy,
methyl, acrylate



Inorganic
backbone

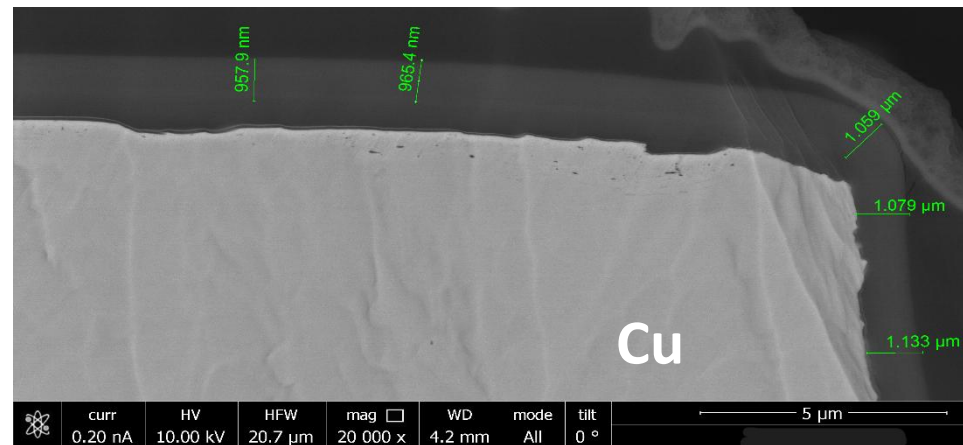
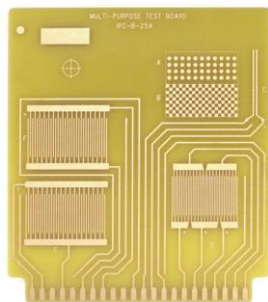


Control of Nanocoating Structure



Dielectric/Barrier Coatings

- Dielectric coating for wearable and other low power electronic circuits
- Thin lightweight conformal coating with moisture barrier properties
- Alternative to parylene, urethane coatings



