Engineering UAV Reliability

Manufacture More Fail-Safe Drones with Lightweight Coatings for Extreme Environments

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About HZO

HZO delivers highly reliable thin-film coating solutions, such as Parylene and nanocoatings, that safeguard electronics, electrical products & critical applications. We work with some of the largest companies across industries, including a major drone manufacturer, from design through production, to deliver a better, more reliable, and more durable product.

Introduction

The global commercial market for unmanned aerial vehicles (UAV) – or drones – is expected to grow at a compound annual growth rate of over 16% between 2021 and 2026. This market growth occurs as large companies explore the capabilities of UAVs: from Amazon and FedEx making parcel deliveries to Bechtel utilizing drones to improve future construction projects. Many smaller companies also see opportunities in the emerging space and are taking advantage of what UAV technology has to offer.

Some Industries that use drones:

- Agriculture
- Delivery & Logistics
- Energy
- Media & Entertainment
- Real Estate & Construction
- Security & Law Enforcement

Beyond e-commerce package delivery, drones are used for:

- Medical supplies & prescription deliveries
- Irrigation monitoring & other agricultural uses
- Aerial inspection of sprawling industrial sites
- Surveying & mapping
- Filming & photography
- Border security

Worldwide Adoption in Harsh Environments

As UAVs diversify in function, fostering growth, the global commercial drone market is also shifting. While North America represented roughly 37% of the market share in 2020, by 2025, the Asian drone market is expected to be the largest market in the world, reaching about $17.9 billion. The shifting landscape speaks to the fact that UAVs must operate across the globe - in different climates and weather conditions.

However, drones rely on sensitive electronic systems such as sensors, cameras, flight controllers, mission payload controls, and communications equipment, all of which are easily harmed by common weather conditions. Therefore, all require protection against failure due to corrosion or shorting.

Components include:

- Onboard circuit assemblies
- Sensors
- Light controllers
- Mission payload controls
- Communications components
- A variety of cameras

Weather conditions that can pose a risk to electrical drone components include:

- Ambient humidity
- Rain
- Salt fog
- Torrential rain
- Pollution

Reliability Flies in the Face of Failure

While drones serve distinct functions, operate in varied climates and locations, and may use different components, they share one thing in common: the need to remain reliable regardless of the environment.

Drones are tasked with enduring harsh weather conditions, unpredictable application environments, and longer missions that entail bigger payloads. Depending on the application, they may require water, dust, shock, pressure, temperature, and humidity resistance. Sensors within UAVs that measure atmospheric parameters and gas concentrations must remain especially resilient in hazardous conditions.

Therefore, designers and manufacturers need to identify a protective solution that:

- Safeguards electronic components from dust, moisture, and corrosives
- Does not interfere with radio frequency communications
- Is thin enough to enable heat dissipation
- Is light enough to foster longer flights and maintain target weight
- Is applied with a repeatable method to minimize defects

Here are just a few reasons why reliable drones are a business requirement:

Businesses often require commercial UAVs to complete deliveries 24/7 across large distances. Therefore, flight range and time need to increase for economic viability regardless of the weather.

UAV repairs, service calls, and downtime can quickly erode profits as well as hinder drone availability.

Local and national governments are creating regulations to ensure that drone manufacturers can guarantee their fleets are reliable and safe.

A commercial UAV falling out of the sky due to failure can damage brand equity at best and cause catastrophic danger at worst.

