Halogen-Free Nanocoatings – Promoting Environmental Sustainability and High Device Protection Performance

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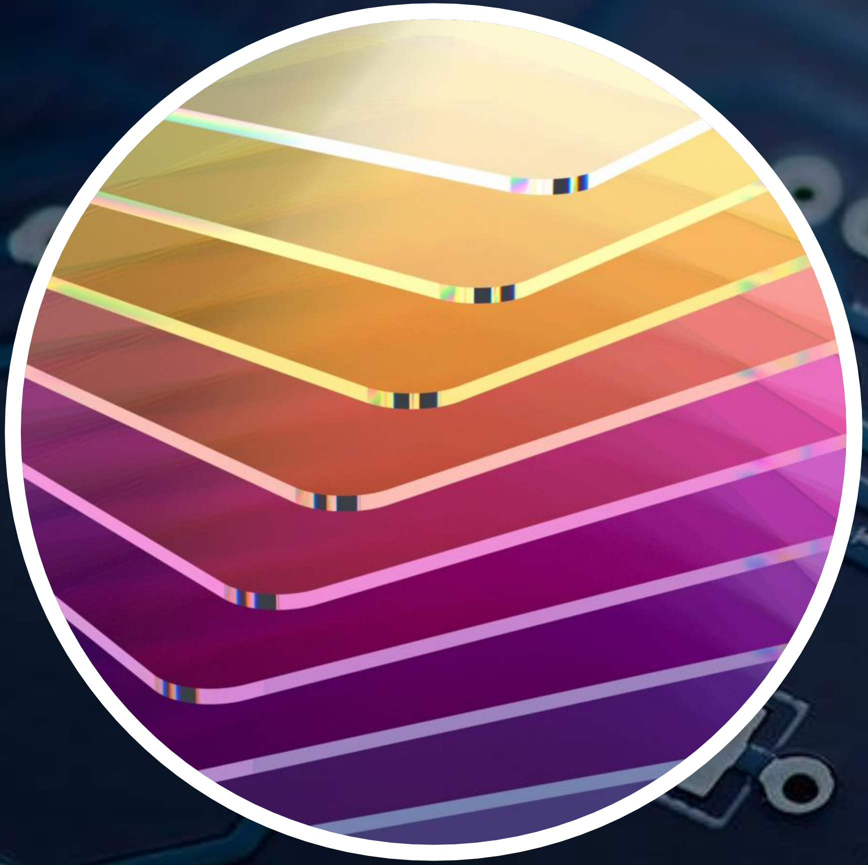
Agenda



1. Environmental Sustainability Challenges
2. Coating Benefits and Selection
3. Thin-Film Coatings
4. PECVD Performance Testing & Results

Environmental Sustainability

- Policies underway globally to drive reduction in electronic waste
- Existing and new technologies can be implemented to further reduce waste or extend overall product life
- Material selection plays a vital role in promoting sustainability
- When considering existing or new product design it's important to think how to achieve the following

Extend Product Lifecycle

Reduce Emissions and Overall Carbon Footprint

Prevent Waste and Enhance Material Utilization

Eco-Friendly Product Design

Electronic Industry Challenges

1. Expansion of connected devices and components across the globe
2. Use of technology to drive innovation to meet environmental and climate change initiatives
3. Refurbishing and renewing existing electronics (Right to Repair)
4. Managing electronic waste and raw material usage

Conformal Coating Benefits

1. Enhances service life of individual components and products
2. Material selection can lead to recyclability or safe disposal
3. Provides barrier protection for environmental threats including moisture, corrosion, chemicals, etc.
4. Can drive regulatory compliance for new or existing industry standards
5. Helps promote device reliability and reduces product failures, replacements, and repair costs

Coating Selection – Environmental Sustainability

Material, application, and process selection can support positive impact on environmental sustainability

Solutions that are biostable, biocompatible, and completely environmentally friendly are readily available

Regulatory compliance to consider include:

- REACH
- RoHS
- PFOA / PFOS-free
- CA Prop 65

No VOCs

No Solvents

No Catalysts

No Disposal Issues

No Pollution Threats

No Cure Time

Thin-film Solutions: Avant Guard Protection

Physical

- Lightweight
- Uniform
- Transparent

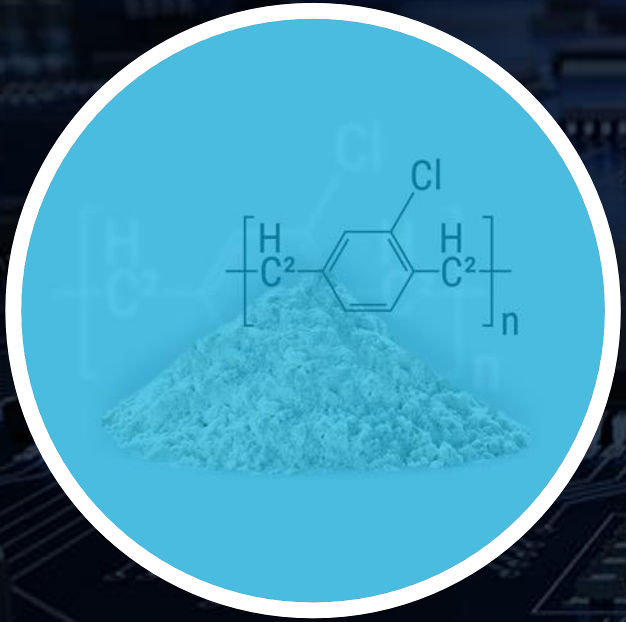
Protective

- Water Resistant
- Corrosion Resistant
- Acid Resistant
- Chemical Resistant

Additional Benefits

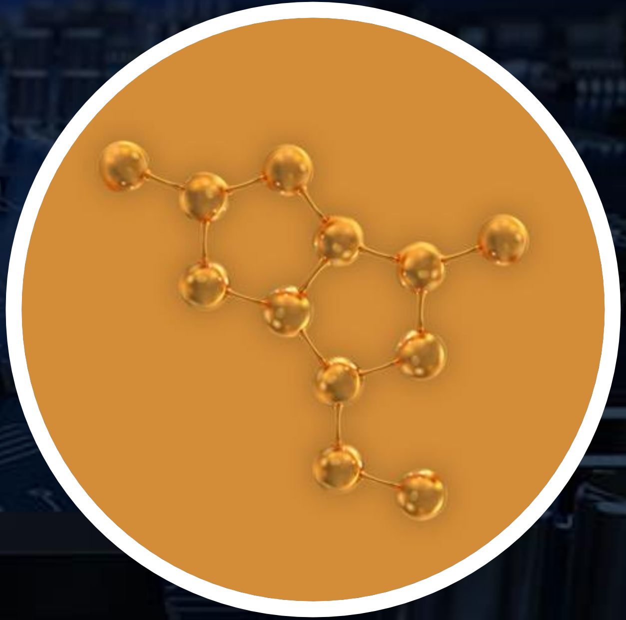
- Halogen-Free
- Thermal Stability
- Dielectric Properties
- Chemical Resistance