1µm dielectric coating deposited on IPC-25A printed boards

Moisture and Chemical Resistance

Substrate: Aluminum

500nm siloxane coating on top

Immersed in water for 4 hrs

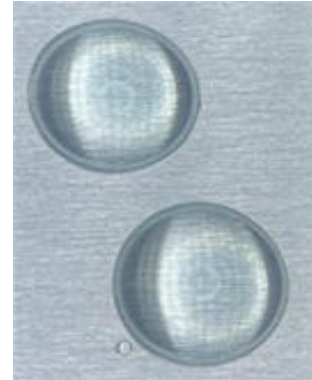


5 min exposure to CuSO_4

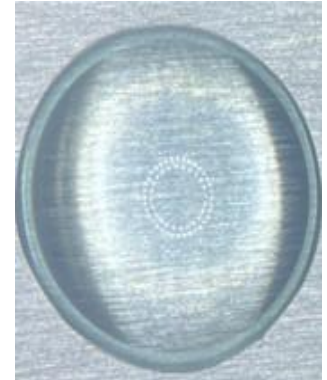
As-received



Coated



**Coated & After
4h in H_2O**

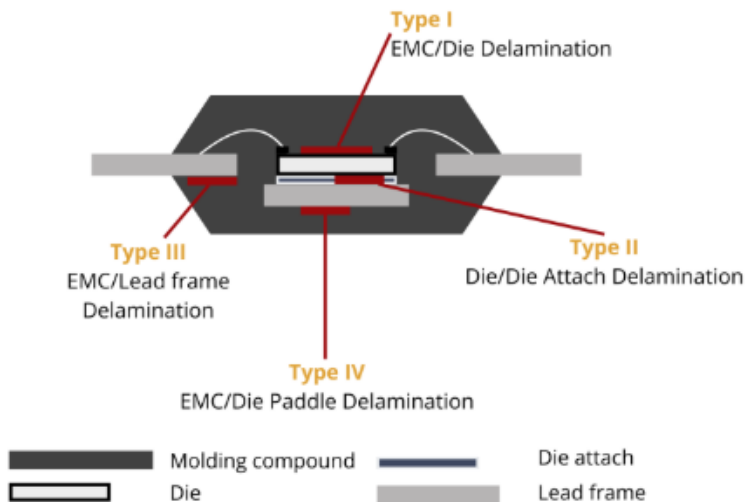


Dielectric and Other Properties

Property	Test method	Test conditions		Result	
Dielectric strength	Referring to DIN EN 60243-1	Voltage rise: 20 V/s Electrode: ball	Copper	170 kV/mm	Up to a coating thickness of ≤ 1,5 µm
			Aluminum	160 kV/mm	
			ENIG	125 kV/mm	
			ENEPIG	140 kV/mm	
			Tin	130 kV/mm	
Thermal shock test	Referring to ISO 21736	Temp. range: -40 °C – 125 °C Cycle duration: 1 h Cycles: 500	Passed		
High temperature storage		Temperature: 125 °C Duration: 500 h	Passed		
Salt spray test	Referring to MS941-04	Spray: 5 wt% NaCl Temperature: 35 °C Duration: 96 h	Passed		
Flexibility test (Mandel bending test)	Referring to ISO 1519:2011	Diameter: 3 mm Bending angle: 180 °	Passed		
Migration test	Referring to IPC-TM-650, 2.6.3.4	Duration: 500 h Humidity: 90 % RH Temperature: 85 °C	Passed		

Delamination – Interfacial Properties are Critical

Types of Delamination in Semiconductor Packages



How is this addressed?

- EMC Formulation changes
- Adhesion promoting primers
- Solvent cleaning, sanding (lead frames)

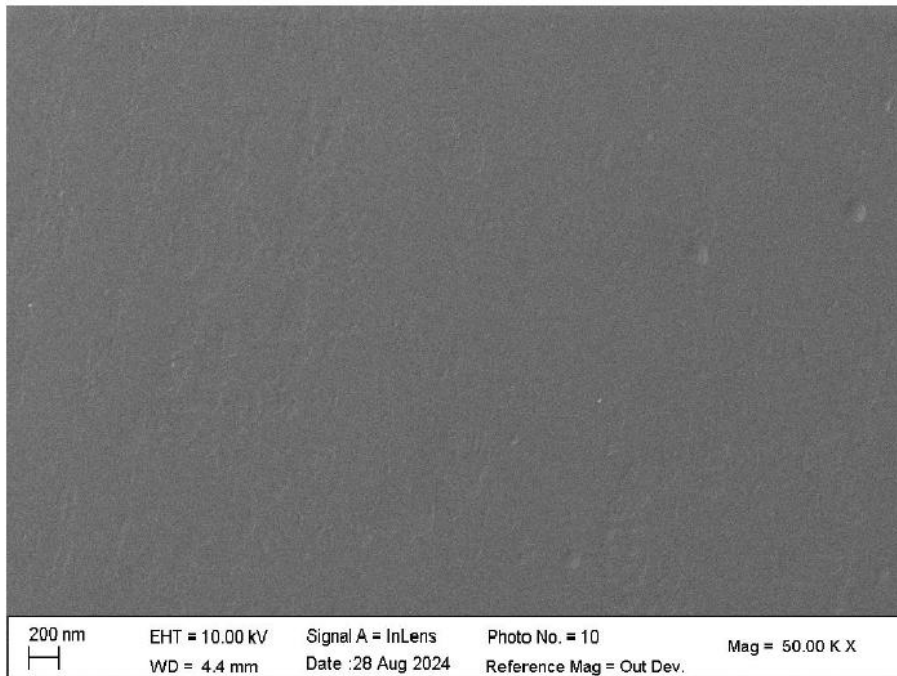
Alternative



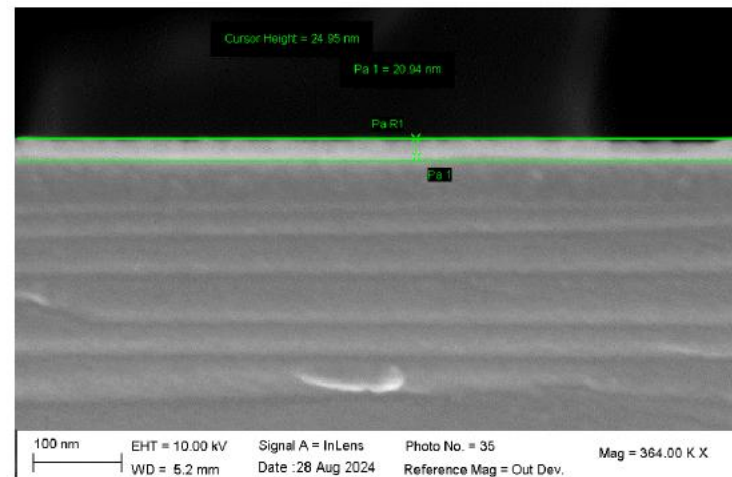
Plasma cleaning and deposition of nanocoatings: dry method

