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The Role of Parylene Conformal Coatings in Next-gen Electronics

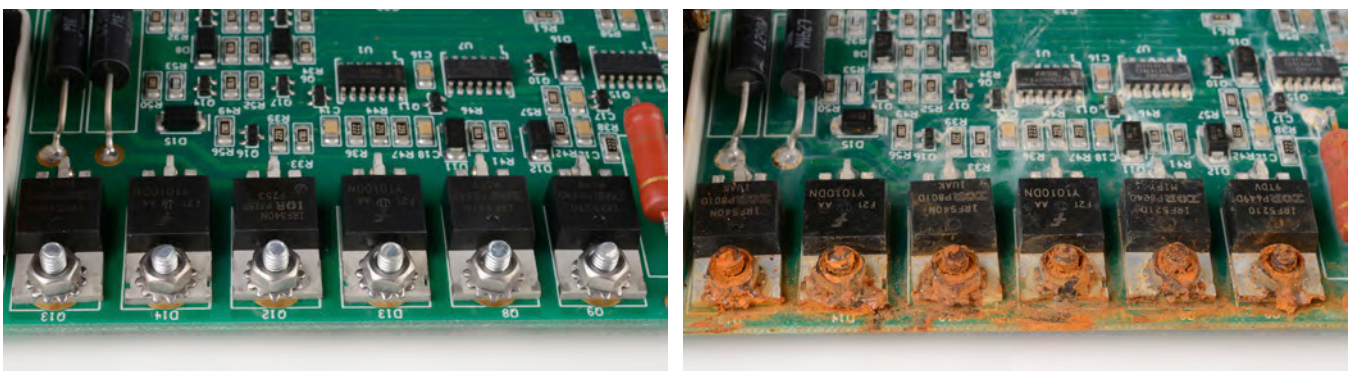
Feature by Tim Seifert
SPECIALTY COATING SYSTEMS (SCS)

Designers and manufacturers of electronics are under pressure to make packages smaller, lighter, and more environmentally friendly. They also need to ensure that their new technologies perform reliably in their operating environments, which may include exposure to chemicals, moisture, electrical charges, and extreme temperatures while maintaining compliance to a growing number of stringent environmental, safety, industry-specific, governmental, and/or biological regulations. In this article, I will take a closer look at Parylene conformal coatings and the role they can play in helping manufacturers address current and future challenges in the electronics industry.

Developed by Union Carbide scientists in the late 1950s, Parylene is the generic name for a unique series of polymeric organic coating materials. They are polycrystalline and linear in nature, possess useful dielectric and barrier properties per unit thickness, and are chemically inert. Parylene coatings are ultra-thin, pinhole-free, and truly conform to components due to their molecular level polymerization—basically "growing" on the substrate surface one molecule at a time.

Parylene coatings are applied in a vapor deposition process rather than by dispensing, spraying, brushing, or dipping. The process begins by placing parts to be coated in the deposition chamber. The powdered raw material—known as "dimer"—is then placed in the vaporizer at the opposite end of the system. The dimer is heated, causing it to sublimate to a vapor, and then heated again to break it into a monomeric vapor. This vapor is transferred into an ambient temperature chamber where it spontaneously polymerizes onto the parts, forming the thin Parylene film. The Parylene deposition process is carried out in a closed system under a controlled vacuum with the deposition chamber remaining at room temperature throughout the entire process. No solvents, catalysts, or plasticizers are used in the coating process.

Because there is no liquid phase in this deposition process, there are no subsequent meniscus, pooling, or bridging effects as seen in the application of liquid coatings; thus, the entire part is equally protected. The molecular "growth" of Parylene coatings also ensures not only an even, conformal coating at the thickness specified by the manufacturer, but because Parylene is formed from a gas, it also penetrates into every crevice—regardless



ParyFree coated and uncoated board after salt-fog testing.

of how seemingly inaccessible. This ensures complete encapsulation of the substrate without blocking small openings.

Additionally, Parylene coatings are extremely lightweight, offering excellent barrier properties without adding dimension or significant mass to delicate components. Typical Parylene coatings range in thickness from 500 angstroms to 75 microns. Most other coating materials cannot be applied as thin as Parylene and still provide the same level of protection.

There are several variants in the poly-para-xylylene family, but all are completely linear, highly crystalline materials that provide the benefits of being ultra-thin and lightweight. They all also provide an excellent dielectric, moisture, and chemical barrier, add strength to wire bonds, ensure efficient signal transmission, and are biocompatible. Parylenes have extremely low dielectric constants and dissipation factors, enabling them to provide small, tight packages with dielectric insulation via a thin coating. The voltage breakdown per unit thickness actually increases with decreasing Parylene film thickness.