CVD Applied Thin-film & Nano Coatings



Parylene Coatings

Plasma-Applied Nano Coatings



Atomic Layer Deposition Coatings

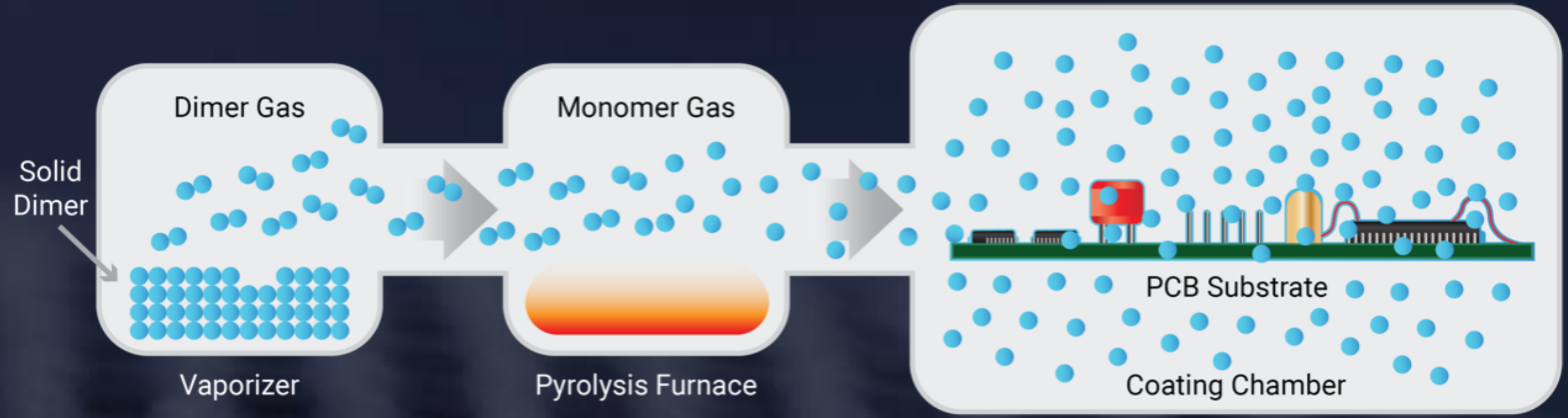
Coating Material Considerations

	Acrylic	Urethane	Epoxy	Silicone	Plasma	Parylene
Cure Time	Moderate	Poor	Poor	Moderate	Excellent	Excellent
Conformality	Good	Good	Good	Good	Good	Excellent
Adhesion	Good	Good	Excellent	Excellent	Good	Excellent
Component Stress	Poor	Poor	Poor	Excellent	Excellent	Excellent
Cost	Low	Low	Moderate	High	Moderate	High
Reworkability	Good	Difficult	Difficult	Moderate	Good	Difficult
Solvent Resistance	Poor	Good	Excellent	Good	Excellent	Excellent
Corrosion Resistance	Moderate	Excellent	Excellent	Good	Excellent	Excellent
Abrasion Resistance	Moderate	Excellent	Excellent	Moderate	Good	Good
Dielectric Strength	Good	Good	Good	Poor	Excellent	Excellent
Transparency	Excellent	Poor	Poor	Poor	Good	Excellent
Thickness Required	Moderate	Thick	Thick	Moderate	Thin	Thin

Coating Materials Considerations

Protection Characteristic	Virgin PCBA	Mechanical Seals	Silicone Coatings	Parylene (CVD) Coating	Plasma (PECVD) Coating	Atomic Layer (ALD) Coating
Protection Barrier	None	Good (bad for impact)	Good (application dependent)	Excellent (adhesion critical)	Good (multi-layered)	Excellent (multi-layered)
Hydrophobic	No	No	Yes (>90°)	Partial (75-90°)	Yes (>90°)	Yes, multi-layered
Thickness	N/A	1-10 mm	0.1-10 mm	0.002-0.05 mm	<0.005 mm	< 0.002 mm
Application Uniformity	N/A	N/A	Poor (pooling, wicking)	Excellent	Good	Excellent
Water Protection	Poor	Good: Ingress Poor: Egress	Good	Excellent	Good	Excellent
Sweat Submersion MTTF	Seconds	Varies	Weeks+ (for thick films)	Days to Weeks+	Minutes to Hours	Days to Weeks+
Durability	Low	Varies	Moderate	High	Low	Moderate
Masking Requirements	N/A	N/A	Costly selective application	High	Low	High
Dielectric Characteristics	N/A	N/A	Moderate	Excellent	Good	Excellent

Chemical Vapor Deposition (CVD)



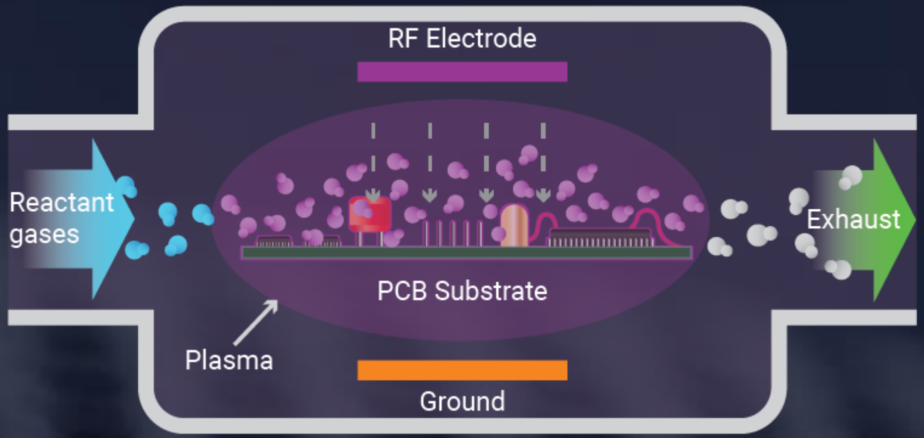
Deposition Materials Include:
- Parylene C
- Parylene N (Halogen Free)
- Parylene F – VT-4
- Parylene F – AF-4