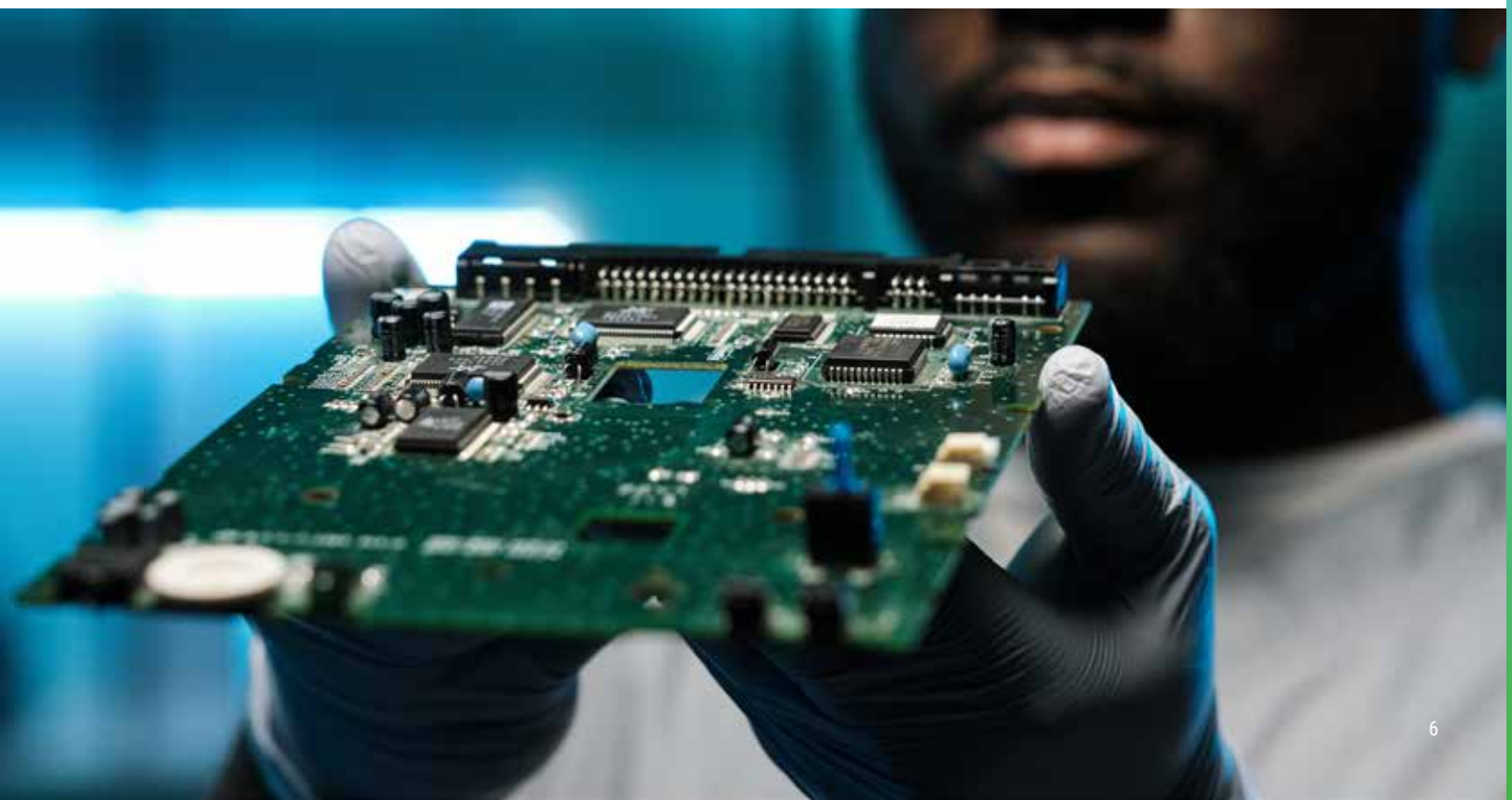
Fortunately, HZO's coating capabilities are as extensive as the environments and functions of UAVs.

Barrier Properties for Hazardous Conditions

Our coatings have the attributes required to ensure that drones can safely complete missions. The focus of this document is to describe the characteristics of our protective conformal coatings and why they are a good fit for UAV applications. Both our Parylene and nanocoatings are well-suited for UAV use and will be outlined in the information below.

Parylene coatings come in various types, including Parylene C, Parylene N, and Parylene F (VT-4), and have nearly 60 years of excellent performance with critical applications and industries. The coating is superior in uniform coverage, barrier properties, and performance at comparably thinner films, with less stress on mechanical structures and virtually no added weight.

HZO Sentinel™ nanocoatings are hydrophobic, oleophobic, functionalized thin films that can be used to improve reliability.



Robust Protection Throughout Temperature Extremes

Protective coatings have temperature limits that, when reached, shorten the coating's usefulness, which can be an issue for drones that may need to function dependably in extreme temperature ranges.

Fortunately, Parylene's melting temperature is high, at 290 °C. Parylene N maintains performance through temperatures even more extreme. The temperature stability values for the Parylenes are collected in the included table and are based on industry literature.

