Protecting Electronics with Parylene

DIAMOND-MT

www.paryleneconformalcoating.com

A Brief Introduction to Parylene

Conformal Coating

Conformal coatings are polymetric materials used to protect electrical and mechanical circuitry, parts, and related components. They safeguard parts and products from environmental contamination during use, insulating the substrate while doing so.

To accomplish this, conformal coatings are applied in extremely thin layers—usually just a few millimeters thick—directly onto the substrate. Most conformal coatings—acrylic, epoxy, silicone, and urethane—are applied by dipping, flow-coating, or spraying on the substrate, then allowing the liquid to dry or cure. Select-coating or robotic dispensing are also being used more frequently.

A major exception is parylene conformal coating, which is applied through a unique vapor deposition process.

Conformal coating provides protection from:

1. Contamination caused by exposure to harsh physical environments, extreme temperatures, and humidity
2. Abrasion during performance and contact with acids, solvents, or body fluids (in the case of medical devices)
3. Conductor electro-migration, corrosion, dendritic growth, or short circuits within electronic assemblies and circuitry
4. Stress-relief and insulation to help ensure ongoing functionality

Conformal coating protection has been adapted to wide range of product applications, including:

- Aerospace and military technology
- Consumer electronics of all kinds
- Harsh automotive mechanical applications
- Industrial uses
- Microelectromechanical systems (MEMS)
- Medical products that operate either within or attached to the human body.

Indeed, without conformal coatings, many of the products we use every day and take for granted would not function nearly as well and would need to be replaced far more frequently.

Parylene: The Distinctive Conformal Coating

As we noted earlier, parylene is a unique conformal coating. In many ways, parylene has become the “gold standard” conformal coating for electronic devices of all kinds.

Parylene provides excellent substrate coverage, offering the thinnest effective coating application available in comparison to other conformal coatings. The vapor deposition process penetrates into the substrate surface, generating the highest levels of protection available for many products.

Parylene surfaces are exceptionally resilient, withstanding extremes in temperature and physical stress. Their consistency remains very uniform, yielding excellent pinhole coverage that prevents leakage. Parylene's exceptional dielectric properties also make it the covering of choice for a wide array of electrical components.

Other Conformal Coatings Options

The other major types of conformal coating are acrylic, epoxy, silicone, and urethane.

- **Acrylic:** Acrylic coatings dry rapidly after application (via brush, dip, spray methods), and they do not shrink during cure. They also persistently exhibit good fungus and humidity resistance in use. However, they often break-down more readily at higher temperatures than other polymers, and have limited abrasive and stress-relieving capabilities. Their cost advantage compared to other coatings has declined in recent years.

- **Epoxy:** Unlike acrylics, epoxy resins have good abrasive and chemical resistance. They are applied similarly to acrylics, and they demonstrate good humidity resistance. However, film shrinkage during polymerization is common, which somewhat counteracts the effectiveness of the extremely durable coatings they provide. In addition, thermal extremes significantly lower the stress resistance of epoxy coatings.

- **Silicone:** Silicone is able to withstand extreme differences in temperature and has a useful operating range of -55°C - +200°C. Its dissipation factor is low, and it exhibits good PCB-adhesion, as well as high levels of resistance to heat, humidity, moisture and ultraviolet light. Silicone is very versatile and can be customized according to a product's precise requirements, with surfaces ranging from elastomeric, stress-relieving coverings to those far more abrasion-resistant and durable. Their toxicity is low and they are easily repairable.

- **Urethane:** Urethane coatings have excellent dielectric properties, good chemical resistance, low moisture permeability, and good temperature flexibility at low temperatures. Although they are tough and display dependable resistance to solvents, their bond-strength is limited; urethane coatings covering larger areas have a tendency to flake and peel. This factor largely negates urethane's fine capacity for abrasion resistance, high-temperature resistance and repairability are also limited.

Which Coating Is Right for Me?

Each conformal coating has its own unique properties which dictate its particular range of product uses. These conditions vary according to product and purpose.

