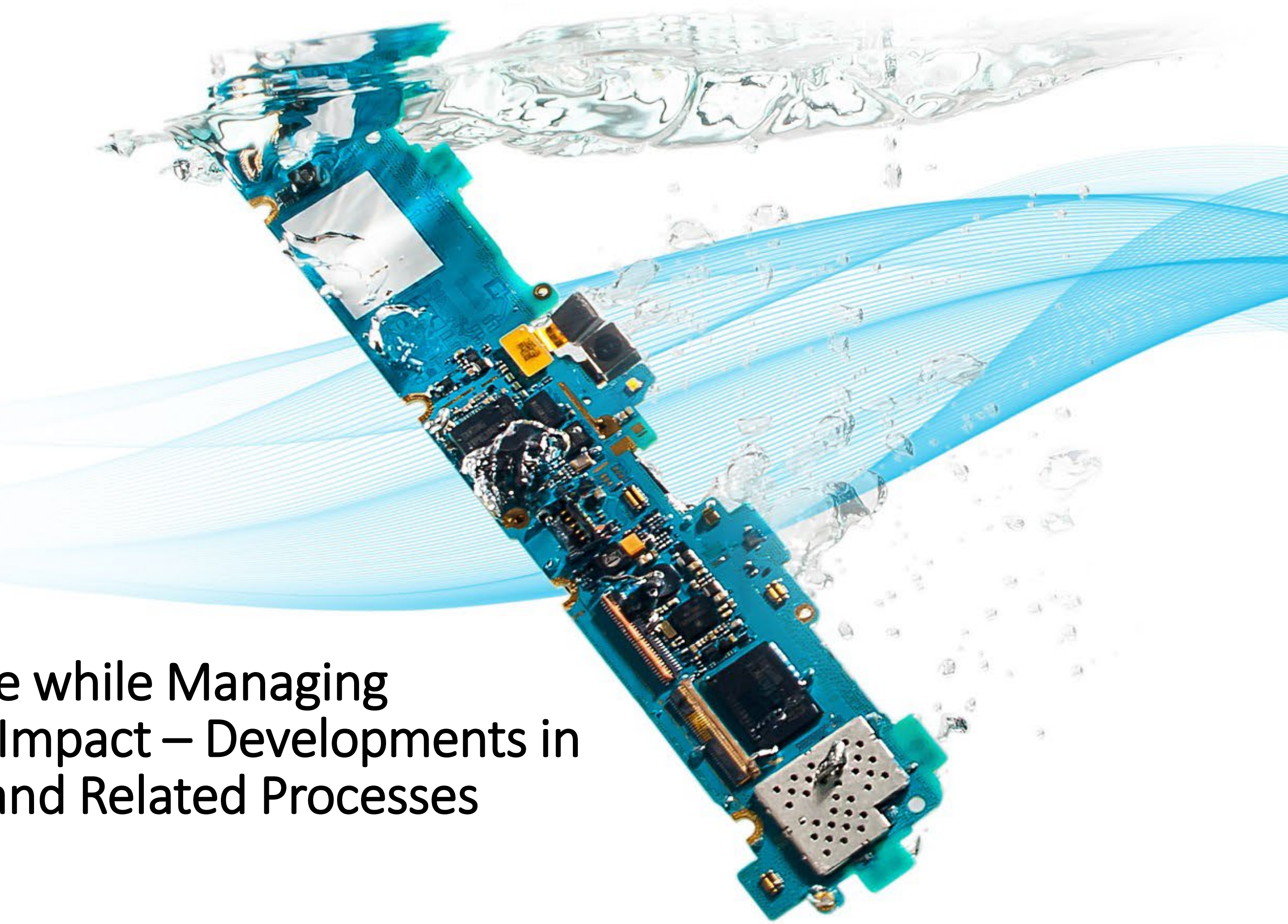

Ensuring Long-Term Performance while Managing Affordability and Environmental Impact – Developments in Electronics Conformal Coatings and Related Processes

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12 October 2022

Agenda

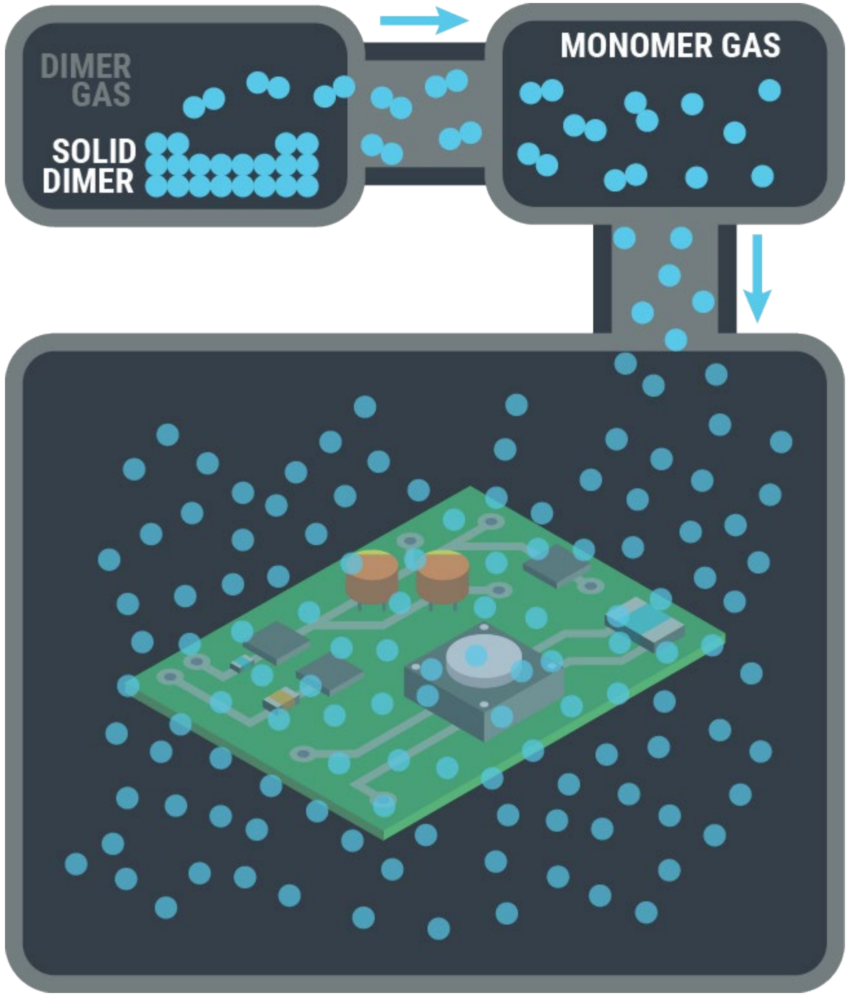
- ***Conformal Coatings and Performance Testing***
  - Comparisons of electronics conformal coatings
  - Development of “nano-coatings”
  - Nanometer-sized *friends* and *foes*