Parylene coatings have been used throughout the electronics, transportation, aerospace, defense, and medical device industries for over 45 years to solve industry challenges. In fact, where other solutions have become insufficient to meet the growing needs of the industry, Parylene coatings are providing answers at a time when products need to be small, lightweight, robust, and reliable.

Industry Challenges and the Parylene Solution

Small and Lightweight

Whether working on gadgets for the consumer market or defense hardware, electronics manufacturers face relentless pressure to make electronic packages smaller and lightweight; this is a constant, regardless of the size of the overall device. While mobile phones have actually become larger in recent years, they are packed with more power and functionality than their predecessors so their internal components had to shrink. Similarly, automobiles and aircraft stay roughly the same size, but

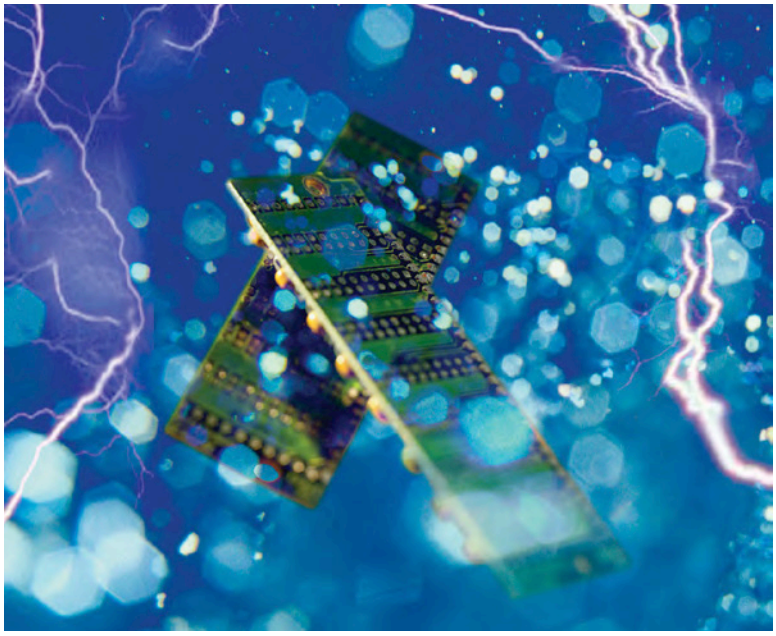
SCS PARYLENE PROPERTIES

		Parylene N	ParyFree	Parylene C	Parylene HT	Acrylic (AR)	Epoxy (ER)	Polyurethane (UR)	Silicone (SR)
Dielectric Strength V/mil		7,000	6,900	5,600	5,400	3,500	2,200	3,500	2,000
Dielectric Constant	60 Hz 1 KHz 1 MHz	2.65 2.65 2.65	2.38 2.37 2.35	3.15 3.10 2.95	2.21 2.20 2.17	– – 2.7 – 3.2	3.3 – 4.6 – 3.1 – 4.2	4.1 – 3.8 – 4.4	3.1 – 4.2 – 3.1 – 4.0
Dissipation Factor	60 Hz 1 KHz 1 MHz	0.0002 0.0002 0.0006	0.00001 0.0009 0.0007	0.020 0.019 0.013	<0.0002 0.0020 0.0010	0.04 – 0.06 – 0.02 – 0.03	0.008 – 0.011 – 0.004 – 0.006	0.038 – 0.039 – 0.068 – 0.074	0.011 – 0.02 – 0.003 – 0.006
Water Vapor Transmission Rate ($g \cdot mm)/(m^2 \cdot day$)		0.59	0.09	0.08	0.22	13.9	0.94	0.93 – 3.4	1.7 – 47.5
Water Absorption (% after 24 hours)		<0.1	<0.1	<0.1	<0.01	0.3	0.05 – 0.10	0.6 – 0.8	0.1
Service Temperature	Continuous Short-Term	60°C 80°C	60°C 80°C	80°C 100°C	350°C 450°C	82°C –	177°C –	121°C –	260°C –
UV Stability		≤100 hrs	≤100 hrs	≤100 hrs	≥2,000 hrs	–	–	–	–
Coefficient of Friction	Static Dynamic	0.25 0.25	0.23 0.23	0.29 0.29	0.15 0.13	– –	– –	– –	– –
Tensile Strength (psi)		7,000	9,600	10,000	7,500	7,000 – 11,000	4,000 – 13,000	175 – 10,000	350 – 1,000
Penetration Ability		40 x dia.	10 x dia.	5 x dia.	50 x dia.	Spray or Brush	Spray or Brush	Spray or Brush	Spray or Brush
Rockwell Hardness		R85	R136	R80	R122	M68 – M105	M80 – M110	68A – 80D (Shore)	40A – 45A (Shore)
USP Class VI Polymer		Yes	Not Yet Available	Yes	Yes	Varies	Varies	Varies	Varies
Biocompatibility		ISO 10993	Not Yet Available	ISO 10993	ISO 10993	Varies	Varies	Varies	Varies