As an example, NASA Standard (NASA-STD) 8739.1a for space flight and exploration systems requires a specific coating-thickness for each coating material. These are levels of coating that assure reliable, safe performance of circuits and components under often-extreme conditions. When assessed by these standards, thinner layers of parylene provide equal or superior protection, compared to other conformal coatings (measured in millimeters (inches)):

- Parylene: 0.013 – 0.051 (0.0005 to 0.002).
- Silicone: 0.051 – 0.203 (0.002 to 0.008).

- Acrylic, urethane, epoxy: 0.025 – 0.127 (0.001 to 0.005).

Parylene displays similar coating-thickness and temperature advantages for most conformal coating projects. Each of the major types of conformal coatings offers particular advantages for a range of uses. All are less costly and easier to apply than parylene, but none displays parylene's versatility of uses—from aerospace/military to medical, consumer goods to automotive, for MEMS and technologies waiting beyond.

Of available conformal coatings, parylene is best able to withstand specialized and often harsh environments with optimal functionality.

Benefits of Parylene

Conformal Coating

While parylene can coat just about anything, one of its most common uses is for protecting printed circuit boards. Product engineers specify parylene because it offers a unique blend of five capabilities.

1. It's Thin and Complete

Parylene is the only commonly used conformal coating that gets deposited in a vapor state. While vapor deposition is a relatively complicated process, it offers two fundamental benefits over the more typical liquid deposition processes used for other conformal coating materials.

First, because it is a vapor, it goes everywhere that air can. This means that the coating is truly conformal. Thick liquids have trouble coating in the small gaps between parts and the PC board substrate. Parylene has no problem covering these small gaps, since it is just a vapor.

Second, because of the combination of the vapor deposition a unique chemical makeup, parylene works even when applied in an extremely thin layer. It can be so thin as to have almost zero impact on the total thickness or weight of a coated item. This has the obvious benefit of working well when products need to meet tight tolerances.

2. Tin Whisker Mitigation

Tin whiskers are small crystals of tin that grow out from soldered joints. Over time, tin whiskers can become long enough to touch other nearby connections, creating short circuits. Since printed circuit boards usually have a significant number of solder points, tin whiskers are extremely likely to form.

Typically, there are two ways to mitigate tin whiskers. One is to use solder containing lead. Unfortunately, lead solder is a major environmental and health hazard and is almost never suitable for applications where the item will be used in a consumer or healthcare device.

The other solution is to conformally coat the PC board with parylene or another compound which prevents the whiskers from crossing with other connections.

3. Parylene as a Dielectric

While electric signals are what make printed circuit boards work, interference from outside signals can also make them fail. Luckily, parylene is an excellent dielectric. Coated boards are better able to resist outside electrical and radio frequency signals, leading to better-operating and longer-lasting electronic devices.

Parylene doesn't just insulate PC boards from the outside. It also insulates PC boards from themselves. Every printed circuit board has traces that carry signals from place to place—those traces are the circuits. However, because those traces are uninsulated, they leak RF or EMI signals into the air and into each other.

A parylene coating doesn't just protect the board from the outside world. It also protects it from itself, letting designers build smaller boards with closer-together traces since they are able to resist each others' interference.

4. It Resists (Almost) Everything

Parylene doesn't just resist electric signals, though. It also protects printed circuit boards from just about everything else that nature can throw at it.

Moisture, acids, bases, solvents, corrosive materials and most other chemicals and liquids cannot permeate it. This makes it an excellent choice for protecting PC boards that will be used in the real world—or in outer space.

It is such a good coating for chemical and moisture protection that is also approved for use in one of the wettest and most chemical-laden places on earth—inside the human body.

5. It’s Workable and Reworkable

Parylene provides a comprehensive and strong coating, which is what most PC boards need. However, just because it can cover just about everything and can resist just about anything doesn't mean that you can't also work with the coating when it is applied and rework it if you need to make changes or do repair work.

Masking allows you to control where the parylene deposits. For instance, you might want to coat a PC board, but leave its contacts uncoated so that data or power signals can flow through them. Putting a masking compound down before coating the board will allow you to do this.

