Common Problems with Parylene

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Although it is rightfully recognized for the overall superiority of the conformal coatings it provides in the majority of cases, parylene is not infallible. If the preparation and application aren't properly managed, for example, conformal coating defects can develop that compromise the parylene film covering the substrate and, ultimately, the end product. In these cases, the parylene coating can be affected by substandard performance for any of its applications, be they aerospace/defense, automotive, electronics, LED or medical.

One defective condition of concern is surface cracking, wherein the normally reliable uniform conformal film generated by parylene simply fractures into segments of coating independent of the unified whole. The consequent fissures in the coating surface expose underlying substrate regions to potential contaminants; for instance, debris, moisture, or water may reach down to the circuit board level where additional defects, including subsequent corrosion, may then develop. Dysfunctional component performance.is a common occurrence in these circumstances, which are potentially life-threatening in the case of aerospace, defense or medical applications.

Cracking as a Failure Mechanism of Parylene Conformal Coatings

A major source of surface cracking occurs if a deposited film thickness is too wide, deep or stiff. In these cases, a mismatch of the coefficients of thermal expansion (CTE) develops, generating rifts within the dried parylene conformal coating.

One of the more frequent causes of surface coating brittleness and cracking is environmental stress cracking (ESC), which is responsible for between 15-30% of all component failures during operation. Environmental extremes develop when the operating temperature of the circuit board is either too high or too low, creating conditions of excessive flex, that can lead to cracked coating. However, rather than break the parylene's polymer bonds as a result of stress cracking, ESC cracks the substance's secondary linkages. These breaks result

- when mechanical stresses generate minute, nearly undetectable cracks in the parylene surface,
- which briskly proliferate under the harsh operational conditions that stimulate ESC,
- generating further surface and interior coating fracture.

Evidence further suggests that discontinuity of secondary linkages common to ESC may be a consequence of contamination by a reagent substance that would otherwise be harmless if the coating were in an unstressed condition.

Solutions to Prevent Cracking

Minimizing cracking to parylene conformal coating surfaces is possible through the following methods:

- Minimizing CTE mismatch issues by reducing the coating thickness during application procedures.

- With regard to material selection, ensure the type of parylene used to create the film has an acceptable range of temperature performance for the product's functional purposes, and that it is sufficiently flexible for those purposes.

There will be cases where more specialized solutions are required. For instance, where wires are hand soldered to assembly bond pads, a room temperature wire bonding process for interconnects of parylene encapsulated devices may be necessary. Its objective is preventing thermally-generated stress cracking from the base of component electrodes, due to shrinkage after cooling of high process temperatures.

Summary

Although most parylene types demonstrate a consistently reliable thermal stability that provides for dependable product performance through ongoing exposure to temperatures of 100°C for 10 years, degradation can nevertheless occur. Applying the parylene conformal film too thickly generates conditions where drying is uneven throughout the coating, which can also lead to cracked surfaces. Environmental stress is another problem that contributes to cracking of parylene conformal coatings.

Strategies for avoiding this defect include reducing coating thickness to manage the coefficient of thermal expansion and paying strict attention to temperature control, resolving cracking issues when applying parylene conformal coatings to targeted assembly substrates.

Safely Removing Parylene Coatings

Despite conformal coatings' ability to dependably protect substrate surfaces of printed circuit boards (PCBs) and related electrical components, problems can sometimes occur which compel their removal. Chemical removal, which does the least damage to PCBs, is fine for wet coating substances like acrylic, epoxy, silicon and urethane. Chemical removal methods are far less successful for parylene, despite the use of a chemical vapor deposition (CVD) process for its film application.

CVD processes generate many of the property advantages that distinguish parylene from wet coatings. Parylene offers significant application advantages in comparison to the liquid methods – immersion, spray, etc. – used by acrylic, epoxy, silicone and urethane. Surface tension and gravitational influences effect wet coating methodologies, limiting the capacity to evenly cover all component surfaces. CVD generates uniform, pinhole-free, hermetic and homogeneous coverage of all surfaces with the gaseous parylene, including the smallest corners or crevasses, pointed edges or surface ripples. These properties position parylene as an ideal conformal coating for critical uses in aerospace, medical and microelectricalmechanical systems (MEMS) applications.

In addition to excellent film uniformity, parylene also provides:

- biocompatibility,
- chemical resistance,
- high dielectric strength,
- hydrophobicity,
- low friction,
- minimal permeability to gases,
- optical transparency, and
- thermal stability.

But CVD-applied parylene is far less amenable to chemical removal than its wet competitors. There is one major exception.