For references and applicable testing methods, please contact SCS.

additional electronic components are used to increase their functionality and reliability. At the same time, there is an increasing call in these industries to reduce weight to improve system efficiencies.

Because Parylene coatings are applied as a vapor, the molecules grow into a film, adhering equally to every surface and edge and within crevices. The coatings completely encapsulate complex substrates, providing excellent barrier and dielectric protection. Additionally, due to their ultra-thin nature, the protection they provide is achieved without adding significant dimension or mass.



Parylene coatings provide excellent moisture, chemical and dielectric barrier protection.

Comparatively, liquid coatings are commonly applied by spray, brush, or dip and may not provide complete coverage due to pooling, bridging, or meniscus effects. While these coating solutions may be sufficient for some applications, they have their limitations when it comes to today's advanced electronic designs.

Green Electronics

Globally, more than 1.5 billion cellphones are sold each year. Often, these devices are replaced every two years; some are recycled, but others end up in landfills or incinerators. As such, many device manufacturers have committed to reduce or eliminate the use of fluorine, chlorine, and other halogen materials that can emit toxic pollutants when discarded devices are disposed or incinerated.

As international standards and initiatives continue to evolve, the availability of environmentally friendly products and materials must increase. Although Parylene variants that contain chlorine molecules are extremely stable even at high temperatures, a new variant has been introduced—ParyFree®—that is entirely halogen-free and offers the beneficial attributes of other commercially available Parylenes. ParyFree offers electronics manufacturers a halogen-free coating solution that provides improved moisture barrier properties over traditional non-halogen Parylene variants.

Protection From Moisture, Dust, and Chemicals

At the same time, electronic content in devices has increased across industries; the range of demanding environments in which these systems must reliably operate has also increased. Whether in the vacuum of space, under the hood of an automobile, on a rig in an oil field or inside the human body, critical electronics must be well-protected from their environments (e.g., moisture, chemicals, fluids, dust, etc.) to ensure reliable operation; lives are literally on the line. In addition, the use of wearable devices has skyrocketed over recent years, and users demand that their gear (e.g., phones, headphones, watches, fitness monitors, etc.) can fully withstand the elements. Essentially, defense-grade ruggedization is now required for consumer electronics.

Circuit boards coated with ParyFree were salt-fog tested by an independent facility. The coated boards exhibited no corrosion, salt, or heavy iron oxide deposits after 144 hours of exposure in accordance with ASTM B117-(03). Boards coated with Parylenes C and Parylene HT® exhibited similar results.

ParyFree-coated electronics were also recently tested in accordance with the applicable requirements of IEC 60529, test condi-

tions 14.2.7 and 14.2.8 for IPX7 and IPX8 designations, which demonstrates protection from harmful effects due to the ingress of water. The uncoated (control) electronics functionally failed during the test, but all ParyFree-coated electronics passed both test conditions, functioning normally both during and after testing. These tests demonstrate that ParyFree conformal coating, like other Specialty Coating Systems (SCS) Parylene variants, is suitable to protect electronics and other devices against water splash and water immersion for more than 30 minutes at a depth of 1 m (IPX7) and 1.5 m (IPX8).

Protection From Electrical Arcing and Electrostatic Discharge

Electronics have long been susceptible to electrical arcing and electrostatic discharge (ESD). However, modern devices are actually more susceptible to these electrical risks because individual components are smaller. Additionally, contact points are also closer together, and thinner wiring simply cannot withstand the same sudden jolt as the thicker wiring of older equipment. If not protected, such electrical mishaps can cause premature device failure.

Halogen-free ParyFree protects a wide range of consumer electronics devices.

Parylenes have very high dielectric strength—up to double that of other coatings of the same thickness. As such, they provide excellent insulating protection to prevent damage from arcing and ESD without adding significant mass. For example, a 25-micron Parylene coating will have a dielectric capacity of 7,000 volts. No other coating can be applied as thin as Parylene and still provide the same level of protection.