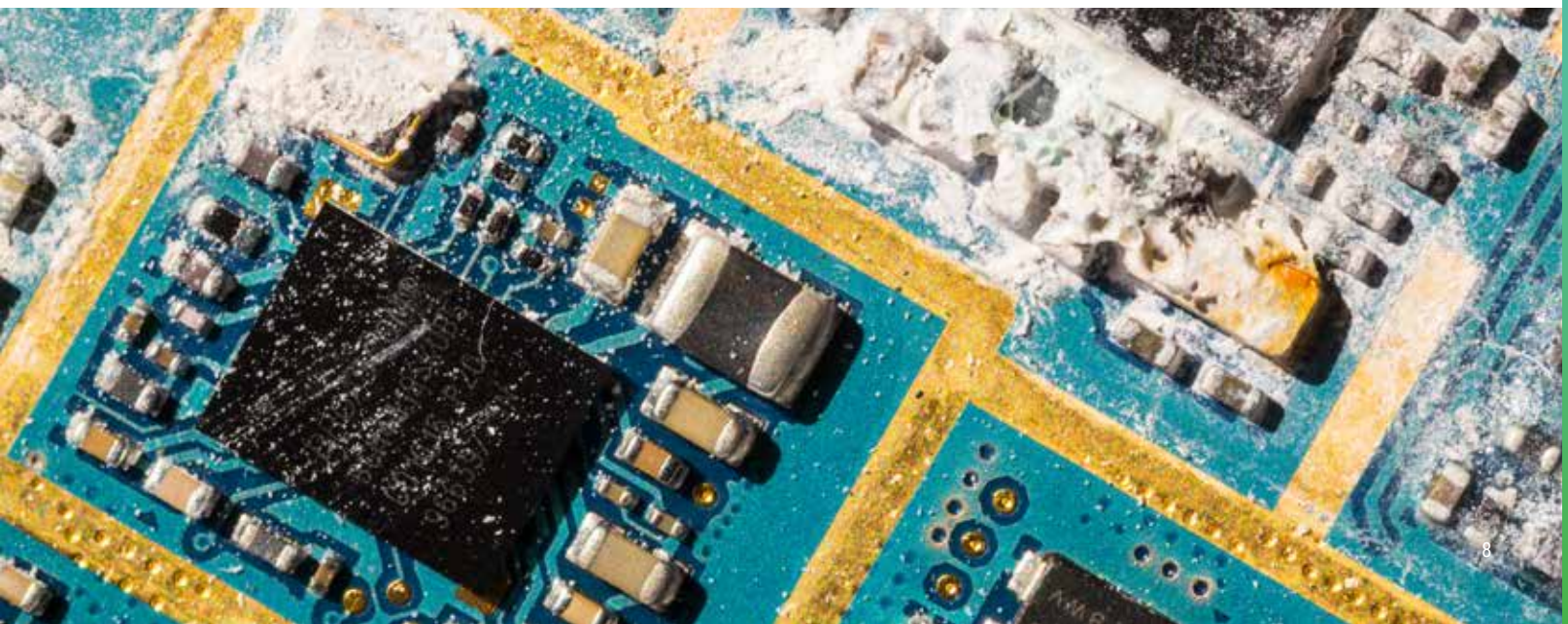
Parylene Type	Long-Term Temperature Limit (°C) Duration= ~10+ Years	Short- Term Temperature Limit (°C) Duration= ~1 Month	Melting Point Temperature (T_m)
Parylene N	60	96	420
Parylene C	80	115	290

Waterproof and Liquid Resistant

UAVs must reliably operate in hazardous weather conditions and corrosive environments. Our proven coatings can sustain electronics through liquid submersion without the need for hours spent on customizing designs for seals or risking failure with conventional conformal coatings.

LIQUID INGRESS PROTECTION STANDARDS

Level	Protects Against	HZO Coating Protection
0	None	Exceeds
1	Dripping Water	Exceeds
2	Dripping Water When Tilted at 15°	Exceeds
3	Spraying Water	Exceeds
4	Splashing of Water	Exceeds
5	Water Jets	Exceeds
6	Powerful Water Jets	Exceeds
7	Immersion, up to 1 Meter Depth	Exceeds
8	Immersion, 1 Meter of More Depth	Exceeds



Humidity Protection

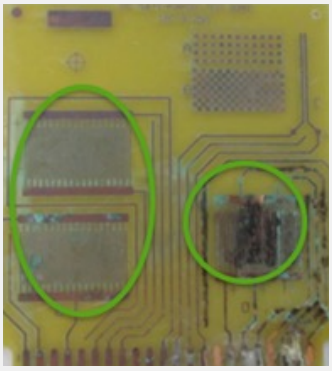
Salt fog and humidity – standard environmental variables – could cause legacy protection methods to fail. The images below show our Parylene coating performance when subjected to salt fog and humidity.

Seeing is believing when it comes to protection.

