Parylene Inspection and Related Issues

Identifying Defects Correctly Before Film Replacement is Necessary

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Introduction

After pertinent research you've determined parylene (XY) is the best conformal film for your coating assignment. Especially relevant were XY's uniform protective and insulative properties, which are useful for numerous applications, ranging from printed-circuit boards (PCBs) to medical implants to military-grade purposes. Among parylene's other advantages are:

- adherence to an exceptional quantity of substrate geometries/materials,
- biological/chemical inertness,
- bubble- and pinhole-free conformability/flexibility at film thicknesses greater than 0.5 microns,
- excellent dielectric/moisture barrier properties,
- high optical clarity,
- penetration of extremely small crevices/spaces,
- tin whisker mitigation, and
- withstanding autoclave-level heat.

XY's very effective chemical vapor deposition (CVD) application process is aided by thorough process inspection, at all stages.

The Importance of Parylene Inspection

Parylene conformal coating (XY) provides insulative protection for complex electronic circuit assemblies expected to function through rigorous operating conditions -- potential chemical, electrical, moisture and vapor incursion during performance. Applied through CVD, parylene penetrates deep within substrate surfaces, generating a level of assembly security surpassing that offered by liquid coatings such as acrylic, epoxy, silicone and urethane. Yet, although XY is applied in a vacuum, it's capacity to provide these extraordinary qualities does not exist in one. Parylene's durable protective value depends on film adhesion, a quality subject to persistent, thorough inspection throughout the production process.

Inspection Before Coating

Diamond MT's parylene services include coating provision for clients' PCBs, and similar electronic assemblies, shipped to our production facility. The incoming inspection process begins immediately after items awaiting parylene coating have been unpacked:

- Received assemblies are counted to verify quantity in comparison to the client's provided packing slip/purchase order.
- Damage-inspection verifies assemblies arrived at our facilities without breakage or defacement.

Individual processing follows these procedures, with additional inspection and cleanliness testing. This is imperative; substrate contaminants may have accumulated during manufacture, handling and transportation. Without question, the most significant factor affecting parylene (or any conformal coating) adhesion is surface cleanliness; contaminated surfaces lead to poor coating quality, limited adhesion, and delamination, defeating the purpose of XY application. To this degree, cleanliness inspection is a vital step in the coating process, assuring the substrate surface is ready to accept parylene conformal coating without incident.

Visual inspection alone is insufficient to confirm a PCB's suitable cleanliness and other stage-readiness for XY coating. Throughout the production-run, every phase of the process must be consistently measured and monitored; this ongoing performance inspection averts costly cleaning issues, or subsequent need for rework. At Diamond, we maintain a sampling process throughout each production run, designed to:

- confirm the readiness of a customer's assemblies for parylene coating, per IPC-J-STD-001 stipulations,

- ensuring consistent quality levels throughout XY coating procedures.

Contaminants like dirt, oil, or even the presence of insects under conformal coatings can gradually degrade PCBs. These debris corrode assemblies, reducing their overall lifespan and destabilizing performance prior to breakdown. Thorough cleaning of all substrates is essential prior to coating application, to assure contaminants do not nullify PCB function.

According to IPC-J-STD-001 specifications, surface cleanliness levels should register 10µgm NaCl/in2 or less. Diminishing adherence to this standard is inadvisable; doing so jeopardizes coating and assembly performance. Substrate contamination undetected prior to film application requires process-cessation, and substrate recleaning, until acceptable non-contamination levels are achieved. These costly missteps are avoided by appropriately implemented cleanliness inspection before XY application is commenced.

XY inspection for quality assurance also details the degree of the coating thickness necessary to meet assignment specifications, PCB-area of coverage, visual, and adhesion-testing requirements. Subject to intensive inspection and evaluation, micron-thin XY-films are constructively measured:

- using spectral reflectance directly on components or
- by comparing project film-application with witness coupons previously XY-coated to ascertain similarity of result.