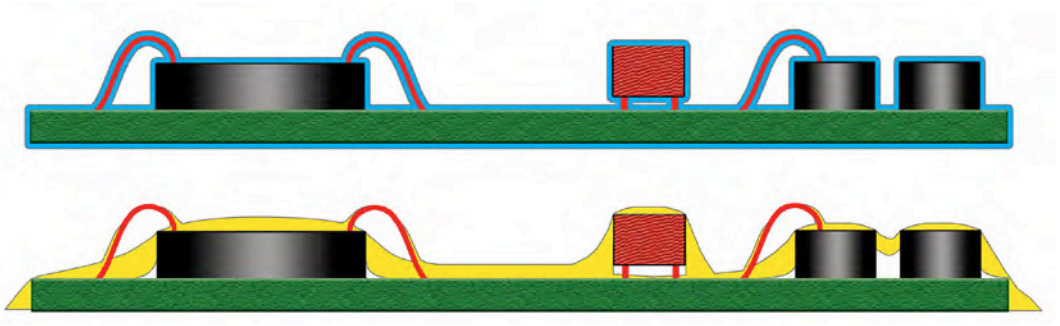
Stability to Endure Thermal Cycle Extremes, Pressure, and Vibrations

Electronics used in automobiles, aircraft, oil drilling, and space exploration are exposed to harsh environments and expected to operate reliably in them. Circuit card assemblies in the wing of a jet or in a rocket carrying a satellite into space, for example, will travel quickly from ambient, sea-level temperatures to a stratospheric altitude at subzero temperatures. In addition to the temperature change, the tiny, delicate mission-critical electronic circuits have to endure rapid pressure changes and intense vibration as part of the ride.

Some of the protective methods that have been successful in earth-bound applications can fail in the atmosphere of space. Air that may be trapped under an epoxy or acrylic sealant due to the nature of coating application can release, leaving critical components unprotected in the midst of a flight or operation.

Parylene HT was specifically designed to protect components that must survive exposure to harsh, high-temperature environments. The coating is thermally stable in air at 350°C (long-term) and remains stable with short-term excursions to 450°C, offering excellent protection to many aerospace, defense, and transportation applications. Parylene HT is also UV-stable.

Parylene coatings, though ultra-thin and lightweight, have been known to strengthen fine components and wire bonds, helping to secure delicate electronics. Additionally, due to the film's



Parylene (top) vs. liquid (bottom) coating comparison.

molecular growth, there are no voids or air bubbles to pose a catastrophic risk upon rapid pressure changes.

Biocompatibility and Biostability

Neurostimulators, pacemakers, cochlear and ocular implants, electrosurgical tools, and an ever-increasing array of other devices can make a dramatic difference in patients' lives, provided they are biocompatible, biostable, and can operate reliably when in contact with or implanted within the human body. Parylenes protect medical electronic components from moisture, biofluids, and biogases that can cause assemblies to fail prematurely. Such protection not only extends the life of the device but also reduces the risk of failure at the most critical times. SCS Parylenes N, C, and Parylene HT comply with biological testing requirements for ISO-10993; testing included cytotoxicity, sensitization, intracutaneous reactivity, acute systemic toxicity, implantation (2, 12, and 26 weeks), hemocompatibility (hemolysis and PTT), and pyrogenicity. The coatings are also certified to comply with the biological testing requirements for USP Class VI Plastics.

Conclusion

When choosing materials and solutions, product design engineers need to know both a product's function and how it will react in a given environment. To help ensure these requirements are met, industries outline various regulations that manufacturers—and often their subcontractors—must meet. These requirements establish standards against which products and processes can be tested and certified.

While Parylene coatings can be evaluated based on their certification to various standards and industry regulations, coating suppliers can also be evaluated, in part, based on their process certifications and compliance. Following are a just few of the process and product specifications and/or certifications that should be reviewed, if applicable, by manufacturers:

- AS9100 and/or ISO 9001 management systems
- Requirements of IPC-CC-830
- QPL for MIL-I-46058C
- Production Parts Approval Processes (PPAP)
- European Union's RoHS Directive
- REACH compliance
- Halogen-free initiatives
- ISO 10993, USP Class VI biological evaluations and certifications
- ISO 14644 cleanrooms
- UL (QMJU2)

As worldwide industry requirements and directives continue to evolve, manufacturers must ensure their products comply with relevant standards. Additionally, they must be certain that their products operate reliably in whatever conditions they encounter. Parylene conformal coatings provide designers and engineers a range of solutions to help increase the reliability and performance of their latest innovations. **SMT007**

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