TEST RESULTS: HZO SOLUTION AGAINST SALT FOG

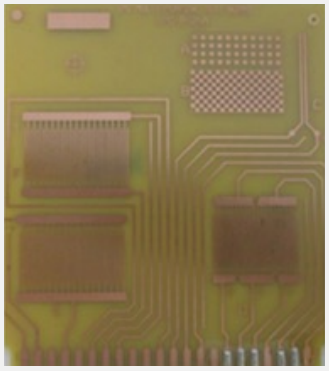
Chlorines from salt corrode copper traces to copper chloride (green color)

- Temperature: 35°C
- Concentration: 5% NaCl by weight
- Duration: 168 hours



Unprotected Board

Positive control board showing massive corrosion



HZO Protected

Discolored, but no corrosion

Corrosion Resistance

Corrosion is a natural process that, when left unaddressed, can devastate the electronic components in UAVs. Thankfully, OEMS can hinder this damaging process with proper protection. Coating components with Parylene makes it possible to avoid premature failure caused by exposure to corrosive substances.

Water vapor transmission rate (WVTR) and gas permeability are properties that indicate barrier effectiveness for corrosion resistance. The following chart illustrates that Parylene C and N's WVTR and gas permeability properties are exceptionally low, evidence of HZO coating's corrosion-resistance capabilities.

BARRIER PROPERTIES OF CONFORMAL COATINGS

Polymer	Gas Permeability at 25 °C, (cc·mm)/(m²·day·atm)							WVTR, (cc·mm)/(m²·day·atm)
	N_2	O_2	CO_2	H_2	H_2S	SO_2	Cl_2	
Parylene C	0.4	2.8	3.0	43.3	5.1	4.3	0.1	0.08
Parylene N	3.0	15.4	84.3	212.6	313	745	29.2	0.59
Parylene F (VT-4)	-	-	16.7	-	-	-	0.28	-
Epoxy (ER)	1.6	4	3.1	43.3	-	-	-	0.94
Polyurethane (UR)	31.5	78.7	1,181	-	-	-	0.93	-
Silicone (SR)	-	19,685	118,110	17,717	-	-	-	-

Ref.: Licari, James J. Coating Materials for Electronic Applications - Polymers, Processes, Reliability, Testing. William Andrew Publishing, 2003 and various companies' literature.

Lightweight Yet Powerful

There is a correlation between the weight of a drone and its expected battery life. Some studies indicate a direct proportion between an increase in weight and a decrease in battery life. Unfortunately, standard protection methods can add weight to UAVs.

Meanwhile, HZO has passed IPC CC-830C testing at 50% of the film thickness of traditional conformal coatings. This proves that HZO's Parylene can provide as much — or more — flexibility, fungus resistance, flammability, dielectric withstanding voltage, thermal shock, moisture, and insulation resistance at a fraction of the mass.

In previous partnerships, our customers have been able to reduce their products' weight by 10% . If that translates to a 10% improvement in battery life per charge per single drone, the effect this could have on an entire fleet would be substantial.

Class	Type	Specimen — Avg. Coating Thickness (µm)
XY	Parylene N	24
XY	Parylene C	30.75
XY	Parylene F	38.5
AR/UR	Acrylic	71.75
SR	Silicone	117.25
AR/UR	Acrylated Polyurethane	99

Enabling Heat Dissipation

Overheating can pose serious reliability challenges for UAVs. The components require protection from corrosives, but conventional conformal coatings can interfere with the heat transfer path, impeding heat dissipation when used in thick layers. As thermal conduction is inversely proportional to thickness, integrating the thinnest coating possible is a solution that does not hinder heat dissipation while allowing for the highest levels of corrosion protection.

As the chart indicates, Parylene coatings are a fraction of the mass of traditional conformal coatings. Meanwhile, epoxy or acrylic conformal coating applied at 50µm thickness can reduce an uncoated sample's ability to dissipate heat by 10x.

Coating	Thermal Conductivity (W/mK)	Emissivity	Film Thickness (µm)
Desired	High	High	Low
Parylene-N	0.13	-	2-50
Parylene-C	0.08	-	2-40
Acrylic	0.13-0.25	-	30-130
Epoxy	0.17-0.21	-	30-130
Silicone	0.15-0.31	-	50-210
Urethane	0.21	-	30-130

Thermal conductivity, emissivity, and film thickness are the most critical parameters for heat dissipation when selecting a conformal coating.