Once the item has been coated, parylene can also be removed through mechanical means. Microabrasive tools gradually remove parylene in small areas, letting you access exactly what you want to work on without compromising the rest of the printed circuit board's coating.

Understanding the Parylene

Deposition Process

The parylene deposition is relatively easy to understand. Parylene dimer is heated into a vapor, then pulled through a vacuum into a coating chamber where it “deposits” onto the substrate

Even though it’s a simple concept, the parylene deposition process can be difficult to implement, particularly when trying to control coating-thickness and otherwise ensuring a successful coating cycle.

Because coating type and required surface thickness vary according to substrate material and coating-project, deposition rates fluctuate. Processing can require less than an hour or more than 24 hours, at a deposition rate of about 0.2/mils-per-hour.

While this slower rate of substrate covering generates parylene's superior conformal coating—compared to other coating options—it also adds to its cost. Mastering the parylene coating process helps assure these production expenditures are diminished.

The Parylene Deposition Process in Detail

Parylene's complex and specialized vapor-phase deposition technique ensures the polymer can be successfully applied as a structurally continuous film, entirely conformal to the characteristics of the selected substrate.

To correctly master the process, we ensure each incoming order possesses all pertinent information affecting parylene application. This includes include drawings, specifications, and special instructions that distinguish the order from others, allowing creation of customized solutions for the particular item.

Parylene's deposition process completely eliminates the wet deposition method used by such other coating materials as epoxy, silicone, or urethane. It begins in a chemical-vacuum chamber with raw, powdered parylene dimer, which is placed in a loading boat and inserted into the vaporizer.

The dimer is initially heated to between 100º – 150º C, converting the solid-state parylene into a gas at the molecular level. The process requires consistent levels of heat; the temperature must increase steadily, ultimately reaching 680º C, sublimating the vaporous molecules and splitting it into a monomer.

Drawn by vacuum onto the selected substrate one molecule-at-a-time in the coating chamber, the monomer gas reaches the final deposition phase, the cold trap. Here, temperatures are cooled drastically to levels sufficient to remove any residual parylene materials pulled through the coating chamber from the substrate, between -90º and -120º C.

The Steps of the Parylene Deposition Process

Mastering the parylene coating process requires detailed attention to these procedures, prior to commencement of deposition and coating:

1. Inspection

The first step is to inspect the items to be coated, verifying their quantity and condition.

2. Preparation Procedures

For example, cleaning/cleanliness-testing or similar unique processes are started, followed by masking of connectors and electrical components.

Accumulated substrate contaminants diminish adhesion, so assuring appropriate levels of surface cleanliness is integral to parylene coating. Depending on the substrate surface, cleaning may be enacted manually, or through application of batch, inline, or ultrasonic methods.

3. Masking

Exceptional care is required to ensure every connector is effectively sealed so gaseous parylene molecules do not penetrate their surfaces. All tape, or other covering materials, must thoroughly encompass the keep-out regions, without gaps, crevices or other openings, to ensure connector function is retained after coating.

4. Application of A-174 Silane

Some materials—glass, metal, plastic, etc.—require treatment with A-174 silane prior to parylene coating.

Typically, A-174 silane is applied using either manual-spray, soaking, or vapor-phase technology and done after the masking and preparation work.

A-174 silane's molecule forms a unique chemical bond with the substrate's surface, improving parylene adhesion for the final product. Further inspection assures masking is in compliance with customer specifications.

Coating Requirements

Parylene coating is applied through the deposition process described above. Once coating has been deposited, masking materials are removed; extreme caution must be exercised not to damage the thin layer of applied parylene.

An important consideration of appropriate parylene thickness is total required clearance. While an enclosure-printed circuit board has few clearance issues, in many cases even an additional millimeter of parylene coating can be sufficient to generate dysfunctional mechanical abrasion, damaging the parylene surface and reducing its conformal qualities.

Dielectric Strength

Regarding dielectric strength, items whose required levels of dielectricity are higher will need a thicker coat of parylene.

Balancing dielectric strength with clearance generally requires quality testing to determine their correct ratio. The end-item customer may not always provide these specifications. Learning how to determine dielectric/clearance ratios without this data is integral to mastering the parylene deposition process.