Adhesion Promoting Thin Layers

Plasma deposited siloxane layer



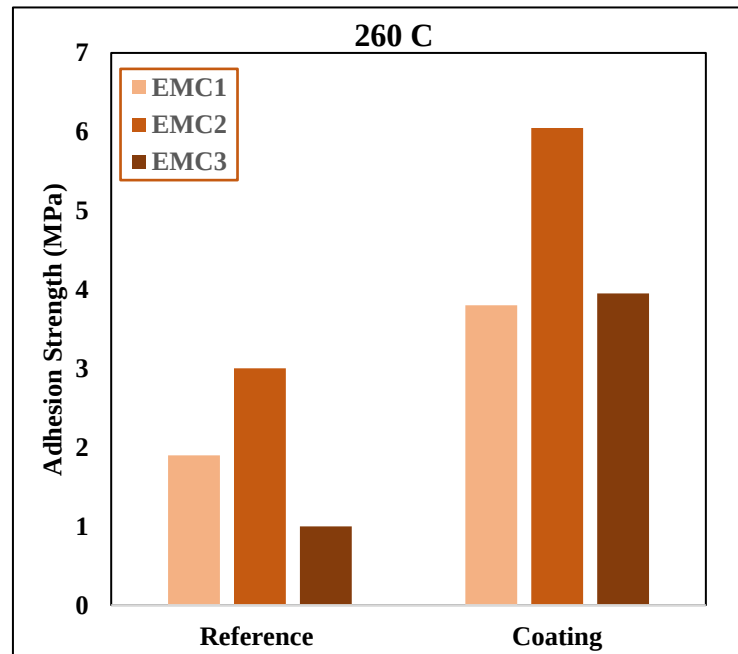
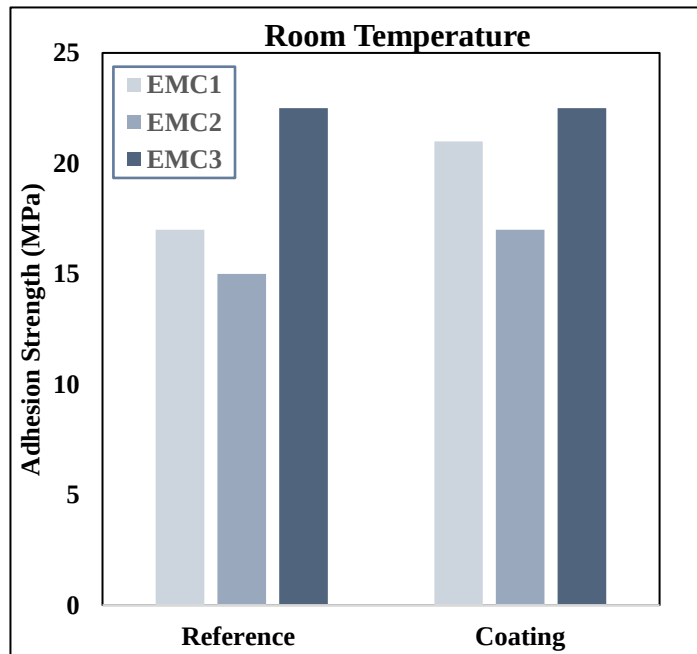
Results



Smooth uniform coatings on Si wafers

000365

Adhesion Test Results – 3 EMC Compound Study

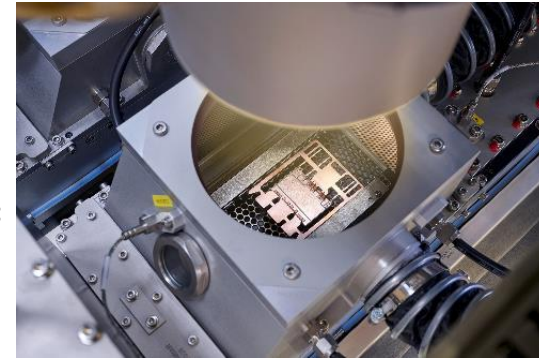


**Coating
thickness:
36nm**

Button shear testing: Improved adhesion strength due to the nanocoating

Summary

- ❑ Plasma-induced copper oxide removal for inline industrial processes
- ❑ Applicable to other metals, such as Ni, Sn and Ag
- ❑ Oxide layers do not negatively affect the performance and reliability of the power module throughout the assembly process from the DCB substrate to die attach, wire bonding and sintering
- ❑ Flux-free process, subsequent removal of flux residues is no longer necessary
- ❑ Atmospheric-plasma deposited thin siloxane films applied on copper lead frames exhibited improved adhesion strength to 3 epoxy molding compounds, even at elevated temperature
- ❑ Improved device performance through enhanced electrical performance and thermal management, and overall enhanced reliability



Thank You!



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