I-Connect007

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SMT007 MAGAZINE

Conformal Coatings

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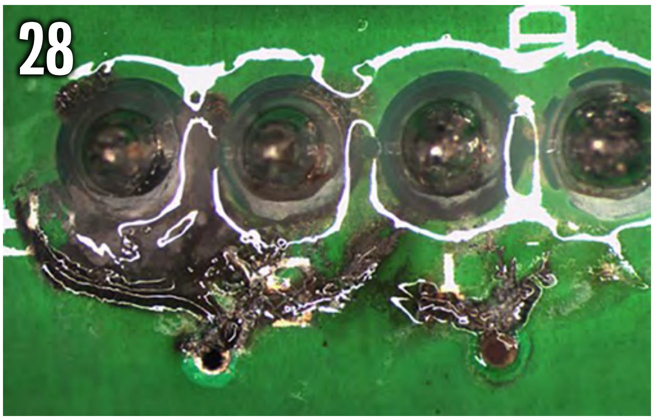

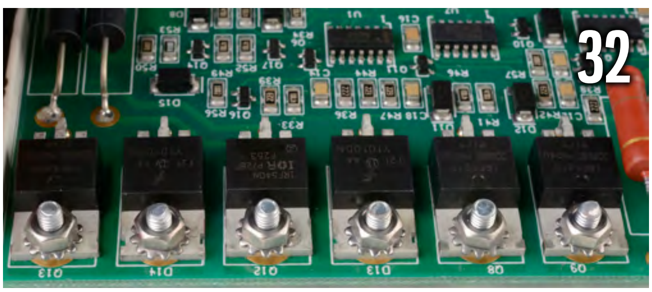

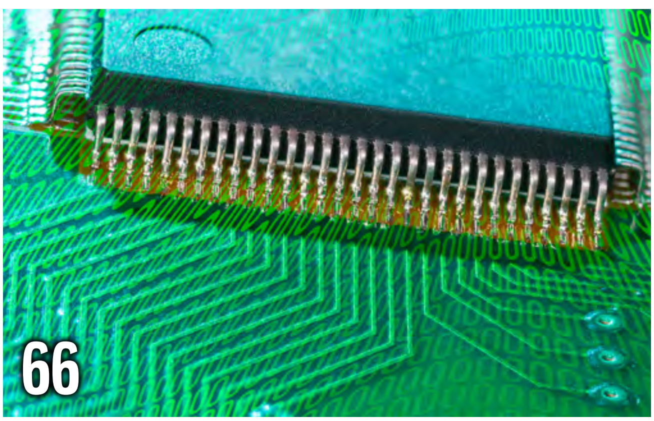

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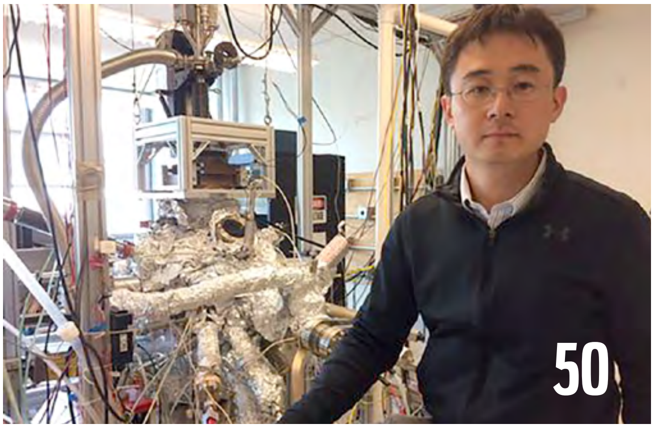

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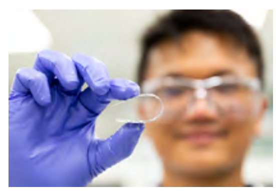