Meeting Specifications

The coating process must generate a conformal covering explicitly meeting the customer's precise specifications. If changes are necessary, making them to order and on time are essential elements of mastering the parylene coating processes. A final inspection ensures successful completion of all process phases, and that the final product complies with the customer’s drawings and specifications.

Disadvantages of Parylene

Even with all of parylene’s benefits, there are still some disadvantages to using parylene versus other conformal coatings.

1. Cost

The cost for parylene is typically higher than other conformal coatings. This is because of many factors, such as the process itself, the raw materials involved, and the labor required to properly prepare a device for coating.

While this is not necessarily true for all parylene applications, a quote for parylene will usually be higher than a quote for one of the other “wet” chemical coatings.

2. The Batch Process

The parylene process is a batch process. This means that there is only a finite amount of space available in the chamber for every coating machine run. The goal is to maximize the amount of items to be coated in the chamber. If there is a suboptimal amount of items to be coated available, the difference in price per piece could escalate drastically.

The raw material, parylene dimer, is rather expensive—ranging from $200-$10,000+ per pound. Because parylene is applied through a vapor deposition process, everything, including items that do not need to be coated like inner diameter of the chamber, gets coated. This makes parylene an inherently inefficient process and wasteful with materials, which escalates the end cost to the customer.

3. Masking and Prepping

Masking and prepping an article for parylene coating can be a labor intensive affair. Because parylene is applied as a vapor, it literally gets everywhere that air can. Our operators and quality inspectors have to take this into account prior to coating to ensure that every one of the customer’s coating free areas are just that.

4. Limited Throughput

One major issue that often comes up for several of our high-volume manufacturers is the limited throughput of parylene. Runs of the parylene machine can take anywhere from eight to over 24 hours.

As a result of the limited chamber space, there is a fixed amount of product that can be processed during one coating cycle. This, coupled with the high capital cost of new equipment, can wreak havoc with customer’s delivery schedules.

5. Adhesion

One final disadvantage of parylene to consider is the poor adhesion to many metals. Parylene has always had poor adhesion to gold, silver, stainless steel and other metals. Many printed circuit board manufacturers use gold in their products because of its conductivity. While there are some adhesion promotion methods that will greatly improve adhesion to these metals, they are either material or labor heavy and can increase costs significantly.

Parylene Protection for

Ruggedized Devices

Wet application materials such as acrylic, epoxy, silicone and urethane can offer degrees of coating hardness or flexibility, heat resistance or surface protection useful for specified ruggedized purposes. None, however, exhibits parylene's versatility for ruggedized applications.

Parylene's chemical vapor deposition (CVD) process permeates deep into the substrate surface. This property provides the PCB or electrical assembly a truly uniform, pinhole free coating that is exceptionally dielectric, maintaining long-term surface insulation resistance (SIR) appropriate to the optimal function of the protected electrical system.

In addition, the increased development and use of MEMS/nano-scale electrical systems for ruggedized devices largely eliminates the use of competing coating materials. Their standard dip, spray, and brush-on coating methods simply cannot protect MEMS/nano applications.

Prior to CVD, treating substrates with A-174 silane, or newer pre-treatment technologies, assures adhesion to surfaces as diverse as an elastomer, glass, metal, paper, and plastic, enhancing parylene's versatility for ruggedized purposes. Its conformal coatings generate:

- Barriers capable of withstanding the impact of bodily fluids, dirt, hazardous chemicals, heat, moisture, and other contaminants on assembly performance
- High dielectric strength, coupled with favorable mechanical/physical properties, providing
- Resistance to environmental convulsions, heavy vibrations, and shock, natural or man-made.

Parylene as a Medium of Enhanced Ruggedization

Approved as a military-spec conformal coating, parylene enhances the integrity of ruggedized devices without adding high cost. Much depends upon the application process, where deposition of the gaseous parylene onto the substrate generates a simulated organic growth of the coating from beneath the substrate surface to the outer coating-layer.

This ultra-thin protective film is exceptionally durable, yet not brittle as spray/dipped-coated substances like urethane or epoxy can become under harsh, frigid temperature conditions.