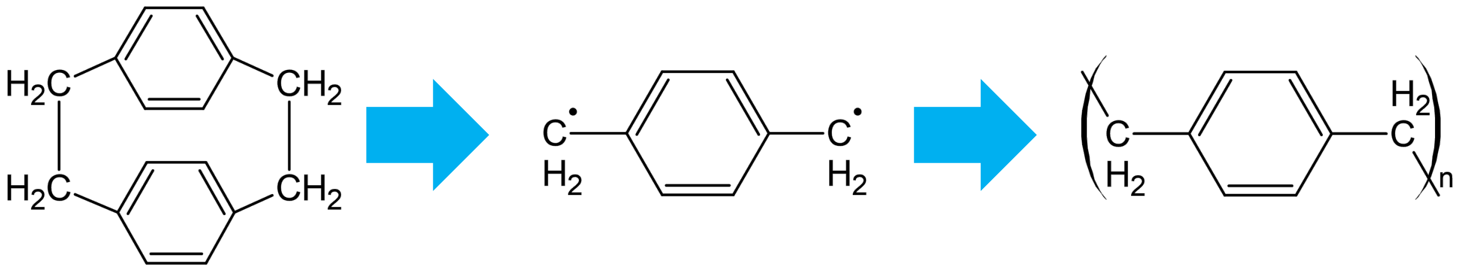
- ***Environmental Impact***
  - Intentional (bio-)degradability

- ***Managing Affordability***
  - Larger batches, lowering the price per unit
  - Automation for masking, de-masking, and inspection
  - Enabling rework, repair, and the “Right to Repair”

Conformal Coatings and Performance Testing

Comparisons of Electronics Conformal Coatings – Parylene Coating Process





Vaporizer

Solid dimer sublimes to a gas in the vaporizer

Pyrolysis Furnace

Dimer gas is cracked into a di-radical in the pyrolizer

Coating Chamber

Di-radicals adsorb on substrates and combine to form a polymer

- **No VOCs**
- **No Catalysts**
- **No Disposal Issues**
- **No Pollution Threats**
- **No Cure Time**

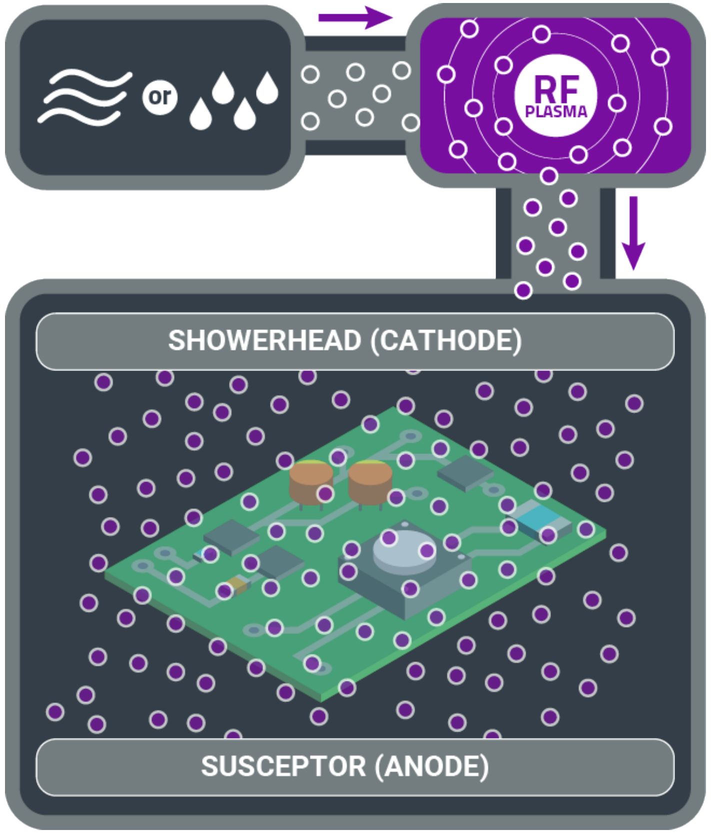
Comparisons of Electronics Conformal Coatings – PECVD & ALD

Other Coatings in Development with Nanometer-Level Thicknesses:

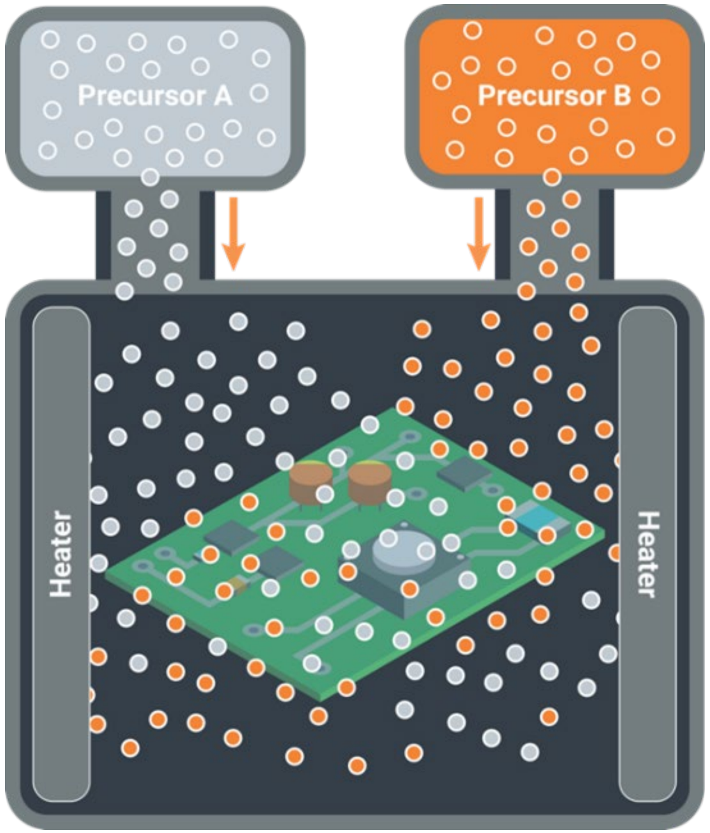
- Plasma-Enhanced Chemical Vapor Deposition (PECVD) Coatings
  - Variety of chemical compositions for specialty applications, including omniphobic (hydrophobic *and* oleophobic) coatings