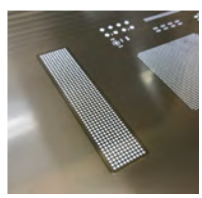

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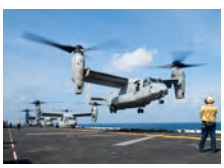

DEPARTMENTS:

Conformal Coatings

Nolan's Notes

by Nolan Johnson, I-CONNECT007

I've been in this industry for a long time. If I'm honest, though, I never gave much thought to conformal coatings. In my defense, I spent most of my career on design tools and PCB fabrication; conformal coating specifications weren't my bailiwick. I'm pretty sure I'm not alone in that regard, which is all the more reason for this issue to exist. In this issue, we look at how the new manufacturing demands are driving change and innovation in conformal coating products, systems, and technologies. It's the voices of those experts who set up this issue best.

John Fix from Taiyo America says of the industry, "Of course, technology can change significantly in a short period of time as well, which is not a perception; it's a reality that we see every day." The changes in the designs we build, coupled with the push to put electronics in harsher and harsher environments, continues to raise awareness for increased reliability techniques, including conformal coating.

Nordson ASYMTEK's Camille Sybert adds, "As we start to see electronics in a variety of different applications, and as we incorporate some more into things like automobiles, then the need for higher reliability in these electronic products increases significantly."

Electrolube's Phil Kinner writes, "As assemblies become more densely populated, and housing/casing designs become more permeable to save weight, the use of conformal coatings is essential to protect the assembly from its operating environment and ensure acceptable reliability for the application intended, especially when operating in hostile environments."

While conformal coatings may have been something of an afterthought at the front of the design process, that can no longer be the case.

Conformal coatings are now a critical part of any board assembly that might be subjected to challenging conditions. But coatings can also contribute to increased mean time between failure in any conditions, even environmentally controlled environments.

Sybert amplifies that point by describing how conformal coatings "serve as an insulation layer that makes sure that the different components stay focused and dedicated to what it is that they're doing as opposed to getting in trouble and causing premature failures on boards."

The quest to protect our electronics from environmental encroachment includes flex and hybrid technologies as well. Dave Lackey points out that it's important to "know and understand that there are different types of materials available for use as coverlayer materials and that there is no single, ideal solution. The appropriate material choice will be based on a number of factors, such as application, cost, projected life, etc."

Sybert also explains that conformal coating is more systemic, saying, "The industry tends to just focus on the conformal coating machine, but conformal coating is an entire process itself from board preparation to coating."

Backing Sybert up, columnist Eric Camden writes that conformal coating "is normally the end of the process with no easy way to make repairs…you can certainly remove coating with a wide range of chemistries or dry ablation processes, but these are time-consuming and have their own inherent risk of introducing failure opportunities."

Clearly, conformal coating is a manufacturing step rising in importance and impact, which has to be done right the first time, every time.

Having all of these conversations about the latest news in conformal coatings, I was struck by how often the experts stated, "It's not just some new hire technician with a shaker can of varnish anymore." Undoubtedly, spray-can coating still persists, but then so do buggy whips. For those moving forward into the challenges facing manufacturing in the rest of the 21st Century, this issue is for you.

We start with some technical detail to help sort out the who, what, where, when, and why of conformal coating. Electrolube's Phil Kinner leads the way with "Conformal Coating Selection: Conventional vs. Two-part." Next is an interview with Nordson ASYMTEK's Camille Sybert, "Conformal Coating Processes and Trends." Eric Camden follows with a look into how CMs may apply conformal coatings incorrectly in his column, "Seal Your Fate." Wrapping up the overviews, Specialty Coating Systems' Tim Seifert delivers a deep dive into Parylene with "The Role of Parylene Conformal Coatings in Next-gen Electronics."

Moving along, Taiyo's John Fix discusses solder mask's ever-adapting role in his article, "Solder Mask Evolves Into a Truly Additive Process." Following right behind, Chris Ellis's column looks at "Custom Reflow Ovens and Curing," and American Standard's Dave Lackey looks to the flex and hybrid technologies, discussing "Selecting the Proper Flex Coverlayer Material."