Quality attributes for parylene typically specify the use of various inspection procedures that verify appropriate surface purity. These include:

- Ionic Exchange Chromatography (IEC), for identifying the presence of inorganic substances like chloride, fluoride, potassium and sodium. Specifying contaminants, IEC aids in selection of appropriate solvent/cleaning systems to resolve the issue.
- Fourier Transform Infrared Spectroscopy (FTIR) denotes the presence of specific organic contaminants, like mold agents or silicon oils.
- Gas Chromatography can also detect/identify surface organic contaminants; sometimes used in conjunction with Mass Spectroscopy, when more complex contaminants are detected.

Once cleaning has been enacted, masking processes assure parylene coating doesn't penetrate assembly keep-out areas, in accordance with client specifications. Subsequent masking inspection verifies compliance, leading to implementation of CVD procedures (the coating process). After XY deposition, masking materials are removed, and the batch is subject to further inspection, to assure even, pinhole free coating without tears along formerly masked regions. Thickness inspection verifies appropriate film thickness has been achieved.

Other essential elements of product testing/inspection include:

- Thermal testing. Divergent thermal expansion rates among such basic PCB materials as component pins, PCB trace/trace coating and solder represent a further source of assembly failure despite coating. All materials within the PCB experience temperature changes (heating and cooling) during operation. Each PCB component has a specified range of heat it can absorb, a quantity dependent on its size and structure. Overheating can generate considerable mechanical stress which may disrupt physical solder connections, damage the effected component, or delaminate the PCB trace.
- Inspecting the assembly's special integrity. If insufficient space exists around the component, in relation to others in the assembly, high operating temperatures can cause component overheating and burning, underneath coatings.
- Solder assessment. Solder improperly heated during board construction can generate cold solder joints and bad surface-mount connections that may burn components and cause power issues. Electromigration of the elements in the solder occurs when the wrong type of solder is used within a PCB. Brittle, intermetallic layers form, generating broken solder joints that often are undetected, even with inspection.
- Reviewing flux residue. Left over soldering-flux may also produces PCB-corrosion.

- Connection testing. Loose connections may lead to poor connectivity between board layers causing inefficient performance.
- Checking for tin whiskers. Tin whiskers' growth from lead-free solder joints can bridge contacts or break-off, causing short circuits. XY coatings can combat the formation of tin whiskers during operation, but are less effective when whiskers exist within the assembly prior to coating application.
- Trace assessment. Traces are the conductive pathways, tracks or signals etched from copper/silver coated sheets and laminated onto the non-conductive substrate. If accidentally placed too near each other, they can short circuit during operation. Use of inappropriate acid core solder is one source of trace shorts, and an example of a pre-existing PCB condition that good inspection can uncover and correct. Parylene cannot protect a board from a problem already extant when coating is applied.

Before commencing to final inspection and shipment of the completed coating assignment, you'll want to assure parylene conformality, ascertaining that the XY film reached all designated coverage regions on each assembly.

Assuring Parylene Conformality Throughout Coating Application

CVD-applied, gaseous XY s can be deployed and adhere on any surface that touches air. Thus, it has the capacity to coat under components, inside minute substrate fissures, and inside semi-sealed areas. Unlike liquid film materials, the micron-level thinness of parylene films generate coatings without forming bridges in tight areas.

These properties have been verified repeatedly through parylene's use and have been extended as application technologies improve. But, for your own coating assignments, you need to know if the parylene has film reached and adhered to every assembly region required by the coating assignment's specifications. This will entail accessing the most reliable proof available of the coating's absolute conformality.

Verifying Parylene Conformality

Verifying XY conformality – the property of uniform parylene application throughout the project-specified surface-coverage for each coated assembly -- may require specialized inspection methods. With greater resolution power than a light microscope, electron microscopy (EM) offers much higher magnification than most alternatives; it permits finely-detailed views of much smaller objects, like XY's many microelectricalmechanical systems (MEMS)/nano-tech applications. EM uses a beam of electrons –stable, negatively-charged subatomic particles found in all atoms, the primary carriers of electricity in solids -- to create an image of the specimen. This technique can provide images suitable for confirming XY conformality.