CVD Material Benefits:
- Thickness control from 1 µm to 50 µm
- Films are cross-linked, dense, pinhole free, conformal
- Reworkable
- Resistant to a wide range of hazardous environments

Parylene Comparison

Performance Characteristics	Parylene N	Parylene C
Halogen Free	Yes √	No X
Excellent conformality, can completely penetrate spaces as narrow as 0.01mm	Yes - better than Parylene C (higher molecular activity)	Yes √
High dielectric strength	Yes – better than Parylene C (at same thickness)	Yes √
Low dielectric constant with good high frequency properties, high bulk, and surface resistance	Yes – better than Parylene C at high frequency applications	Yes √
Variable deposition time (based on required thickness)	Yes – slower deposition time than Parylene C (lower sticking efficient)	Yes √
Low water vapor transmission rate (WVTR)	Yes – higher than Parylene C (at same thickness)	Yes √
REACH, RoHS, PFOA/PFOS-free and CA Prop 65 Compliant	Yes √	Yes √
Biostable, biocompatible, environmentally friendly – no VOCs, no solvents	Yes √	Yes √
No initiators or catalysts in polymerization process, coating is pure and free from trace ionic impurities	Yes √	Yes √
High levels of submersion protection – IPX8+, depending also on device design	Yes √	Yes √
Uniform, pinhole free coating, no cure time	Yes √	Yes √
High barrier protection against corrosive chemicals/gases	Yes √	Yes √
Optically transparent and can be used to coat optical elements	Yes √	Yes √
High tensile strength, vibration resistant	Yes √	Yes √
No pooling of coating in low areas	Yes √	Yes √

PECVD Process Overview



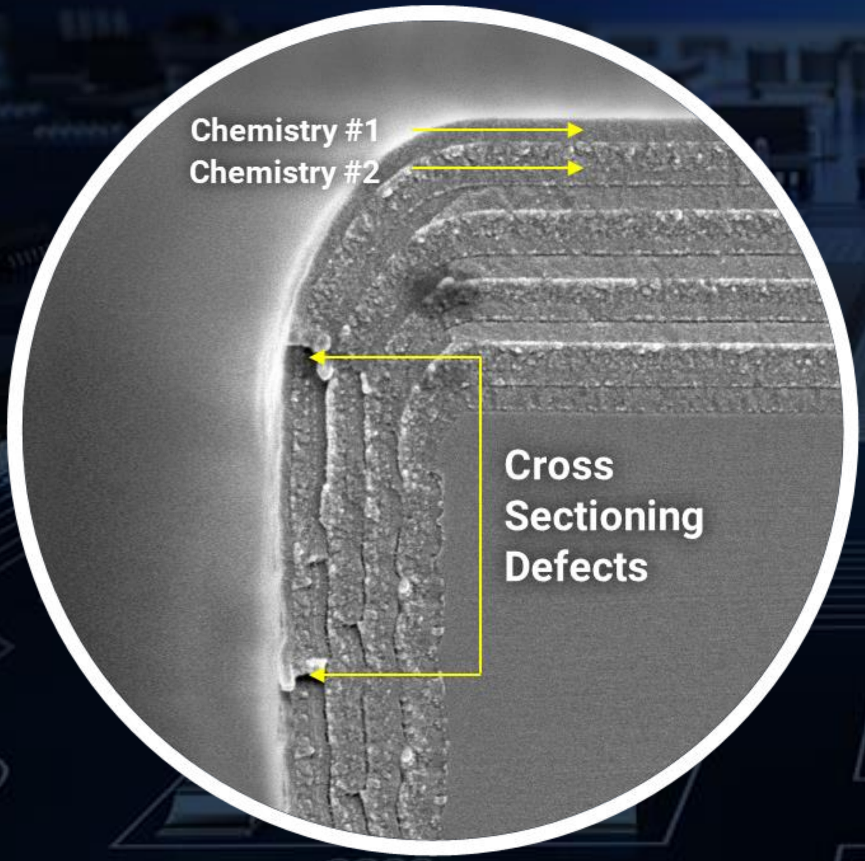
Deposition Materials Include:
- Fluoropolymers
- Silanes
- Oxides
- Metallics
- Unreactive Precursors (N_2, O_2, C_3H_8)

PECVD Material Benefits:
- Thickness control from 0.02 to 5 µm
- Reworkable
- Films are cross-linked, dense, pinhole free, conformal
- Films can be layered using different chemistries

PECVD Equipment Benefits

- Larger chambers for high throughput and scalability
- Removable racks and trays for easy loading and project changeover
- Removeable deposition shields for easy cleaning
- Can use in-situ shadow masking to eliminate traditional masking/demasking processes
- Automated push button processing
- Automated data collection
- Remote monitoring

Multi-layer Plasma Chemistry



- Defect density increased for thinner films
- Defect propagation mitigated by layers
- Conformality and masking/demasking trade-offs