Alfred Macha's column moves on to Phase 3 in "Becoming the Preferred Supplier: Reengineer Your Quality System." Then, Marissa Pati and Ana "Lety" Campuzano-Contreras bring us their technical article titled "Automated Conformal Coating of CCA Using Polyurethane," and Garret Wong and Jinu Choi address "Dispensing EMI Shielding Materials: An Alternative to Sputtering."

Lesson learned. Designers and board fabrication toolers will increasingly be called upon to account for environmental sealing techniques and materials. How the board is sealed will be a critical specification for the entire manufacturing chain.

As always, we're always glad to hear your feedback at editorial@iconnect007.com. **SMT007**

Nolan Johnson is managing editor of *SMT007 Magazine.* Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing. To contact Johnson, click here.

Conformal Coating Selection:
Conventional vs. Two-part

Feature by Phil Kinner
ELECTROLUBE

With electronics increasingly playing a part in daily life, the applications for electronic systems continue to develop at a rapid pace. Miniaturisation is ever-increasing with systems expected to perform more operations more quickly and more reliably whilst becoming smaller and lighter with every design iteration. As assemblies become more densely populated, and housing/casing designs become more permeable to save weight, the use of conformal coatings is essential to protect the assembly from its operating environment and ensure acceptable reliability for the application intended, especially when operating in hostile environments.

Conventionally, conformal coatings are thin polymeric materials intended to protect assemblies from harsh conditions experienced in their operating environment, including moisture, condensation, salt spray, corrosive gases, conductive particles, etc. Coatings can also provide further dielectric insulation, allowing components to be placed in closer proximity than would be possible in the air, and mitigation against the growth of tin whiskers (Figure 1).

To fully protect against corrosion and provide an effective barrier to mitigate against tin whiskers, which can potentially cause failure

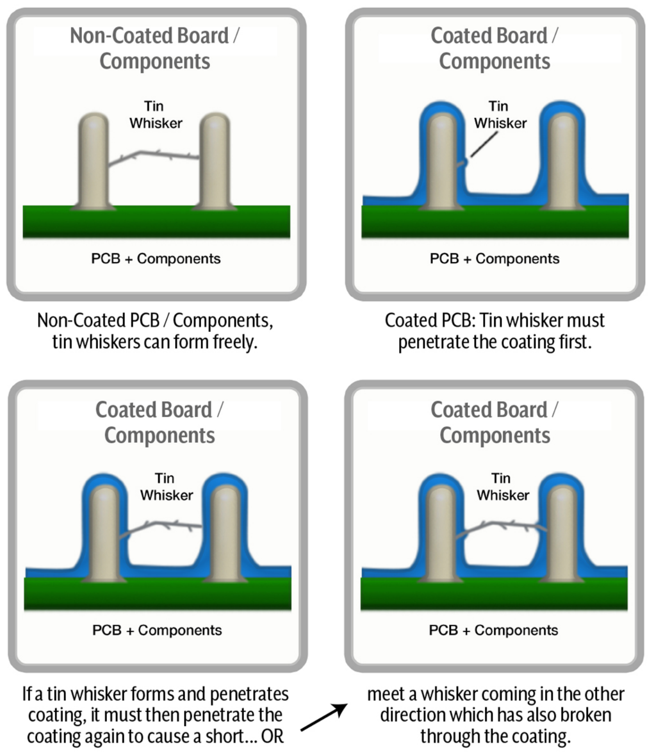

Figure 1: Tin-whisker formation.