Tetrahydrofuran (THF), a Chemical Removal Solution for Parylene

Parylene is chemically inert. This property effectively negates the usefulness of the liquid chemical removal methods that work for the majority of conformal coatings. The one chemical that has been successfully used to strip parylene from substrates is tetrahydrofuran (THF), a colorless organic compound whose chemical formula is (CH2)40. It demonstrates:

- low viscosity at standard pressure/temperature, and
- is water-miscibleorganic.

Duration of use of THF for removal is largely dependent on the thickness of the parylene film. For example, a parylene thickness of .001 mm requires immersion between 2 – 4 hours in a

THF-based solvent. The parylene coating begins to separate from the assembly's surface during immersion. After rinsing the assembly in alcohol and subsequent thorough drying, the parylene film is then removed from the assembly's surface, physically, with tweezers.

Other than THF, the only other chemicals that have successfully removed parylene coatings are benzolyl benzoate and chloronapthelene, at temperatures above 150 degrees Centigrade. However, these chemicals offer only very limited use for removal of parylene films, since they are essentially incompatible with the majority of parylene processes; except for highly specialized cases, their use is not recommended.

Parylene's chemical inertness restricts chemical removal in virtually all cases. Thus, other removal processes should be employed to ensure complete coating-removal and the security of components underlying the parylene film.

Reliable Methods of Removing Parylene Conformal Coating

Abrasion: Expeditious and cost-effective, micro abrasive removal of parylene films are easy to implement and environmentally friendly. Micro abrasive blasting propels explicit formulas of inert gas/dry air and abrasive media at the parylene-coated component, via a tiny nozzle attached to a stylus; either a handheld human or automated systems can be used to pinpoint the targeted removal area. Conducted within an enclosed anti-static chamber, a vacuum system persistently removes the parylene debris from the substrate, with disposal implemented by filtration processes. Grounding devices dissipate electrostatic potential. Abrasion removes parylene coatings from a single test node, an axial-leaded component, a through-hole integrated circuit (IC), a surface mount component (SMC) or an entire PCB. Abrasion is often the easiest and fastest method for removing parylene conformal coatings uniformly applied to substrate surfaces.

Laser: Typically utilizing pulsed laser sources, laser ablation converts parylene to gas or plasma. Control must be exercised, since each laser pulse separates only a tiny proportion of the film's material thickness. Nevertheless, ablation is cost-effective for complex removal jobs, since processing can be enacted in a single step. Better quality removal results, with 100% parylene-free areas; photo-ablation particularly delivers excellent outcomes for these purposes. Design compromise is lower than with other removal processes, since laser application can be controlled to a single micron. 3-D devices can also be effectively serviced.

Mechanical: Most mechanical removal techniques -- cutting, picking, sanding or scraping the precise surface-expanse of coating to be removed – require considerable care and attention. The exceptional uniformity of parylene coatings combines with their capacity to withstand manipulation and overall strength to accelerate damage if mechanical processes are imprecisely applied. While appropriate masking can lead to good parylene spot-removal, mechanical techniques are undependable for larger-scale surfaces.

Plasma: Application of oxygen-based plasmas can remove parylene films. For Parylene C and N, plasma removal begins by opening the benzene ring through introduction of an oxygen radical, causing generation of a hydroxyl radical between the polymer chain's benzene rings. Oxygen absorption at the atomic/molecular level follows, causing development of an unstable peroxy radical, subsequently rearranged into either volatile carbon monoxide or carbon dioxide. Parylene removal proceeds more quickly with additional plasma manipulation on the radical site, growing the opening in the substance’s benzene ring.

Thermal: The thermal parylene coating removal technique (including using a soldering iron to burn through the conformal coating) is the least recommended technique of coating removal. Thermal is difficult to manage. Its use should be restricted to spot-removal; larger-scale removal application can rapidly generate ruined coatings outside the target area, emanating from much diminished process control and emission of toxic vapors.

Summary

THF is the only chemical solvent that consistently provides reliable parylene removal from assembly substrates; the limited chemical options remaining are highly specialized and seldom applied. Abrasion techniques represent a popular removal option; laser methods are expected to develop further as a major removal process for parylene films. Mechanical and plasma-based techniques are useful for spot-removal assignments. Thermal methods also have some use for spot-removing parylene, but are difficult to control.

Common Parylene Coating Problems

In addition to cracking, a range of associated issues may interfere with successful coating of parylene films. Because it is applied via CVD, parylene generates a structurally continuous film covering a PCB or similar assembly. In CVD, the interaction of vapor-phase chemical reactants formulate a non-volatile solid film on a substrate, useful for a variety of applications like corrosion resistance, erosion defense, and high temperature protection.