PECVD Coating Performance Testing

Water Droplet Testing

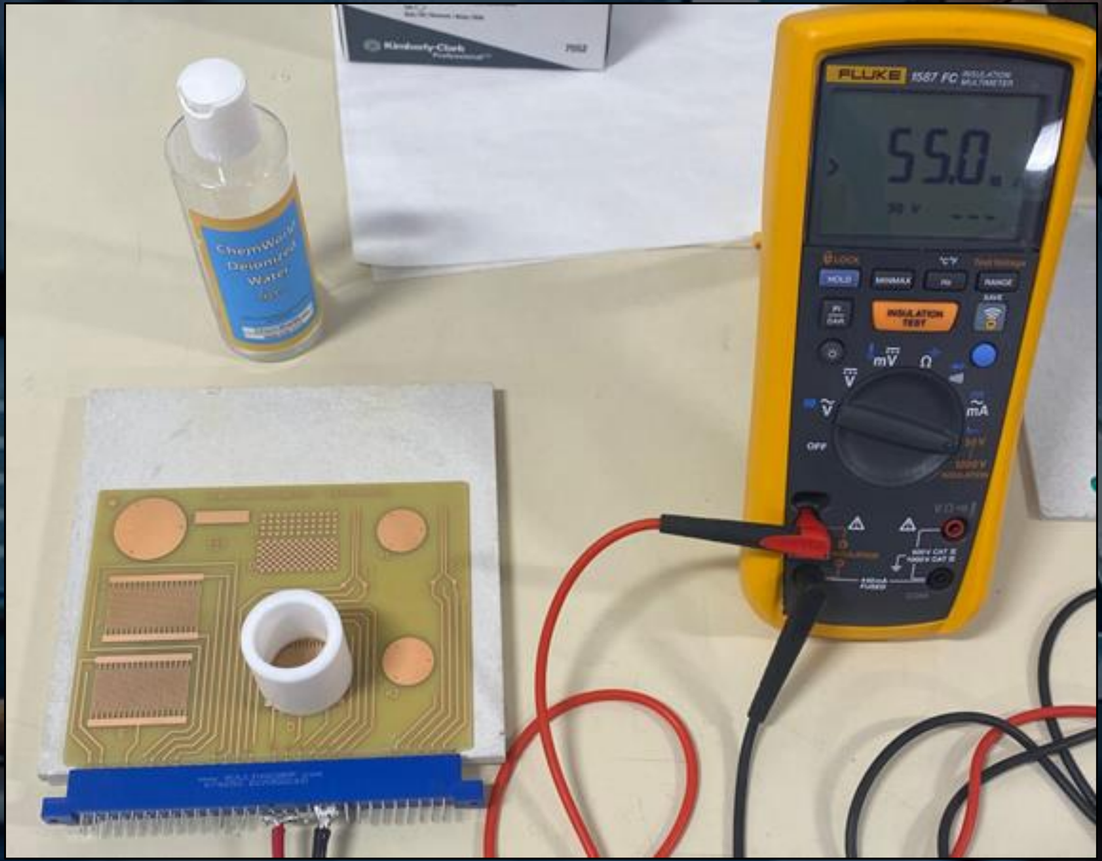
IPX Testing

Temperature/Humidity Testing

Dripping Sweat Testing

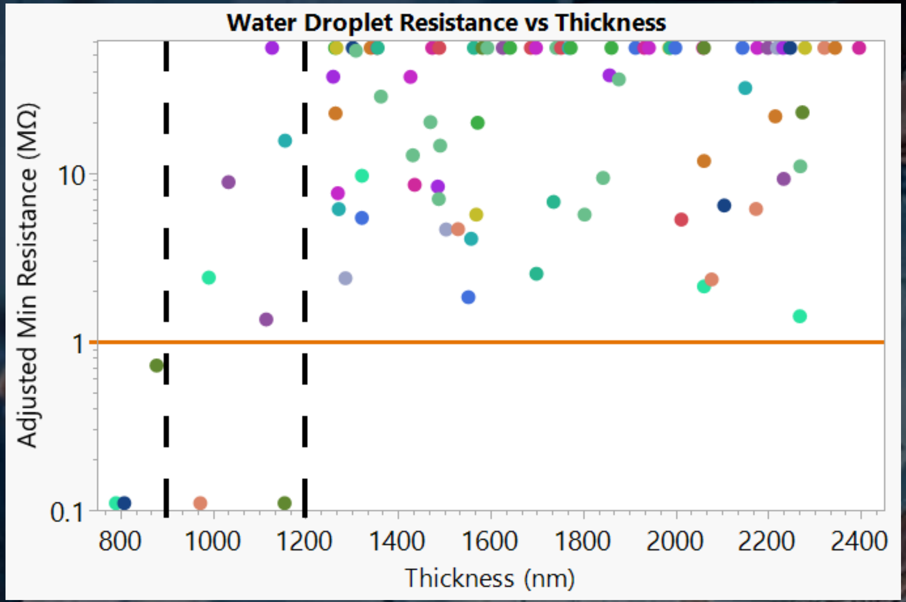
Hydro/Lipophobicity Testing

Water Droplet Testing

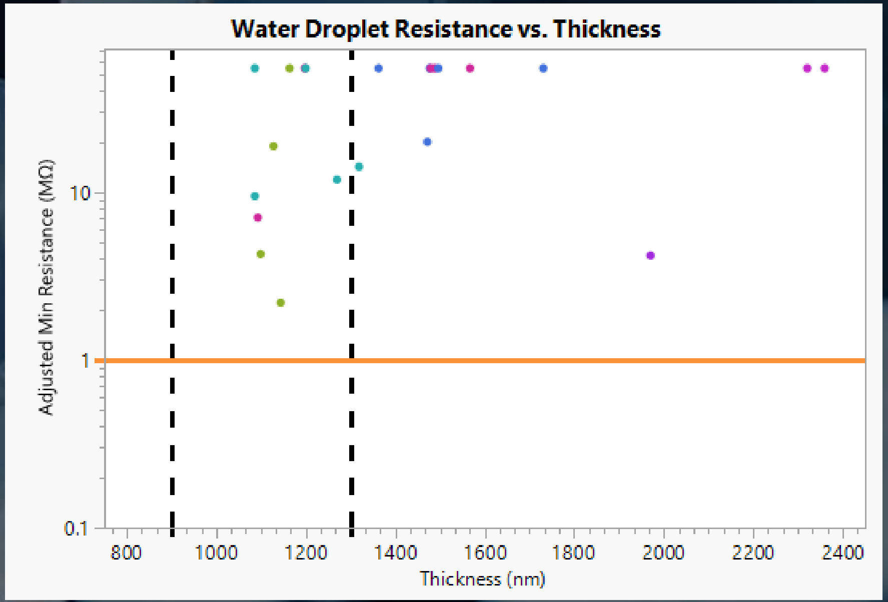


- Water droplet on comb D pattern of multipurpose test board
  - Teflon tube to contain liquid
- 50 V bias applied
- Resistance measured after 60s
- >1 MΩ is pass criterion