HITACHI
Inspire the Next
1 nanometer can be the difference between success or failure.
That’s why you need advanced XRF coating measurement, ready for electronics today, and the nano-analysis of tomorrow.
Choose maximized accuracy for a miniaturized future.
See the full range at: hhtas.net/electronics
HITACHI
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Zero
Stats
FT150 ▸ FT110A ▸ X-Strata920 ▸ X-MET8000 ▸ CMI Gauges
XRF for incoming inspection and production QA/QC.

in electronics by shorting the circuit, it is crucial that the coating material covers all metal surfaces at an appropriate thickness to provide these barrier properties. To understand coating coverage with regards to potential tin-whisker mitigation, the IPC TR-57 "Conformal Coatings: The State of the Industry" white paper investigates hundreds of boards coated with a variety of common coating chemistries and application methods, which were meticulously cross-sectioned for thickness. The results were surprising with numerous areas of extremely low coverage being found along with wide ranges of thickness on different component types. A typical result for a gull-wing device, such as a QFP lead, is shown in Figure 2.

The 2K series of coatings is significantly different in its protective capabilities due to its capacity for greater coating thickness and enhanced edge coverage. 2K coatings are VOC-free, fast-curing, high-performance, two-part conformal coatings that provide a solvent-free alternative to both UV and silicone materials, require less capital investment than UV materials, and improve on the performance of most silicones in harsh environments. The majority of coatings in the 2K range are hydrophobic, giving excellent protection against water immersion, salt mist, and humidity, making them ideally suited for automotive electronics.

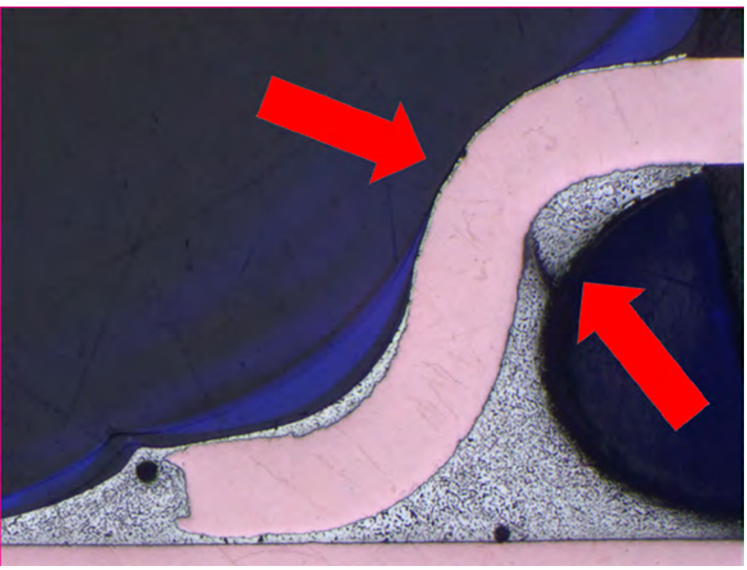


Figure 2: Typical cross-section showing difficulty achieving coverage (blue layer) with traditional coating materials.

Why Was the 2K Range Developed?

The main reasons why Electrolube decided to develop a new breed of two-part (2K) conformal coating systems simply results from the increasing expectations for conformal coatings to perform effectively in higher temperature extremes and withstand more thermal shock cycles and to address the coverage concerns addressed by the white paper. Many conventional materials are becoming obsolete because they are failing to meet new maximum operating temperatures or provide insufficient coverage required for successful condensation tests, which are needed by global automotive manufacturers. Electrolube also wanted to dispel any myth that applying a coating material more thickly achieves better coverage. Overapplying a coating only increases the amount of stress on the coating and the assembly, which can lead to disaster during thermal shock testing, especially with UV-curable materials, which crack and then provide no protection at all.

Addressing these challenges was the driving force behind the development of the 2K range. Electrolube's 2K coatings have been designed to withstand high-temperature extremes and have the application ease of a coating with the performance properties of an encapsulation resin. 2K coatings can be applied more thickly without placing unnecessary stress on the assembly or the coating, which eliminates any concerns about cracking. 2K coatings also accomplish the coverage requirements for successful resistance against condensation, tin-whisker mitigation, and reinforcing dielectric functions. The 2K range is solvent-free, low-odour, and low-hazard, which enables users to reduce their VOC emissions and improve the safety of their process.