- Atomic Layer Deposition (ALD) Coatings
  - Metal oxide coatings for enhanced protective barriers

Plasma-Enhanced CVD (PECVD) Plasma Applied Coating Process

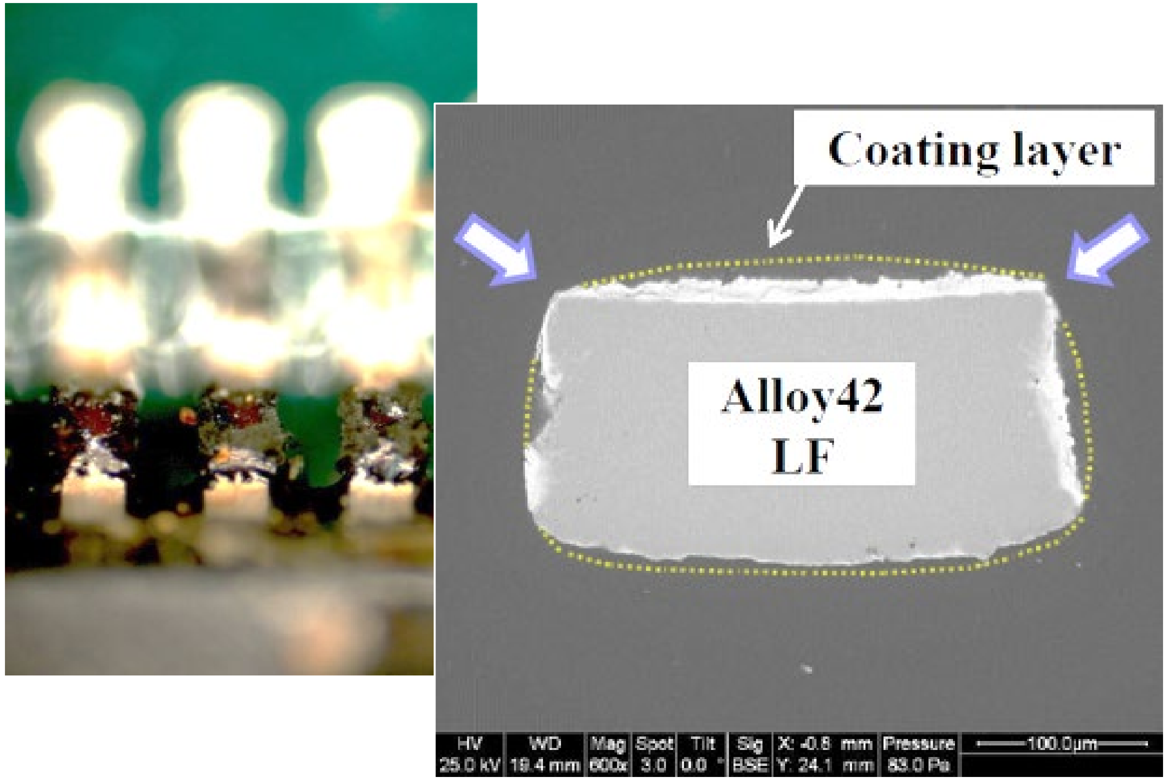


Atomic Layer Deposition (ALD) Coating Process

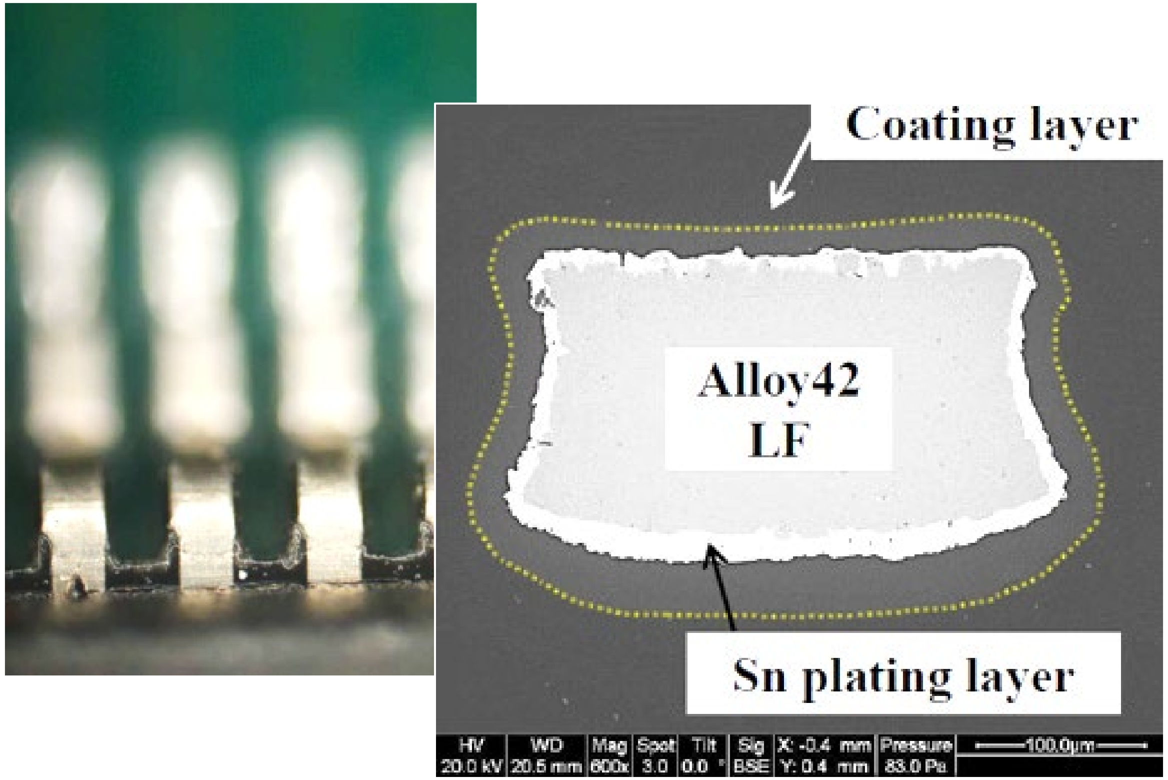


Comparisons of Electronics Conformal Coatings – Sprayed vs CVD Coatings

Silicone Spray-Coated QFP Exposed to MFG Testing, Resulting in Creep Corrosion



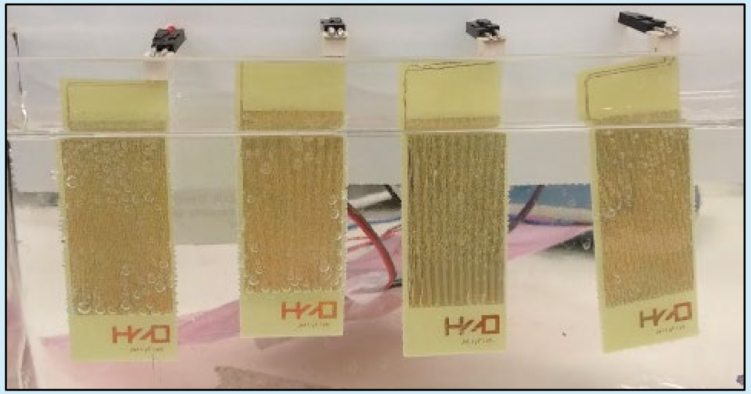
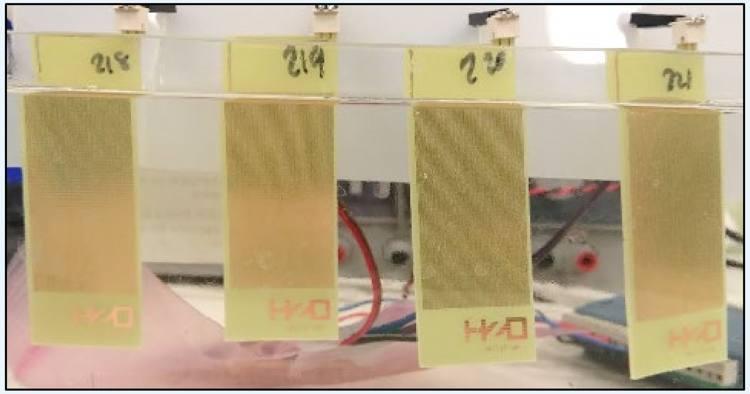
Parylene CVD-Coated QFP Exposed to MFG Testing, Resulting in No Corrosion



Comparisons of Electronics Conformal Coatings

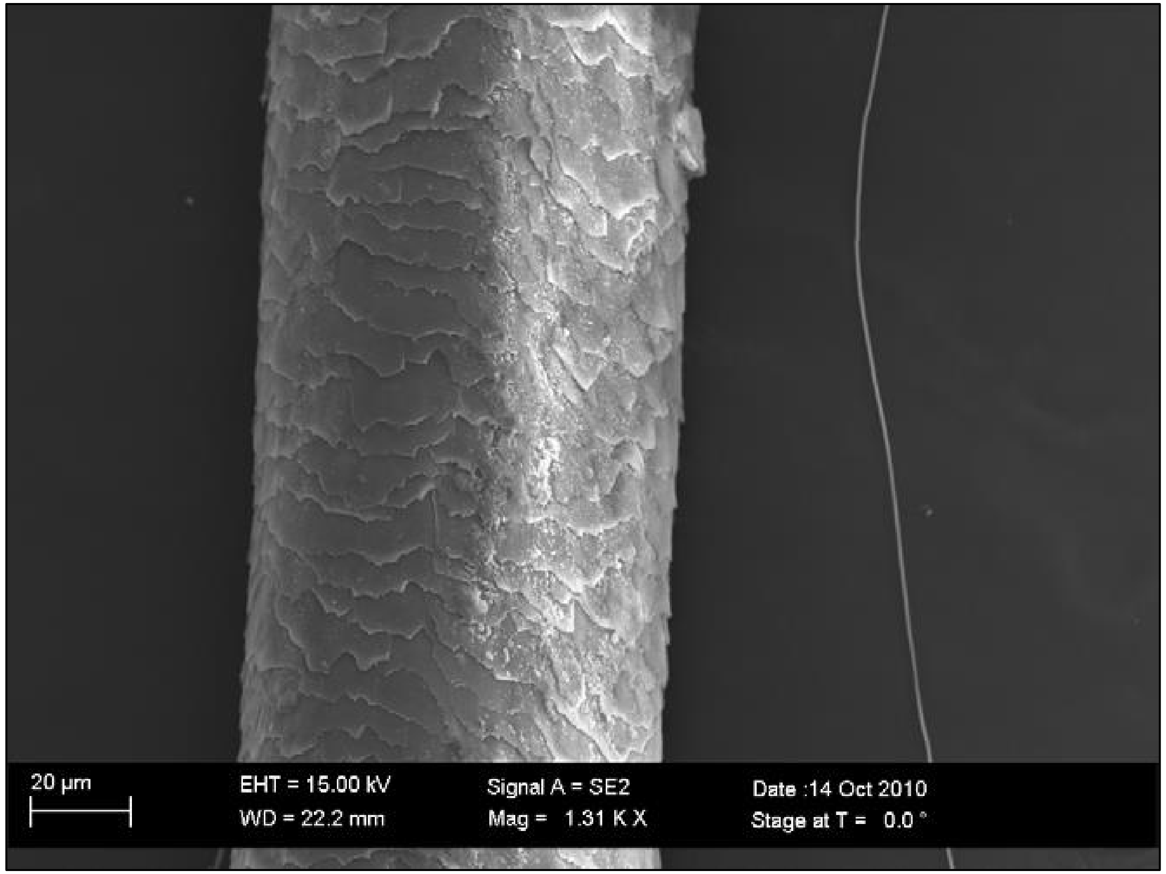
Materials	*Initial State*	*After 264 h of Salt Fog Exposure*	*Notes*
Parylene C (7 µm) Coating on a Copper Clad FR-4 Disc			Prevented Corrosion
ALD (40 nm) & Parylene C (7 µm) Coating on a Copper Clad FR-4 Disc			Prevented Corrosion & Prevented Oxidation

Comparisons of Electronics Conformal Coatings

Materials	*Immersion in Water, 10 V DC Bias, 25 °C*	*Notes*
Uncoated Test Board		Electrolysis Failure < 2 ½ minutes
ALD & Parylene C (1 µm-thick multilayer stack) Test Board		1000x Increase Before Failure

Nanometer-Sized *Foes* and Friends – Metal Whiskers and Electronics

Metal Whiskers are commonly 1/10 to <1/100 the thickness of a human hair



Ref.: "Basic Info on Tin Whiskers." *NASA Electronic Parts and Packaging Program - Tin Whisker (and Other Metal Whisker) Homepage*, NASA, 17 Jan. 2019, https://nepp.nasa.gov/whisker/background/index.htm.