Water Droplet Testing Results



Halogenated



Halogen-Free

- Observed increased failure rates for thinner coatings during initial experimentation
- Halogen-free showed favorable results when compared to halogenated product at similar thickness

IPX4 Testing

Test Parameters for Tablets:

1. Play a movie and turn volume to 100%
2. Run water spray for 10 minutes
3. Remove tablet and dry off external water
4. Immediately perform post IPX4 functional checks
5. PASS if all functional checks pass after 48 hours

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IPX4 Results

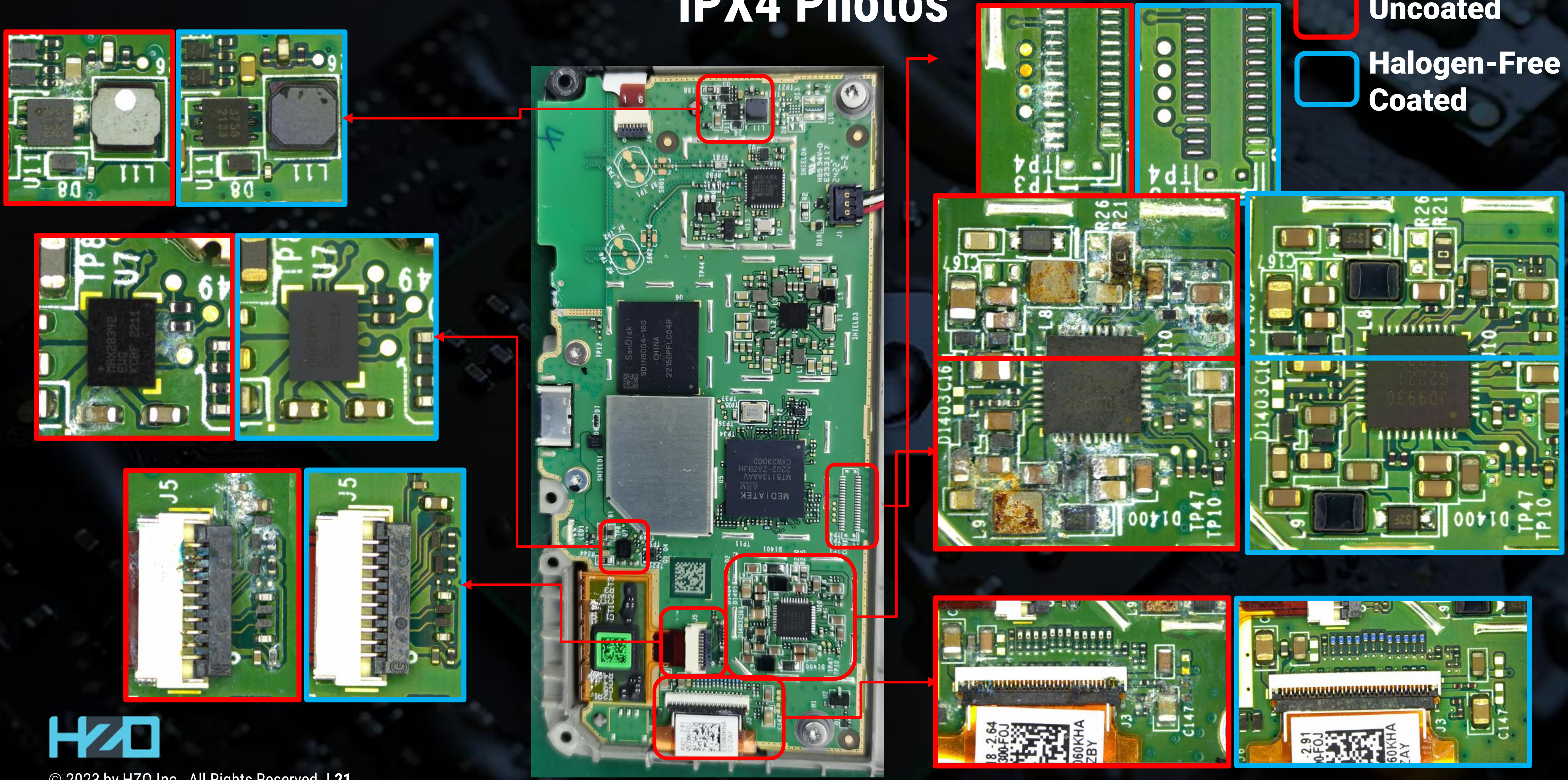
Tablet	Coating Type	Post Coating	Post IPX4	After 48 Hours	After 48 Hours	After 72 Hours
Uncoated	Control	N/A	FAIL	FAIL	FAIL	FAIL
NC-10	EX	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
NC-11	EX	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
NC-12	EX	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
NC-13	EX	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
NC-14	EX	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
SZ-3	ZERO	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
SZ-4	ZERO	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
SZ-5	ZERO	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
SZ-6	ZERO	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)	PASS (6/6)
NC-9	ZERO	PASS **(5/6)**	PASS **(5/6)**	PASS **(5/6)**	PASS **(5/6)**	PASS **(5/6)**

Test Points for Functionality

Item #	Item
1	Bottom Button
2	Touch
3	Overall Screen (Display)
4	Wi-Fi
5	Charging Ability
6	Battery

- **NC-9 had some intermittent Wi-Fi issues after testing, however no observable corrosion**
- **Multiple IPX cycle testing currently underway**
- **IPX7-8 testing also ongoing**

IPX4 Photos



Dripping Sweat Testing

Objective:

Simulate performance under repeated human sweat accelerated testing

Testing Method:

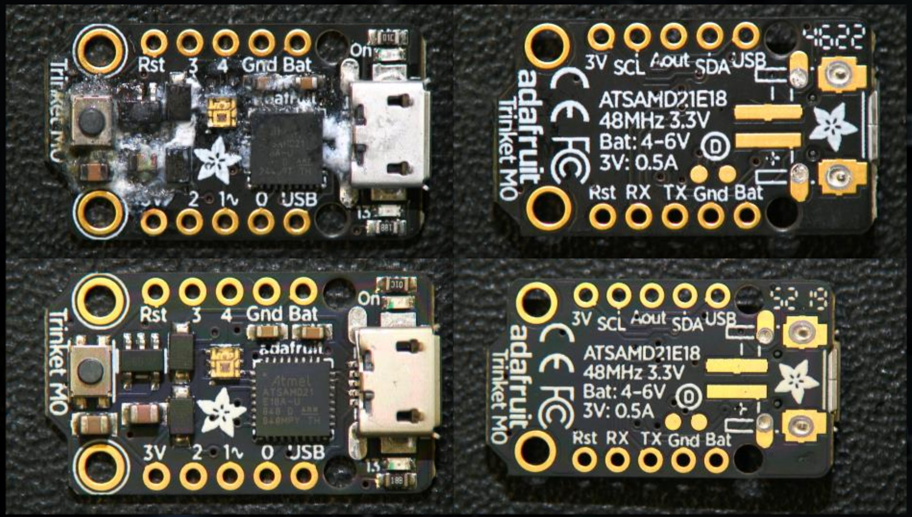
1. Power on (5 Volts) with constant USB communication
2. Drip with sweat solution for 1 hour at 1 drop/min
3. Power off, forced dry for 2 minutes, and left to dry further for the remainder of 1 hour
4. Repeat above cycle

Sweat Solution:

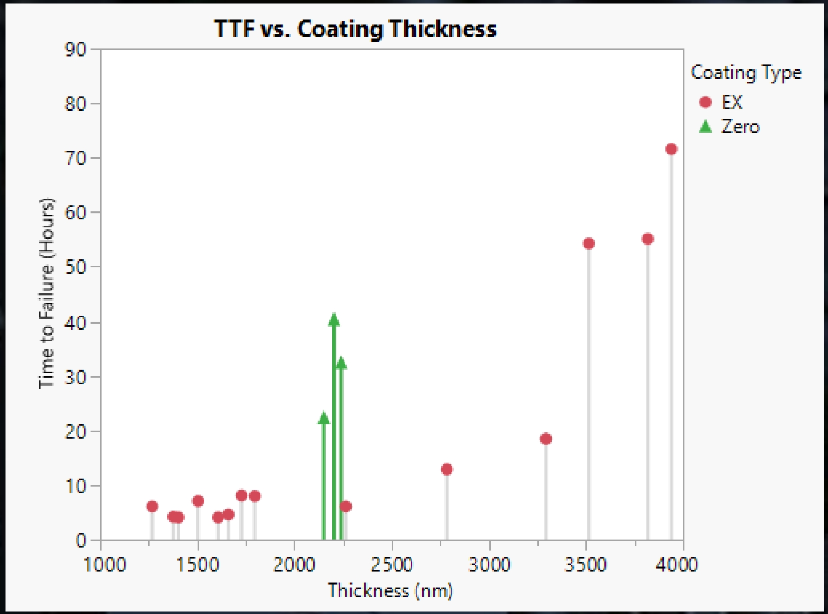
- Concentration of 0.17 M NaCl, 7 mM disodium hydrogen phosphate, 1.6 mM histidine, and 12.7 mM lactic acid