However, additional methods may be required. Physically-cleaving a coated specimen where XY film thickness exceeds 200 nanometers (nm) allows more precise imaging; cross-sectional scanning electron microscopy (SEM) will generate images suitable for conformality determination. SEM images show how well the parylene has coated the specimen, and

- if the coating thickness is pinhole-free/uniform, or
- where any gaps in the coating exist.

Sequential cross-sectioning helps determine conformality (or its lack) along the surface of a single specimen or through an entire sample.

Physical cross sectioning may not work for all substrate topographies. Use of ion/electron beam ablation (I/EBA) can successfully image the XY film/substrate interface, to determine if the parylene has indeed adhered everywhere intended by the coating assignment's specifications.

Verifying XY conformality becomes proportionally more difficult as coating layers decrease in size, as with MEMS/nano-tech applications, where layers frequently 50 nm or less. Analysis of SEM cross-sectioning becomes more difficult under these circumstances, frequently suffering from Z-contrast/charging effect inconsistency. These conditions can be rectified using a focus ion beam (FIB) system in conjunction with transmission electron microscopy (TEM). TEM is used to view thin specimens – like tissue sections, molecules, in addition to conformal layers -- through which electrons can pass generating a projection image.

Electron microprobe analysis (EMPA) can enrich TEM imagery. Working similarly to an SEM, EMPA is an analytical tool used to non-destructively determine the chemical composition of small volumes of solid materials. While this technique is adept at verifying the conformality of thinner, more complex layers of parylene, its accuracy can be challenged by ion damage, as film thicknesses diminish (>20 nm).

In such cases, using SEM images prior to- and following CVD can generate a reasonable view of coating covering and conformality. This technique is valuable in cases characterized by property changes to the substrate surface initiated by CVD. Such applications – where preservation of the precursor functionality down the depth of feature is necessary – benefit from combined (before/after) SEM imaging. Comparing prior-with-final assembly properties verify applied XY conformality in these cases.

One Last Step

Prior to packaging coated assemblies, final inspection is necessary. Encompassing every aspect of the product, this process ensures

- successful implementation/completion of all phases required by the specific XY coating assignment, and
- absolute compliance with the client's drawings and specifications.

Summary

XY coated PCBs are expected to work without fail, largely because of the protection the coatings provide them; coating problems can trigger failure mechanisms for the assembly.

PCB failures occurring despite the ostensible protection of XY can compel a multitude of additional testing, probing and preparation processes, enacted to determine both:

- the precise failure mechanisms effecting board performance, and
- appropriate repair/rework procedures.

Poor manufacture or stresses to the assembly emerging during operation that may cause failure can be minimized by:

- thorough board inspection prior to/after coating, and
- ensuring the selected coating methods/materials are germane to project specifications.

The objective in all cases is to maintain board function and avoid coating repair, removal or reapplication. One must be careful identifying defects, which vary according to coating materials' specific properties.

Parylene "Noodles": Both Benefit and Defect

Unlike liquid conformal coatings joined to substrate surfaces by wet application methods, polymeric parylene CVD has no intermediate liquid phase. Rather, cross-link polymerization of powdered raw XY-dimer converts the solid to a vapor at the molecular level, polymerizing XY directly as a transparent film on assembly surfaces.

Applied in a gaseous state, XY penetrates deep within substrate surfaces, providing an authentically conformal protective covering. In many ways, parylene coatings are superior to those provided by wet materials like acrylic, epoxy, silicone or urethane, for a wider variety of products and purposes. Micro-thin film performance makes parylene especially useful for coating PCBs and in MEMs/nano technology applications.

The XY deposition process assures neither heat nor cooling is needed for coating adherence. The circuit board neither expands nor shrinks, reducing coating-stress. Depositing XY as a dry vapor helps the coated items endure minimal changes during the application process, eliminating another major risk factor of coating defect.