Electrical Properties

UAVs require protection that safeguards electronic components without affecting Radio Frequency (RF) control, communication, and data signals and without distortion, even as operating frequency increases. HZO coatings have low dielectric constants and dissipation factors and are applied in thin layers, ensuring that signal transfer is not disrupted.

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Sustainability

Parylene prevents premature failure and sustains the product lifecycle with superior protection, averting e-waste issues common with electronic components.

With the proper choice of coating type and thickness, HZO coatings are very stable. They will withstand the life of the UAVs they protect.

	60 °C	80 °C	135 °C	150 °C
Parylene C	~100 years	~20 years	~70 hours	~24 hours
Parylene N	~10 years	~1 year	~9 hours	~1 hour

Lifetime of HZO coating at different temperatures in air (with oxygen)

Furthermore, our coatings are inherently sustainable, REACH, and RoHS compliant, with no cure time. There are:

No VOCs

No Solvents

No Catalysts

No Disposal Issues

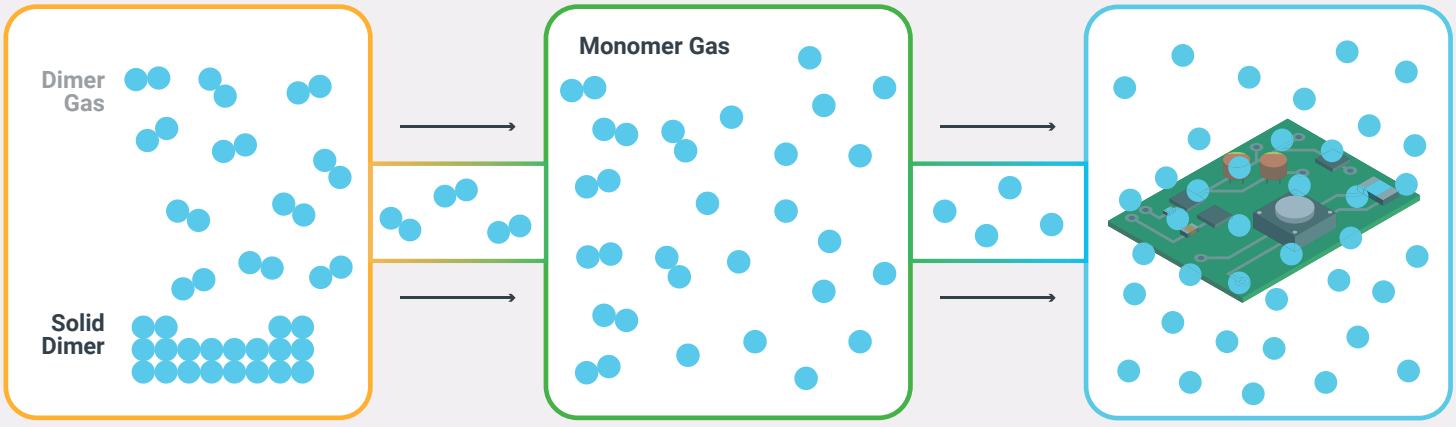
No Pollution Threats

The Parylene Coating Process

Parylene is highly conformal, offering the best protection also on corners & edges of components, creating a thin 3D type film across the PCBA. The high conformality at low thickness offers design flexibility & results in extremely low contact / interfacial resistance. These properties are due to the chemical vapor deposition (CVD) application process specific to Parylene.

The CVD process is performed under vacuum, with specialized equipment that includes a coating chamber. As a result, all surfaces are coated evenly regardless of chamber position, and the coating deposits the same thickness all around the objects being coated. This vapor phase coating process also leads to pinhole-free coatings free from defects.

CHEMICAL VAPOR DEPOSITION (CVD) COATING PROCESS



1. Parylene typically begins as a solid dimer, sublimated to gas.
2. The gas goes through a pyrolysis chamber that cracks the dimer into two di-radical monomers before entering the deposition chamber.
3. The monomers adsorb onto the substrate as a polymer.

Since it is deposited as a vapor that lands on and begins building up a thin film that wraps around components and substrates with little to no change in thickness, Parylene is a truly conformal coating that ensures protection from corrosive environments even at tight corners. Conversely, conventional conformal coatings can leave an uneven application, with much thinner layers at the corners of the component or substrate, unless the coating is made so thick that it starts adding size, weight, and potentially stressing components due to differences in thermal expansion.

In the image to the right, a conventional conformal coating has poor coverage, in which it is thinner on the top corners, thicker on the top than the sides, and much thicker at the bottom. A bubble trapped underneath the component shows the coating didn't push all of the air from underneath as the coating was deposited. With so much coating at the bottom under the component, the coating may push up on the component or against the soldered leads as the electronic device is heated. After several hot-cold cycles, the coating may break the component's connection to the board, creating an electrical open.