A partial list of costly electronic equipment losses and availability losses is highlighted here to underscore the serious risk associated with whiskering phenomena.

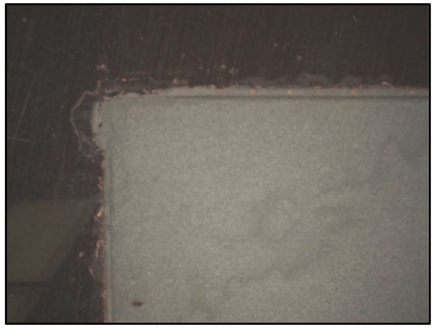
Availability Loss	Complete Hardware Loss
• Nuclear Utilities Unplanned Shutdown	• Seven Satellites with Microprocessor Failures
• Space Shuttle Fleet Main Engine Gimbal Avionics	• Six Other Missile Programs with Complete Failure
• Patriot Missiles	• Heart Pacemaker with Complete Failure
• F-15 Radar	• Heart Defibrillator with Complete Failure
• Several Other Military Planes	
• Telecom Equipment	

Ref.: *The Lead-Free Electronics Manhattan Project: Phase I. Philadelphia, PA: ACI Technologies, 2009.*

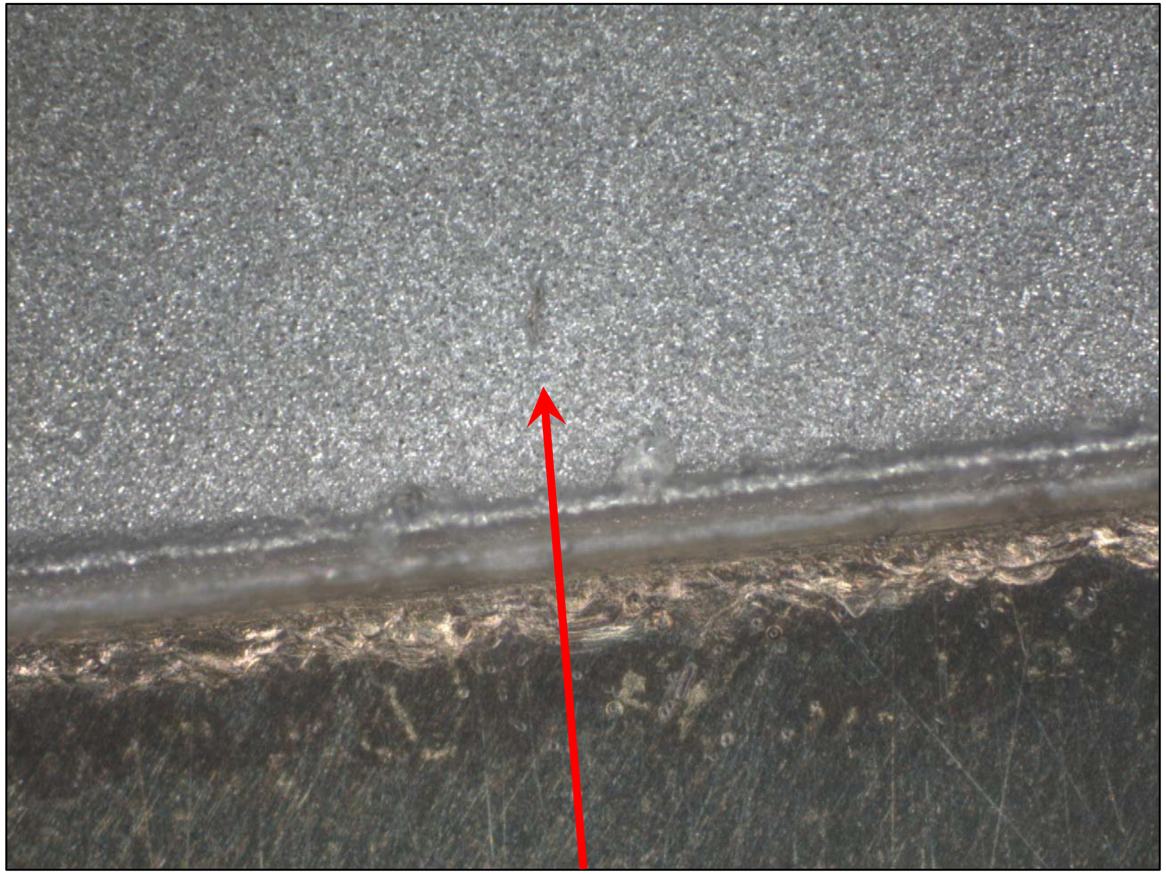
Nanometer-Sized Foes and *Friends* – Whisker-Mitigation Coatings

- CALCE at University of Maryland monitored for tin whisker growth on environmentally stressed, tin-plated coupons after coating with Parylene C by HZO.
- Six tin-plated coupons (3 brass, 3 copper) were coated with 10 µm Parylene C were exposed at 85 °C and 85% RH for 500 hours.
- After exposure, a potential whisker was observed to be trapped under the Parylene coating on one of the tin-plated copper coupons.