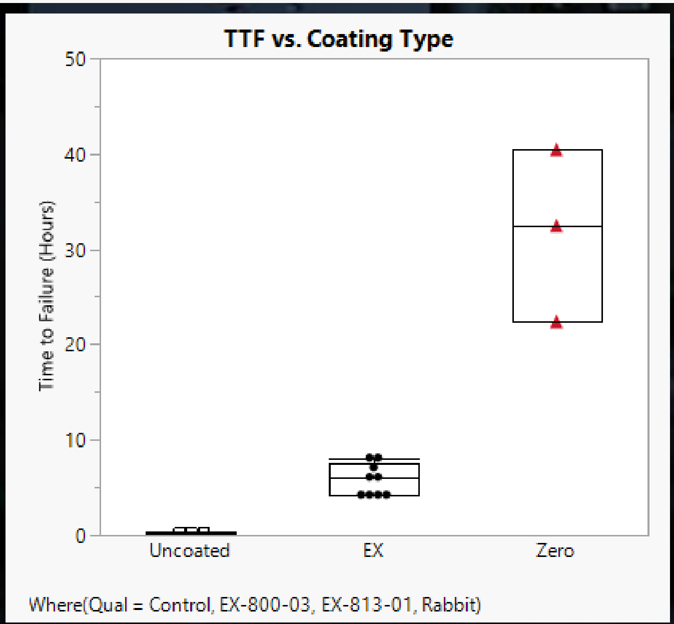
Dripping Sweat Results

Uncoated Front | Uncoated Back



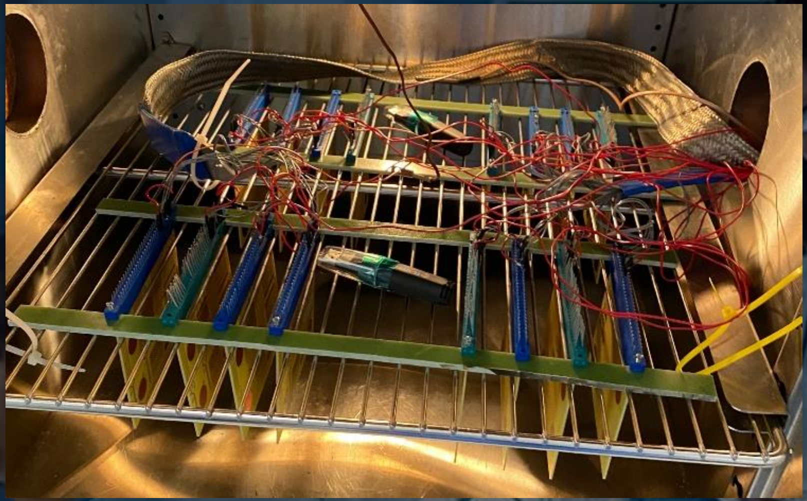
Coated Front | Coated Back

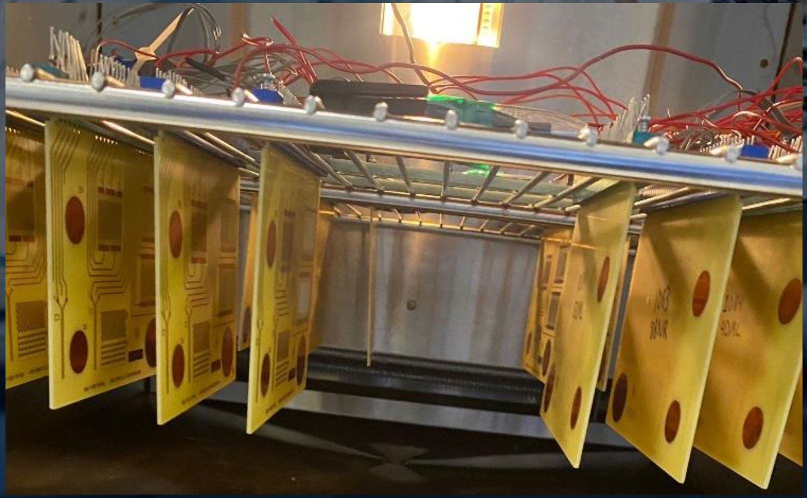




- Time to failure (TTF) improved with increased thickness for halogenated, experiments ongoing to determine halogen-free trend
- Salt builds up from the sweat and corrosion becomes observable

Heat Soak Testing





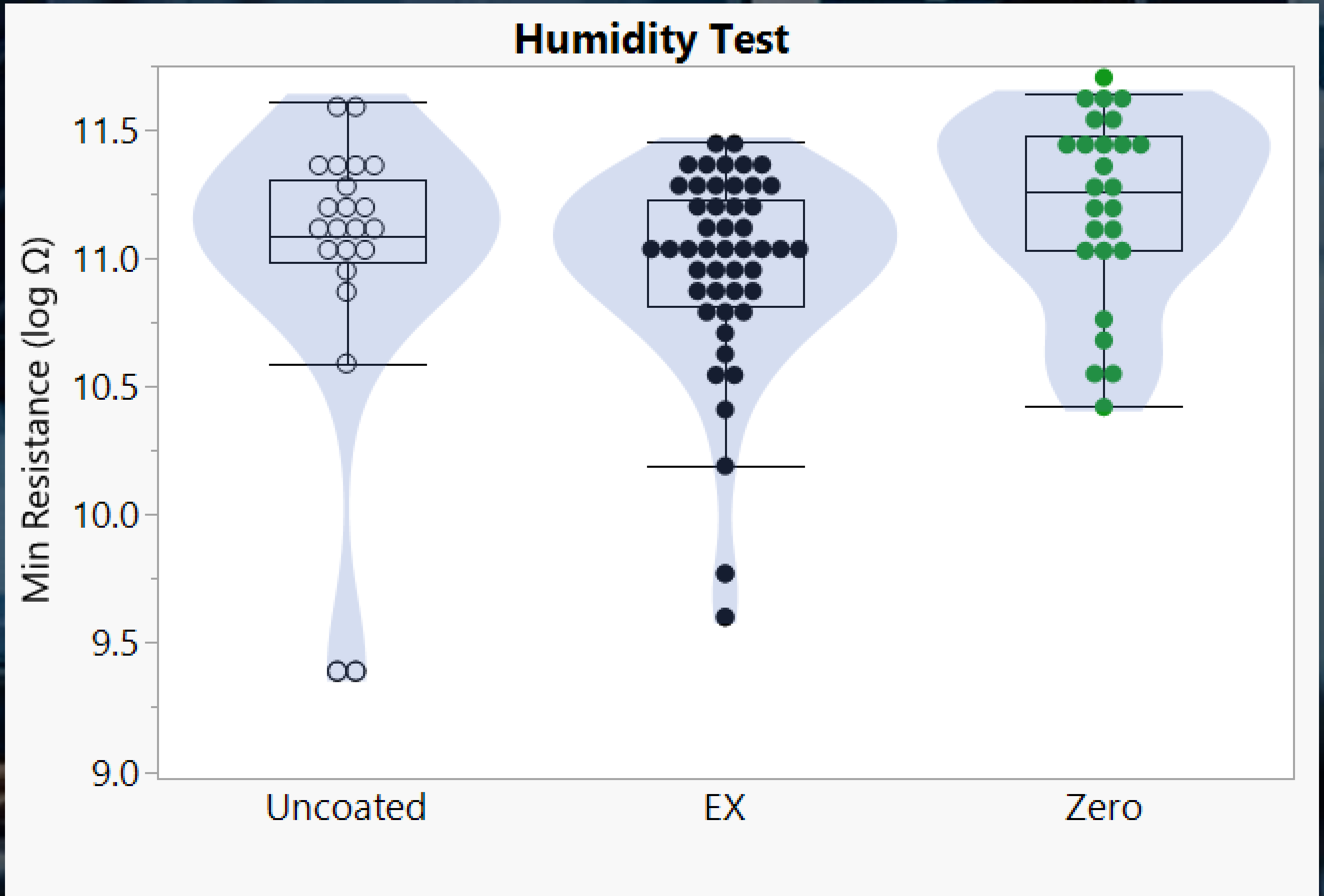
Objective:

To confirm that the coating does not lower electrical insulation during test

Pass Criterion:

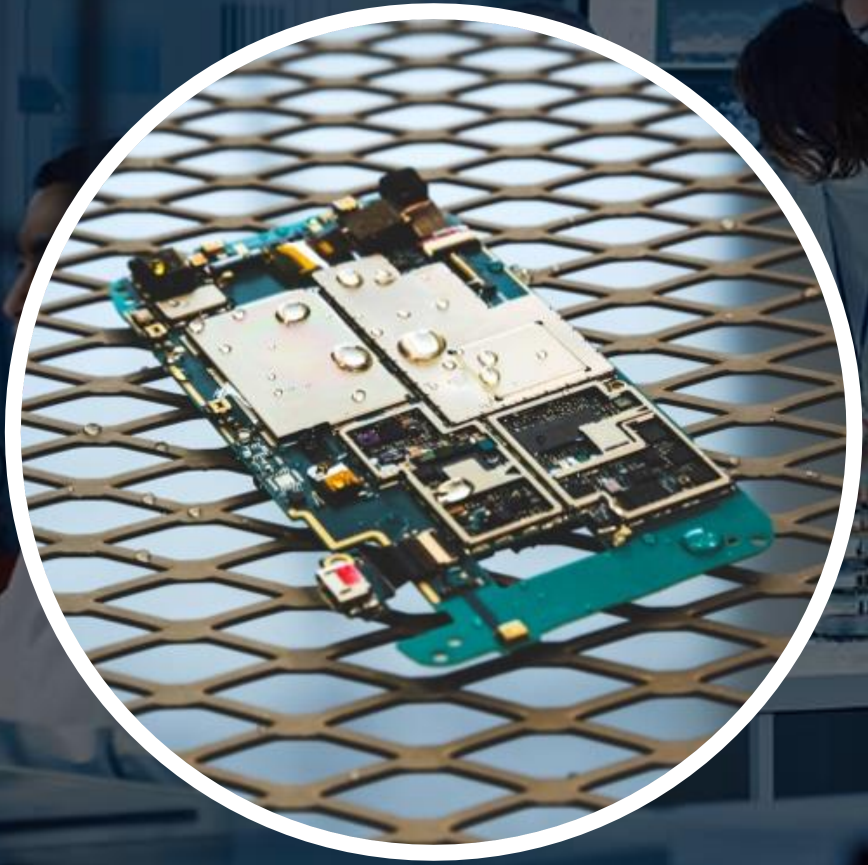
Resistance > 100 MΩ from 24 hours to the end of the testing duration @ 40°C & 90% RH

Temperature / Humidity Results



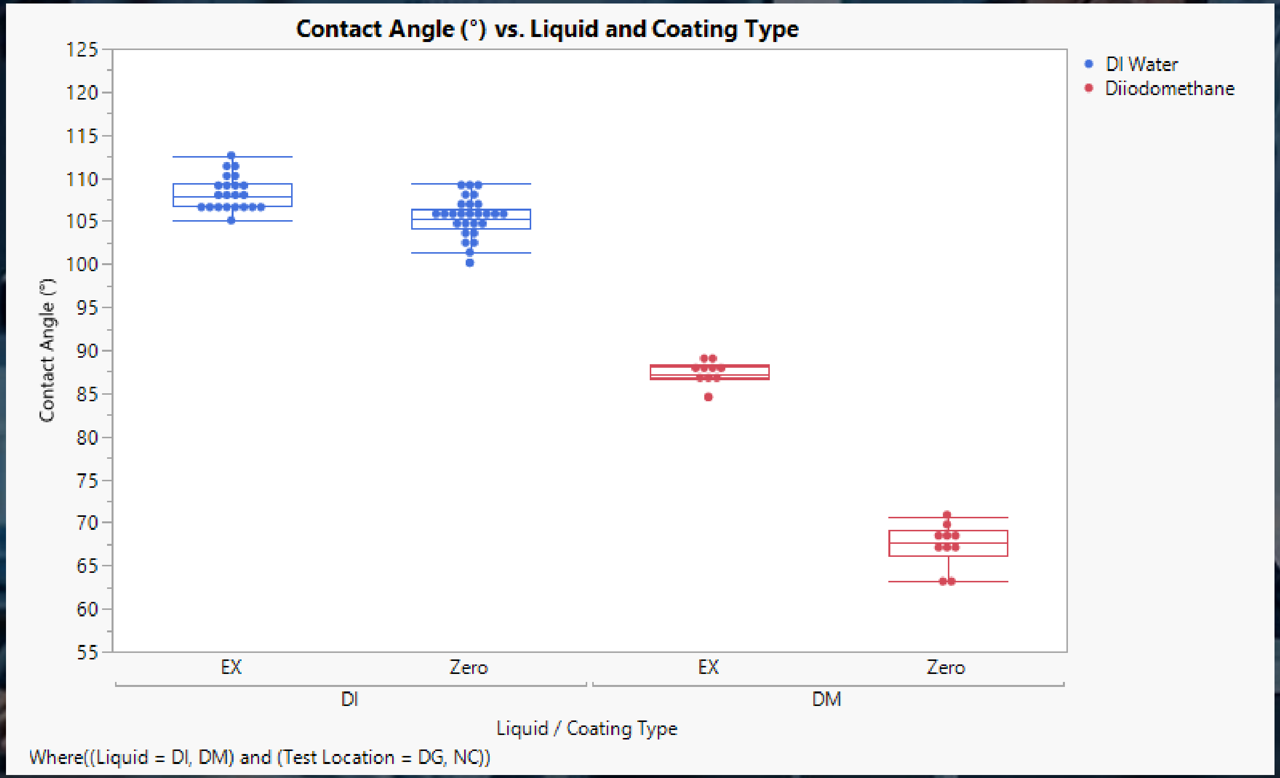
- All coated and uncoated boards passed J-STD-004B
  - > 100 MΩ (8 log Ω) required
  - >1,000 MΩ (9 log Ω) observed
- Coating does not absorb enough moisture to cause conduction

Hydro/Lipophobicity Testing



- Hydrophobicity was measured using static water contact angle (WCA) measurements using Kruss DSA25E goniometer and deionized water
- Lipophobicity was measured using diiodomethane as the contact angle liquid instead of the deionized water
- Left and right measurements were recorded and averaged for each drop
- All contact angles were measured on films deposited on flat and smooth Si wafers

Hydro/Lipophobicity Results



- Comparable thicknesses were used for each of the measurements
- WCAs for both halogenated and halogen-free coatings were in the same range (>100°), however halogenated is higher
- Observed OCAs for halogenated coatings are significantly higher than halogen-free
- Halogenated (EX) films can be considered omniphobic(WCA > 90°, OCA > 60°).

Summary

1. New challenges are being posed to the electronic industry including waste reduction and extending overall product life-cycles

2. Thin-film nanocoatings can be a strong tool to promote product longevity and reliability while mitigating waste and bulk

3. Material, process, and application selection are imperative to ensure design compatibility and regulatory compliance

4. Coating performance in varying environments and applications can help to tailor solutions to a given product or design application

Chemistry Driven Performance

Engineered for Device Reliability

Reduced Repair/Replacement Costs

Sweat

Accidental Spills or Splash Protection

Humidity & Moisture

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Have any further questions or interest?

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