PARYLENE CONFORMALITY COMPARED TO CONVENTIONAL CONFORMAL COATINGS

SEM image of conventional conformal coating coverage (Source: IPC-SMTA)

Case Study: HZO Nanocoatings for Drone Application

HZO recently partnered with a large company that designs and builds delivery UAVs that meet the industry's highest safety and reliability standards. This company investigated various conformal coating materials and suppliers but ultimately chose HZO to attain their target IP rating of IPX4 or greater due to our reduced costs, global locations, and enhanced convenience.

Dedicated engineers and industry subject matter experts guide every project we take on. Our team has virtually seen it all, understands when and how to help, and helps businesses understand complex challenges, offering useful feedback that can avoid complications.

To meet specifications, the company chose to use HZO Sentinel™ nanocoatings, hydrophobic and oleophobic coatings even thinner than Parylene. The properties are listed in the table on the next page.

Our engineers created a one-stop-shop solution for the company, including our capital coating equipment and masking and demasking expertise. To help with implementation, our team continues to conduct weekly meetings to check deliverables, analyze build results, discuss how to improve the current process, and maintain the project on schedule.

With transparency in sharing process information and unmatched availability, we have provided them with the protection and cost savings they need. We have also demonstrated the aptitude to meet the necessary specifications and produce parts that consistently meet these requirements during production.

HZO Sentinel™ EX Properties

Environmental Properties	HZO Sentinel	Test Specification
Insulation Resistance (Ω)	1 x 10^{10}	IPC TM-650 2.6.3.7
Temperature and Humidity Aging	Pass	J-STD-004B (7 days)
Moisture Insulation Resistance (Ω)	1 x 10^{9}	IPC TM-650 2.6.3.4
Ingress Protection	Pass (Coated Tablet)	IPX4
Flammability	Pass [VO]	UL94
Breakdown Temperature (°C)	> 255	TGA (10% wt. loss in air)
Thermal Shock Testing	Pass	IPC-CC-830C 3.7.2

Chemical Properties	HZO Sentinel EX	Test Specification
Water Contact Angle (°)	> 104	Sessile Drop Method
Oil Contact Angle (°)	> 85	Sessile Drop Method
Fluorescence	No	IPC CC-830B 3.5.3
Surface Energy (Dynes/cm)	< 22	ISO 8296, Dyne Pens

Optical Properties	HZO Sentinel EX	Test Specification
Transparency - Visible Light	Pass	IPC CC-830B 3.5.2

Physical Properties	HZO Sentinel EX	Test Specification
Appearance	Pass	IPC CC-830B 3.5.2
Thickness Range in Use (µm)	0.9 to 4.0	Stylus Profilometer
Flexibility	Pass	TPC TM-650 2.4.5.1

Electrical Properties	HZO Sentinel EX	Test Specification
Dielectric Constant (1 MHz)	2.5	CV Plotter and Mercury Probe
Loss Tangent (1 MHz)	<0.01	CV Plotter and Mercury Probe
Dielectric Strength (V/m)	5 x 10^{8}	ASTM-D149
Dielectric Withstanding Voltage (V)	> 1500	IPC TM-650 2.5.7.1
Dielectric Withstanding Voltage	Pass	IPC-CC-830C 3.6.1

MORE ABOUT HZO

HZO has a unique ability to process large, complex boards due to our proprietary coating and automation equipment, coating parts in large qualities and producing repeatable quality coatings with high yield rates. Our customer-focused solutions can be delivered with several flexible end-to-end business models as our dedicated engineers and SMEs walk clients through every coating process step.

Traditionally, CVD coatings such as Parylene and PECVD nanocoatings can be more costly than most conformal coatings, requiring a batch-style coating process and sometimes a longer coating time. However, HZO addresses these shortcomings through engineering and manufacturing solutions to meet or exceed manufacturing requirements and competes with legacy solutions.

Automated and semi-automated masking and demasking effectively drive down costs associated with the coating process. In addition to optimized equipment, HZO exceeds quality assurance expectations. Since our inception, there has not been a single product return attributed to coating issues, although we have coated millions of components.

Finally, we offer considerable convenience with highly configurable processes that integrate into production. We provide a turnkey solution with hands-on help from dedicated engineers who help companies walk through solutions from beginning to end.

Contact our team today for more information about protecting UAV and drone components.

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