Parylene-Coated Tin Plated Brass Coupon



Parylene-Coated Tin Plated Copper Coupon

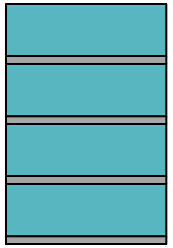


Whisker-like defect trapped under coating

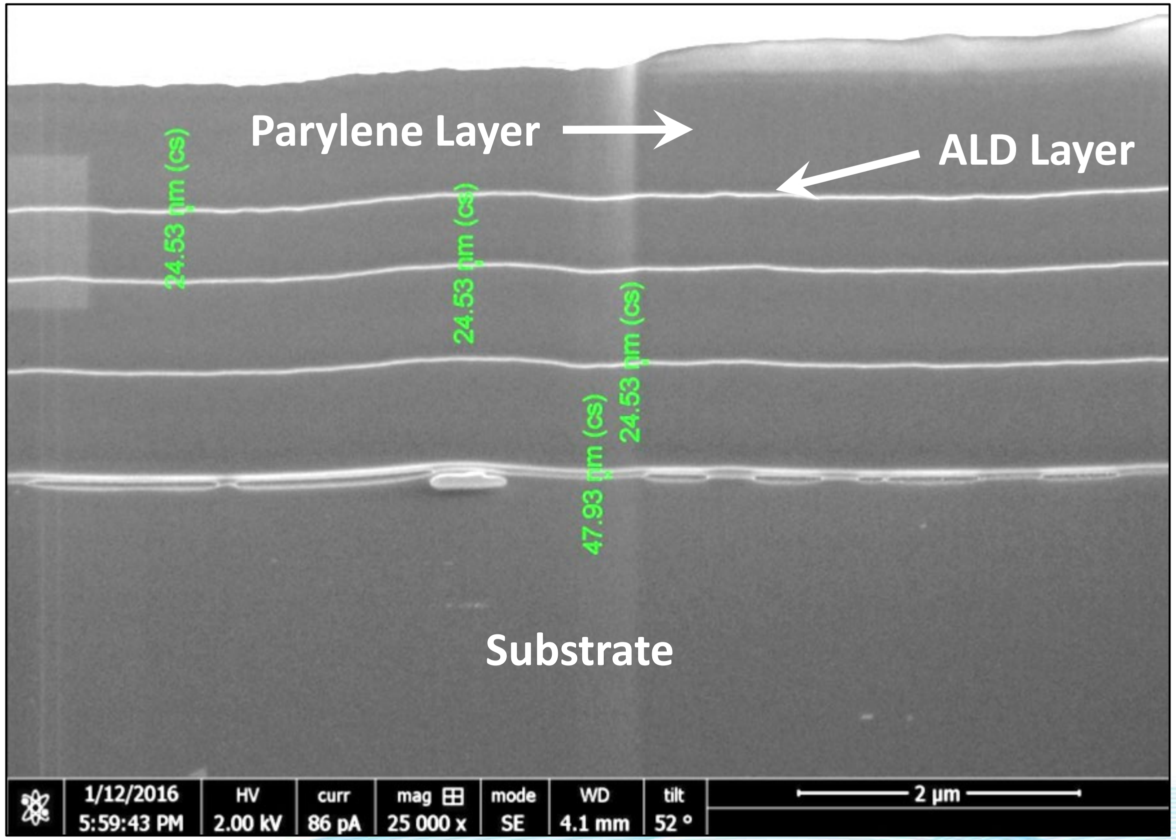
Nanometer-Sized Foes and *Friends* – “Nano-Coatings”

- When functioning as protective barriers, Parylenes are typically in the micron (1000s nm) range and up to 50 µm for the harshest environments
  - Parylenes serve as excellent moisture vapor, bulk water, and ion barriers
- ALD and PECVD-based thin film coatings serve as protective barriers when thicknesses are on the order of 10s and 100s nm, respectively.
  - ALD and PECVD coatings can serve as even better oxygen and moisture vapor barriers
- Coatings that combine complementary materials in multilayer stacks create “tortuous paths” for the ingress of undesirable materials

Multilayer Stacks – ALD and ALD-Polymer Hybrids



- 10s to 100s nm Parylene or other polymers
- 10s to 100s nm ALD Nanolaminates



Nanometer-Sized Foes and *Friends* – "Nano-Coatings"

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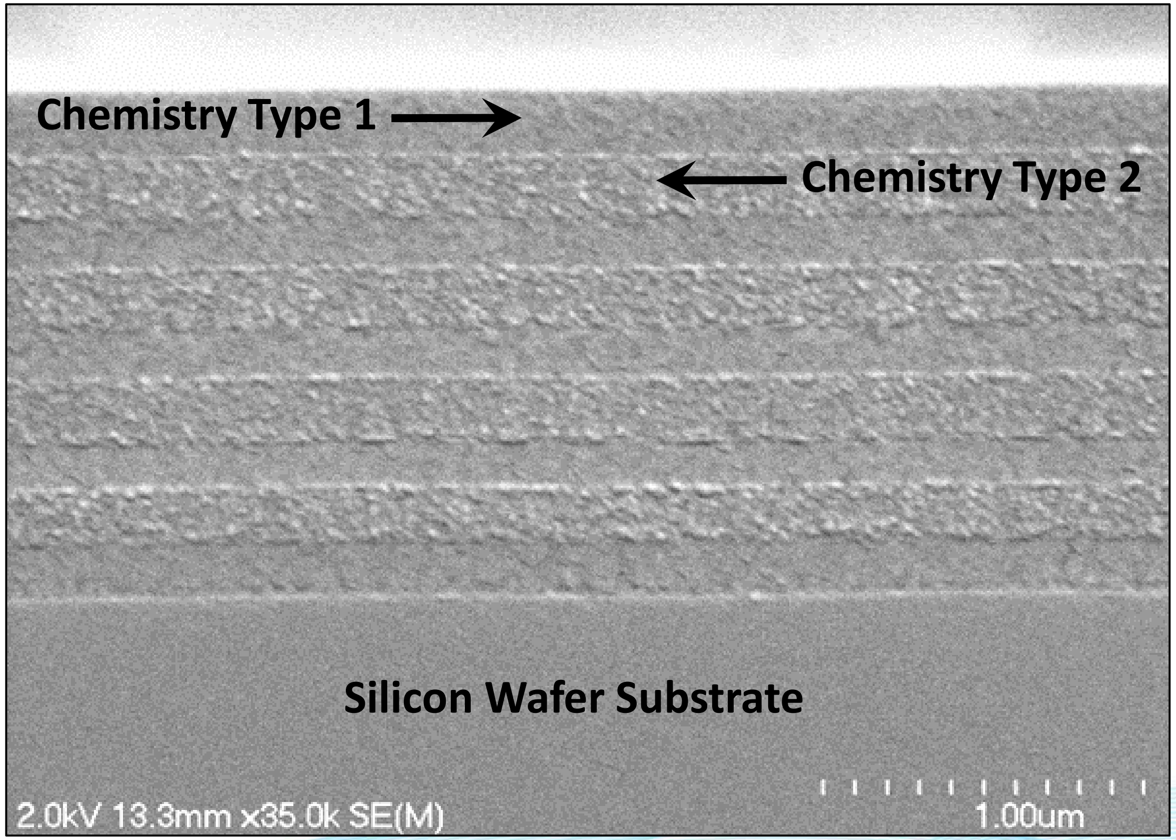
Multilayer Stacks – PECVD Coatings