Moreover, the parylene coatings do not decompose at upper range temperatures. The coating remains intact, maintaining the necessary dielectric and insulation qualities required for component performance.

Parylene types C, F, or N are highly recommended for ruggedization. All types of parylene share similar barrier and conductive properties, combining strength with minimal added weight and surface resiliency.

Parylene for Medical Devices

In addition to aerospace/military applications, refinement of parylene for ruggedized medical components responds to the need for exemplary functionality in the presence of often harsh bodily fluids.

Appropriate masking of fragile electrical assemblies and components prior to enacting the CVD process ensures parylene application will not interfere with their function when in use.

7 Key Points to Remember About

Parylene Coating

1. Parylene’s unique vapor-deposition process allows it to provide superior, pinhole-free protection when compared to “wet liquid” coatings.
2. Parylene is the thinnest available conformal coating, making it ideal for situations with strict clearance guidelines.
3. Parylene resists electric signals as well as moisture, acids, bases, solvents, corrosive materials and most other chemicals and liquids cannot permeate it.
4. From space travel to medical implants, Parylene is used for a wide variety of applications.
5. Without parylene coating, many modern electronic devices would not last nearly as long as they do today.
6. Parylene is an excellent choice to protect electronics in “ruggedized” devices.
7. Parylene is considered “the gold standard” of conformal coating.

Conclusion

Parylene coatings are recommended for any product where reliable, dedicated electrical, biological or environmental protection is required.

The resistance to harsh working environments provided by parylene supports functionality where unprotected devices would otherwise fail.

Likewise, parylene provides an optimal balance of performance across a range of applications when compared to the performance of the other coating types.

In almost any environment, parylene can assist in ensuring all systems work as expected.

About Diamond MT

Diamond MT was founded in 2001 as a firm specializing in contract applications of conformal coatings for Department of Defense and Commercial Electronic Systems. Since our beginning, Diamond MT has established a reputation for providing the highest quality services in the industry. Our commitment to quality, integrity, and customer satisfaction combined with an unmatched expertise in applications and processes has provided every one of our customers with superior results.

Diamond MT operates out of a freestanding 12,000 square foot building in Johnstown, Pennsylvania, which is located 60 miles southeast of Pittsburgh. Diamond MT is located near three major interstates and is supported by the Cambria County Airport, which serves as a primary freight terminal for south central Pennsylvania. Diamond MT maintains a strict program per NSI ANSI Standard 20.20 for ESD protection. All work areas are safeguarded with the latest in protection devices including wrist straps, garments, and workstations.

Quality Assurance: Diamond MT's quality manual ensures every employee is focused on continuous improvement and service excellence. Our ESD safe facilities stretch over 12,000 square feet dedicated to your conformal coating requirements. We are continually researching and updating our equipment to make sure we are providing the best ESD protection available.

All employees have been trained in proper ESD procedures. We operate at a class 3 level to ensure the job is done right the first time and to the highest quality standards set forth in accordance with the MIL-STDs, IPC, J-STDs as well as having our biomedical and ITAR certification. Furthermore, all assemblies are tracked through every step of the process with documentation/serialization spreadsheets as well as each assembly going through a 100% visual inspection.

Diamond MT has a strong organization consisting of highly motivated personnel, modern facilities, and diverse capabilities. Diamond MT represents one of the most modern, well-equipped facilities in the region. Diamond MT offers a highly skilled workforce, rapid turnaround manufacturing and high reliability through an established quality program, along with experience of commercial manufacturing requirements, competitive pricing and on-time delivery.

Rapid Turnaround: Diamond MT understands that oftentimes conformal coating is overlooked because it’s the last step in the process. We are committed to serving the industry with rapid turn times for parylene, (normally 10 business days) with expedited service in as little as 2-5 business days depending upon the complexity and quantity.

For liquid coatings, our normal turnaround time is five business days; again with expedited service in as little as 2-3 business day turns. We understand that there are times you’ll need a project completed FASTER. We will accommodate your needs in a budget friendly manner. This service is offered on a FIFO basis.

To learn more about Diamond MT, please contact us today!

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