Thus, in contrast to competing wet coating processes, parylene exhibits no liquid problems like capillary flow or meniscus. Neither will it

- bridge across substrate features,
- pool in lower areas of the assembly's topography, or
- pull away from the component's edges.

This combination of application advantages is instrumental in establishing parylene's overall superiority compared to such liquid coatings as acrylic, epoxy, silicone and urethane. Nevertheless, parylene films are confronted by several failure mechanisms that need to be managed if coating processes are to be successfully implemented.

Issues that Complicate Parylene Coating

Contaminants: A clean surface is necessary to assure successful application and performance of parylene films. Contaminated surfaces do not support adhesion and are conducive to delamination. Visually undetectable ionic contaminants are capable of short-circuiting the assembly beneath the conformal film, as well as instigating corrosion that can damage the parylene coating. Most ionic contaminants can be removed by cleansing with purified water. Nonionic contaminants are visible along the assembly's surface prior to parylene application. Because their presence attracts debris and foreign matter, they limit parylene adherence, causing pealing, cracking or other performance dysfunction. They're generally organic compounds like greases, oils or hand lotion, although rosin and silicone are also non-ionic. They generally can be removed with solvents and surfactants.

Delamination: Proper adhesion of parylene to the substrate surface is critical to its role as a conformal coating. One problem can be parylene's underlying chemical structure, which can interfere with dependable surface interface, constraining adhesion with some materials. The resulting delamination separates the conformal coating from the substrate, producing a poor, unacceptable finish characterized by torn, unattached, and non-conformal coating. Even where surface exposure is incomplete, uncovering even some segment of the assembly negates the objective of conformal coating. Removal of masking materials, materials incompatibility, or unclean substrate surfaces may instigate delamination and subsequent lack of parylene adhesion. Appropriate coordination between the grade of parylene coating and the substrate material generates reliable adhesion and lamination. In these cases, altering either the coating type or modifying the surface energy better assures adherence. Working with a parylene type maintaining materials' compatibility with the substrate and displaying applicable moisture impermeability is important, as is surface cleanliness. The objective is transforming the interaction of surface energies so they better support adhesion.

Limited throughput: The parylene manufacturing process is valuable because of: 1) the quality of coatings it generates and 2) it is exceptionally controllable and repeatable, delivering extremely consistent results from batch-to-batch. However, CVD is also time-consuming and generally confined to small-batch production, which can vary between 8 – 24 hours, despite smaller batch-size. Deposition chambers are somewhat costly and tend to be physically small, reducing total quantity of product coated during any single coating session. Extreme coordination between the coating service's work schedule and that of its customers is essential to limit production/delivery delays.

Masking/prep: Although directed to targeted assembly areas by the CVD process, gaseous parylene can spread to non-targeted parts of the substrate. Assuring coating does not adhere to inappropriate sections can require labor intensive masking and preparation that further retard completion of production procedures.

Outgassing: The gaseous emission from a processed layer of coating film exposed to either heat or reduced air pressure, or both. Fortunately, Parylene has very low levels of outgassing.

Solder joint defects: Depending on their properties and application processes, conformal coatings can increase assembly solder joint fatigue; parylene can increase solder joint fatigue by about a factor of three, if improperly applied to the component.

Tin whiskers: The growth of spikey, whisker-like protrusions along the surfaces of metal components, believed to be encouraged by mechanically and thermally-induced stresses. Responsible for assembly arcing and short-circuits. Although parylene is very effective in limiting tin whisker growth, the condition can develop if film application is inadequate.

Weak metal adhesion: Parylene adhesion to noble metals such gold, silver or stainless steel is poor. This is a problem, for example, because gold's superior conductivity properties make it a common element in many of today's PCBs. Although several methods of adhesion promotion can significantly enhance parylene's metal adhesion, they generally increase costs substantially because they are either labor-intensive or require specialized materials to generate desired product outcomes.

Summary

Parylene's overall superiority as a conformal coating is verified by both the literature and practical application. However, its performance efficiency can be critically effected by the conditions discussed above. Proper parylene type and application of coating thicknesses appropriate to the particular assembly, its materials and uses, can significantly eliminate these problems.

Reparing Parylene Coated PCBs

Parylene's CVD method of application generates exceptionally lightweight yet durable conformal coatings, with superior barrier properties. Compared to liquid processes, the effects of gravity and surface tension are negligible, so there is no bridging, thin-out, pinholes, puddling, run-off or sagging.