- 10s to 100s nm Chemistry 1
- 10s to 100s nm Chemistry 2



Environmental Impact

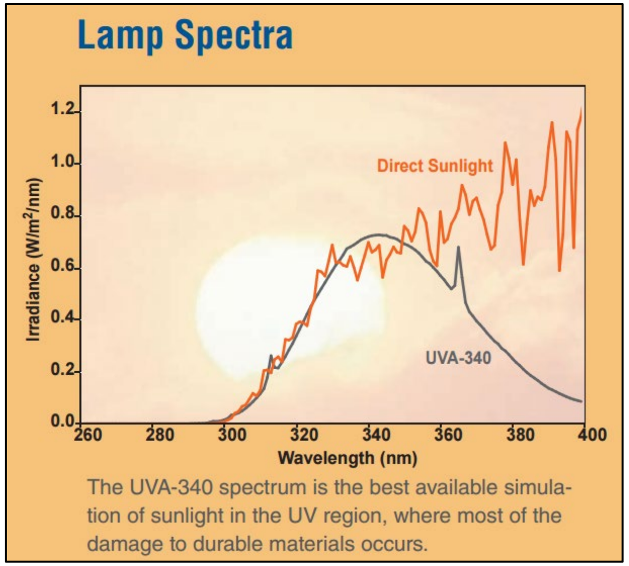
Intentional (Bio-)Degradability – Accelerated UV Weathering

Environmental Stress Screening (ESS) via UV Aging Instrumentation:

- Q-Lab QUV/se UV Accelerated Weathering Tester
- Q-Lab QUV-340 lamps, which give an excellent simulation of sunlight in the critical short wavelength region from 365 nm down to the solar cut-off of 295 nm.

Test Parameters:

Program:	ASTM G154 Cycle 1			
Lamp Type:	UVA-340			
Step	Function	Irradiance (W/m^2)	Temperature (°C)	Time (hh:mm)
1	UV	0.89	60	8:00
2	Condensation	N/A	50	4:00
3	Final Step – Go to Step 1			