Polymeric Noodles

As a polymer, parylene begins as a monomer-based linear chain fused covalently. The ongoing chain entanglements characterizing parylene morphology stimulate a degree of viscoelastic behavior. Viewed microscopically under normal conditions, they resemble noodles, sometimes elongated but neither precisely straight nor clustered together; often compared to a bundle of spaghetti noodles, they are held together by a few chemical cross-links. More precisely,

- the shape of a Gaussian coil develops,
- collected as parylene (or other polymer) molecules join,
- ranging from several nanometers to several tens-of-nanometers in length,
- measured by the root-mean-square end-to-end distance Ree,
- scaled as the square root of the coil‘s total number of monomers (N) or molecular weight (Mw).

In this basic form, which encompasses parylene morphology, noodles are **NOT** a defect, but a normal and characteristic part of the polymer's physical structure. Increasing their density across the strands provides shape and strength, limiting their ability to pull away from each other, while increasing their functional and load-bearing uses. These capacities help XY polymers achieve architectural/performance networks necessary for conformal coating purposes.

Defective Noodling

Despite its general superiority as a conformal coating, parylene application and use can suffer defects. While common XY defects can often be identified, planned for and mitigated through proper inspection procedures, they still occur. Inadequate application or deposition onto a surface unprepared for adhesion can compromise XY function.

Defective noodling is the result of deformation mechanisms developing on the surfaces and interfaces of parylene coated systems. These factors can cause loss of the parylene film's surface pattern-effectiveness, disrupting the structural integrity of the coating's typically reliable noodle-like entanglement. The surface is then characterized by highly disordered structural configuration, resembling a plate of noodles winding chaotically around each other, interfering with parylene's usual uniform, pinhole-free surfaces. Disruption of the coating's performance integrity can lead to both current leakage and voltage breakdown.

If inappropriately cleaned before application, or inadequately deposited, liquids or other substances can penetrate both at the parylene-substrate interface and through the polymer layer, stimulating an environment of disrupted noodle development. Film instabilities can also occur on parylene surfaces when temperatures exceed the polymer's standard glass transition temperatures (Tg). Basic outcomes include sequential disruption of hierarchical coating formation, a condition that can be generated despite the protection usually afforded by XY's reliable CVD application method. Poor adhesion and residual stress can also lead to bending, cracking, peeling and noodling of parylene conformal films.

Summary

Parylene conformal coating defects can be caused by a range of factors. However,

- cleanliness of the product surface,
- carefully matching the parylene type to the coating assignment/purpose, and
- expert performance of the CVD process
- mitigate the potential for these problems to arise.

Undetected trace contaminants disrupt the bond between parylene film and underlying surfaces, leading to disruption of noodle configuration.

Thus, noodles, a basic element of parylene morphology, can themselves be transformed from a tasty dish of conformal coating to one that may need to be scrapped or redone.

- Conventional, non-defective parylene noodles resemble a properly cooked and stirred pot of spaghetti, with a bit of olive oil stirred in, to keep them from only adhering to each other.
- Rather, they adhere also to the substrate. This recipe can be delicious!!
- When defects occur, the noodles resemble a tangled mat of unstirred, cooked spaghetti, assuming a random shape, of little use to the conformal coating project.

Not always immediately apparent, disordered adhesion will eventually compromise the coating and, ultimately, the end-product, thus neutralizing parylene's protective benefits. As an integral structural XY-component, you can't avoid the presence of parylene noodles, but you can control them.

Can Vaporous Parylene Coatings De-wet?

Liquid conformal polymers – resins of acrylic (AR), epoxy (ER), silicone (SR) and urethane (UR) – use wet application processes to attach to substrates. Most prominent of these are brushing the wet coating onto an assembly, dipping (immersing) the assembly in a bath of liquid coating, or spraying the conformal film onto the designated surface. The coating materials are wet when they are applied. If

- application processes are inadequate or
- targeted substrates are inadequately cleaned
- conformal adhesion diminishes and can lead to delamination.

One of the failure mechanisms that can emerge under these circumstances is de-wetting.