Typically, parylene films measure between 500 angstroms to 500 microns in thickness; these ultrathin films eliminate performance complications arising from excessive coating mass or viscosity, conditions that might interfere with components' function. The resultant protective layers maintain the performance capabilities that distinguish parylene from liquid competitors; for instance, a 25 micron coating will have a dielectric capability in excess of 7,000 volts.

Because parylene provides unparalleled component protection at film thicknesses far thinner than competing wet coatings, it is the coating of choice for many MEMs/nano technologies**.** Offering unsurpassed protection for numerous current conformal coating applications – aerospace, LED, medical, military, and a range of ruggedized products -- parylene films ensure high reliability and longer life for customer-end products; they diminish total costs for maintenance, repair and replacement, for producers and end-users. However, this does not mean the coatings themselves are flawless; they occasionally require repair.

Enacting Parylene Coating Repair

The unique CVD process that provides parylene with many of its advantages as a conformal coating also serves as a barrier to reworking the coatings. Circuit repair of parylene coatings is characterized by unique issues, emanating from parylene's divergence from more conventional wet coating types. Reliably strong and hard, parylene coatings are exceptionally difficult to chip away or otherwise mechanically compromise; all covered surfaces are typically resistant when reworking is necessary.

Whereas acrylic- or silicone-based coatings use selective spot- or overall dip-exposure solvent-application methods for ready removal from PCBs, parylene's specialized CVD coating technique results in film thickness and surface qualities that do not respond to these treatments. Similarly, parylene rework/removal cannot be accomplished as reliably through the thermal/physical deletion techniques typically applied for epoxy or urethane.

Resisting organic solvents, parylene's removal is further complicated by melting or burning temperatures in excess of 350°C (higher in a vacuum), which generally exceed those of the plastic substances composing at least part of the PCB's structure. Just as specialized vacuum chamber equipment is required to apply parylene conformal films to assembly substrates, equally specialized methods – such as plasma etching or micro-blast abrasion – are necessary to safely remove parylene from the same surfaces. In addition,

- repair of parylene coated PCBs generally requires recoating with parylene, rather than wet technique conformal films, although

- if an appropriate primer is used, lower-priced, field-friendly substances like flexible polyurethanes can assist the repair process.

Where rework is necessary, incision and removal techniques can also treat the parylene surface. This is a mechanical process involving cutting into the treatment surface to initiate separation of the film from the substrate, followed by lifting the damaged parylene with tweezers or a similar device. Although incision removal is often manual, it is suggested operators wear protective gloves. Human flesh contacting the surface to-be-reworked will invariably leave a residue of bodily fluid (oil, perspiration, etc.), which will require additional specialized removal, further complicating the rework process.

It should be noted that, in many cases, repair does NOT entail stripping the board entirely. It is more likely that spot removal of the parylene coating will be required for localized repair of a minute assembly component; typically, the item needing repair is so small that stripping the entire board is unnecessary, costlier and time-consuming. Under these circumstances removal is readily accomplished by using a soldering iron to burn through the parylene surface, affecting the repair, and touching-up the area with a liquid conformal coating; urethane is used most frequently under these circumstances. Of course, care must be taken: Localized application of extreme heat, such as with a soldering iron, can, in fact, melt or burn through a parylene conformal coating.

Whatever technique is employed, the objective is to strip the damaged parylene from the substrate and efficiently replace it to a state where assembly function can be maintained. Reworked/removed parylene cam frequently be recoated to original specifications.

Summary

Durable and heat/solvent-resistant, parylene is difficult to remove or rework. CVD generated substrate penetration significantly increases problems simply peeling the parylene film from the surface. Parylene can be removed for PCB rework by one of several methods. Among the most common removal techniques are, incision/deletion, laser ablation, mechanical or micro-blast abrasion, plasma etching, and thermal softening.

The optimum process of removal is determined by the nature of the device and the particular needs of the client or end-user. Perhaps the best approach is avoiding the need to rework, by appropriately:

- cleaning the substrate,
- masking the assembly properly prior to deposition,
- ensuring a reliable connection between parylene type and substrate material,

Furthermore, after parylene removal, it is essential to develop machining parameters that will not cause damage to the specific PCBs being reworked. In this respect, thoroughly reviewing data sheets and related information for all assembly components requiring rework is recommended; equally important is establishing consistent performance standards for electrostatic discharge (ESD, a source of electrical shorts or dielectric breakdown), process management, and working temperatures. Rework that proceeds without adhering to these basic guidelines can become the source for future rework. Every case is different, so the rework process will require controlled customization. However, in many cases, areas where parylene has been removed can be recoated to conform to original design parameters.

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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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