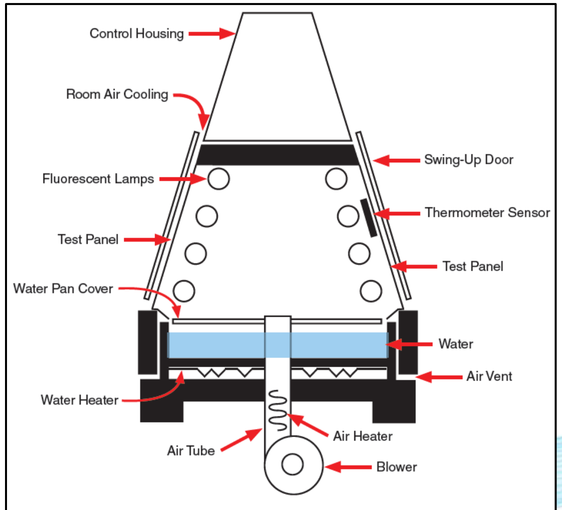


Figure 3.0a: Simplified Cross Section

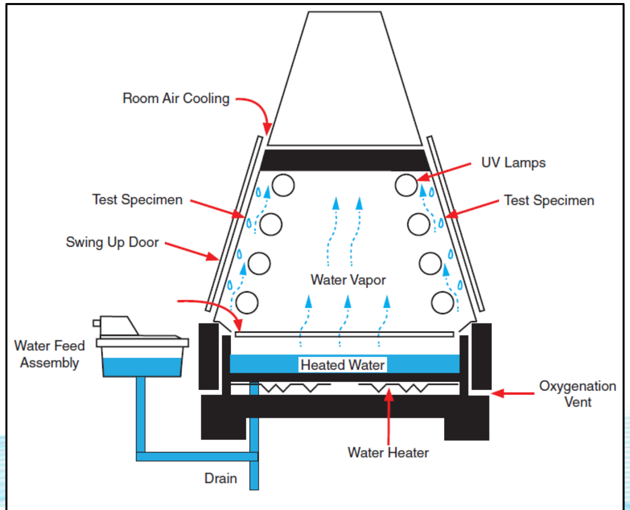
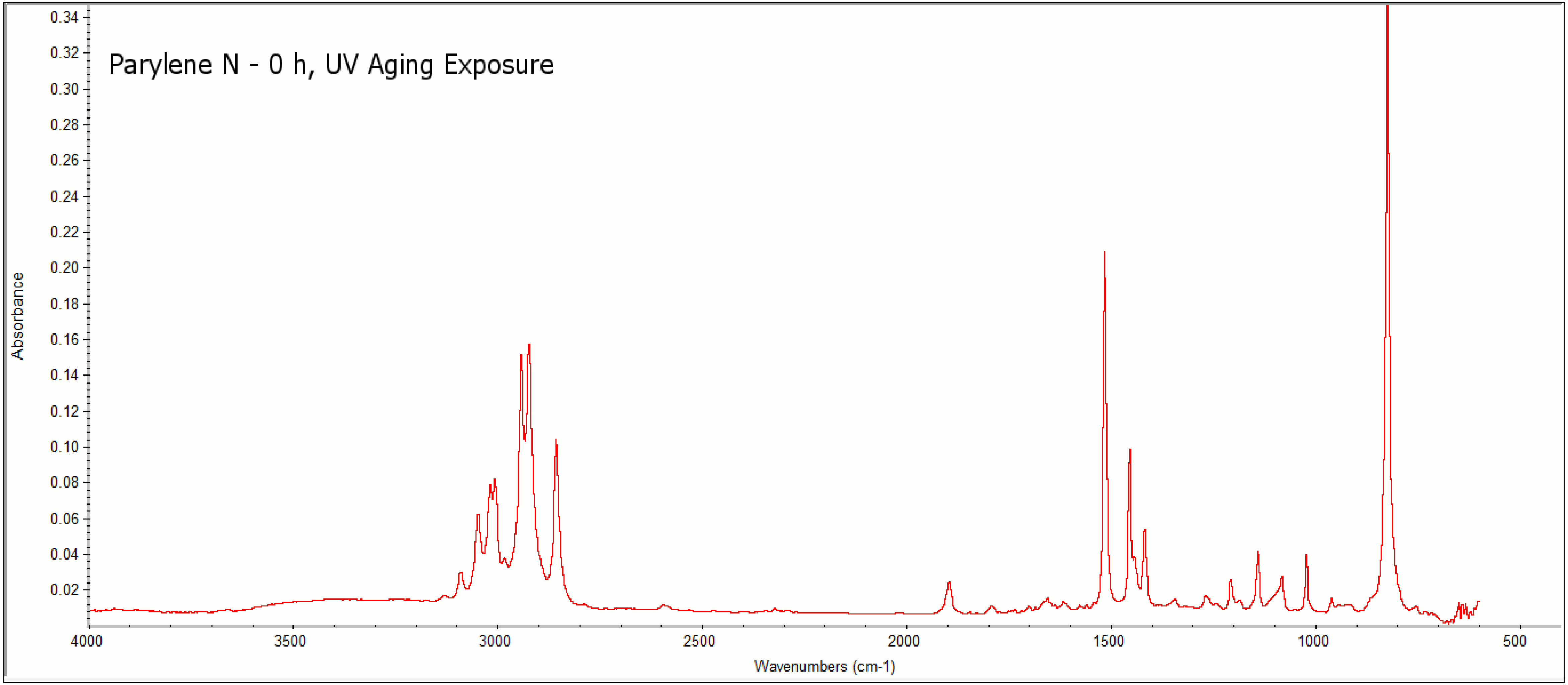
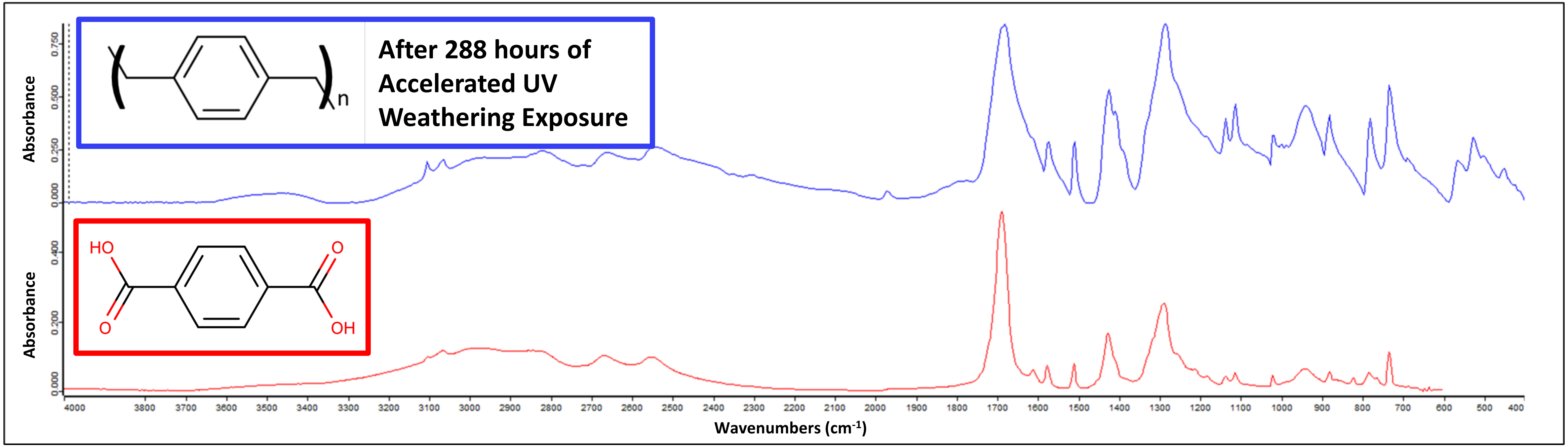


Figure 6.1a: QUV Condensation System Schematic

Intentional (Bio-)Degradability – Convert to Oxidized Form with UV and O_2



Intentional (Bio-)Degradability – Oxidized Parylenes Very Similar to TPA



- Terephthalic acid (TPA) is a component in poly(ethylene terephthalate) (PET), one of the most used plastics in the world.

- Various means of degradation for TPA, PET, and wastes associated with PET manufacturing have been developed and are being improved upon by groups globally, including the biodegradation of PET using microorganisms and enzymes that hydrolyze PET into smaller molecules.

Managing Affordability

Coating in Larger Batches, Lowering Price Per Unit, & Automated Processes

- Large Parylene deposition chambers
  - 36 in x 36 in x 36 in (0.9 m x 0.9 m x 0.9 m)
  - Excellent thickness uniformity throughout chamber

- Automating the masking and demasking processes
  - Individually designed modules cover a variety of different processes

Enabling Repair, Rework, and the "Right to Repair"

Product Longevity

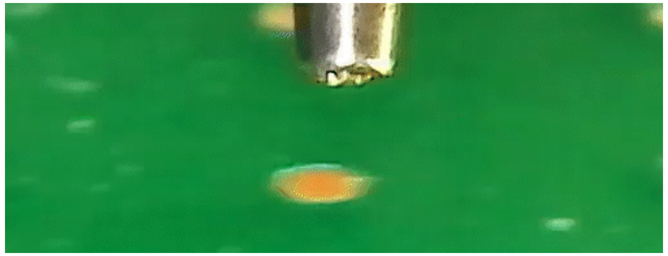
- The European Union plans to be climate neutral by 2050 and reduce e-waste, making durability and repairability a key initiative in the design and manufacturing of Consumer Electronics.
- Coatings extend the functional life of products, which can reduce the rate of those products becoming e-waste.
- When the products eventually no longer have a practical use, the thin film coatings won't interfere with the materials recycling and precious metals recovery processes involved with many forms of e-waste processing.

Design

- Thin film coatings at the functional component and printed circuit board assembly (PCBA) levels reduced the need for completely sealed housings that restrict repairability.
- Housings that allow for water to leave can be beneficial to the device.

Product Use – Easy Removal, Repair, Rework, and Re-Coating

- Extend the life of electronics by reducing the risks of catastrophic failure when exposed to water, corrosives, and other harsh environments.
- Remove thin film conformal coatings with industry-standard mechanical and thermal methods
  - Mechanical
    - Peeling, scraping, or micro-blast abrasion
  - Thermal
    - "Solder through", laser ablation, or plasma etching



- Repairing coatings can involve either of the following:
  - Re-coating with the original coating and process
  - Coating a specific area with a recommended supplemental coating