De-Wetting of Liquid Coatings

De-wetting is the tendency of the coating material to refuse to wet the surface of assemblies to which it has been applied. De-wetting deteriorates the conformal coating. Thin polymer films can fracture into small, non-conformal droplets through de-wetting, which has several distinct phases:

- Hole-formation occurs either spontaneously (spinodal de-wetting), or because of film contact with surface contaminants.
- Reduced surface area of the polymer/air interface stimulates further hole growth.
- Other holes may emerge in consequence, further decreasing the diameter of the coating's polymer fibers (noodles).
- Hole collision creates thinning polymeric lines throughout the film, which continues to diminish in thickness as the film material drains to the apexes of its polymeric rings.
- Rayleigh instability – increased fluctuations on the film surface -- develops.
- Holes eventually dissolve into droplets, disrupting the uniformity of the liquid coating material, and jeopardizing conformal protection.

De-wetting and hole-growth in wet polymer conformal films is a major failure mechanism, diminishing their protective qualities. Liquid films polymeric nature adds to the non-linear viscoelastic effect of their shear thinning.

Surface contamination prevents coating solutions from evenly sticking to and 'wetting' the substrate. Lack of proper adhesions leaves assembly areas uncoated, exposing the substrate to additional contamination and subsequent coating failure. Cleanliness is the key to preventing de-wetting; causes of surface contamination include:

- flux-residue when no-clean flux is used,
- soldering processes,
- hot air solder leveling (HASL) rinse-operations stimulating corrosion,
- component mold release agents,
- silicone oil left from production adhesives,
- cleaning bath contamination and
- operator handling.

When de-wetting occurs, solder fails to adhere to components. In addition to contamination and corrosion, extremely high temperatures above a film material's glass transition temperature can stimulate de-wetting; by increasing the mobility of the polymer-chain molecules, a tendency toward separation from each other and the substrate surface develops, stimulating de-wetting.

The only viable solution is stripping the damaged coating from the affected area, re-coating it with a rigorous, manual re-work process.

Parylene and De-wetting

Providing an entirely conformal, durable, pinhole-free coating for PCBs and similar electronics, parylene (XY) offers a protective, insulative coating for a wide range of products and materials. Applied by chemical vapor deposition (CVD) rather than the liquid methods used by AR. ER, SR and UR, XY is converted from a solid to a gas, with no wet stage. Thus, unlike liquid coatings, parylene is not pre-synthesized and dispensed during application in a wet format.

Parylene's CVD free radical polymerization technique creates XY coating, synthesizing the coating during application, using a reaction mechanism that forms resonance-stabilized XY diradicals, which eventually adsorb on and into a substrate near room temperature. The result is generation of a much better. conformally-thin polymer film on virtually all substrate surfaces than those supplied by conventional wet-solution methods

However, XY's specific material conditions and the CVD application method also quash chemically-based film adhesion for parylene; only mechanical adhesion is possible. Penetrating substrate surfaces gives a parylene a more dependable conformal coat than those provided by liquid polymers, as mechanical adhesion enters and fills pores/voids along covered surfaces, holding together by interlocking film elements.

No wet processes/liquid materials are used, The absence of solvent in XY CVD avoids de-wetting and pinhole-related defects, by enabling growth of high-purity, ultrathin (<10 nm) layers of conformal coating. Precisely-controlled parylene CVD enables direct chemical synthesis of thin-film conformal coating formation in one-step processing. Unlike liquid materials, monomeric reactants in the CVD sequencing process require no solubility, bypassing de-wetting potential and other detrimental impacts accompanying solvent-use.

Parylene Inspection at Diamond MT

Diamond's considerable experience in all aspects of conformal coating processing includes state-of-the-art inspection personnel and facilities. We customize each coating assignment according to client specifications; inspection ensures these specifications are always met before shipment, with minimal downtime -- informed by our established quality control program, knowledge of inspection requirements, competitive pricing and on-time delivery, to offer clients superior parylene coating for products and assignments of all kinds.

After passing final inspection, assemblies are ready to ship. At Diamond MT, return-to-client typically takes about ten business days, but faster turn-around can be negotiated at your request.

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 provide 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 operates one of the most modern, well-equipped facilities in the region. Our highly skilled and reliable workforce adheres strictly to our established quality performance standards, with rapid turnaround for all coating removal projects. Diamond MT always provides these services with 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, with expedited service in as few as 2-3 business days. 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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