Why Would You Use a 2K Coating Rather Than a Single-coating System?

It is time to consider using a 2K conformal coating when a traditional coating fails to deliver the necessary protection for the end-use environment. 2K coating can provide considerably increased protection across the board for resistance against condensation, high humidity, immersion, and corrosion. The additional thickness and coverage are especially beneficial with regards to tin-whisker mitigation and dielectric re-enforcement. 2K materials are also low-odour and solvent-free, providing health and safety benefits in comparison to other chemistries.

From rigorous testing, the 2K systems demonstrate very impressive performance when compared to other coating types. The fact that they can be applied thickly without cracking during thermal shock testing enables a greater degree of component lead coverage to be achieved. This results in improved performance during powered salt spray testing, mixed flowing gas (MFG) testing, and condensation testing; traditionally, these gruelling test regimes are commonly used during automotive qualification campaigns.

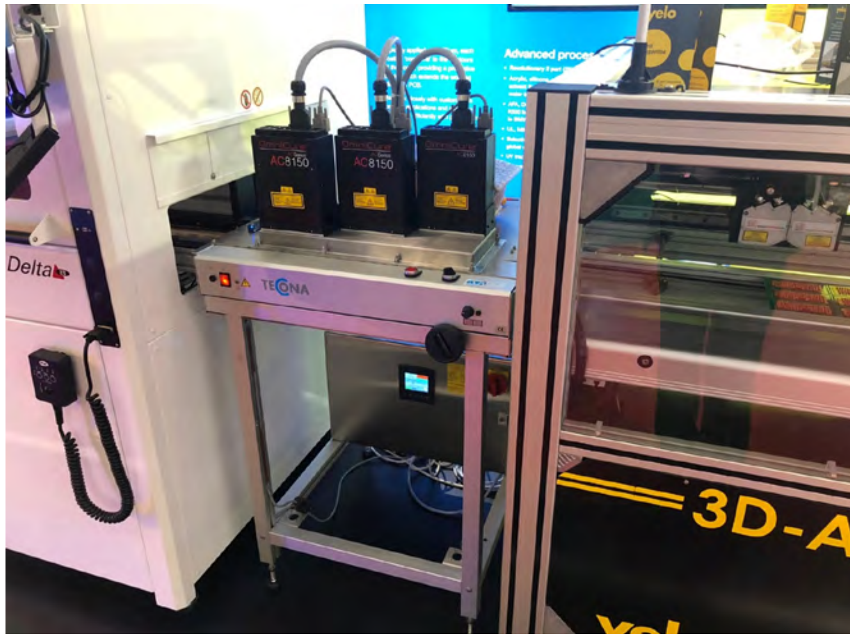


Figure 3: UV-LED curing system for 2K coatings.

What Are the Key Features and Benefits of 2K Products?

The 100% solid material provides increased thickness and coverage, in comparison to single coating systems. 2K materials have also been developed to successfully endure automotive and aerospace thermal shock cycles with minimal impact on solder joint reliability. 2K coating materials can be applied thinly (50–75 µm). However, they have been designed, formulated, and tested to be applied at much greater thicknesses (250–300 µm) to facilitate superior encapsulation of components and component leads.

Further, 2K coatings provide a fast chemical cure with full cure achieved in only 10 minutes at 80°C, significantly improving throughput and reducing work in progress. For instance, the 2K850 is a rapid UV-cure coating system within the 2K range, which is immediately dry to the touch when exposed to regular microwave lamps or LED lamps. Following oven cure, the boards can be bagged without residual solvent odour or concerns about sufficient moisture being available to complete cross-linking process. The overall oven lengths can be as short as 700 mm due to the lower intensity and longer wavelength light being less hazardous, and conveyors can be repurposed for this purpose (Figure 3).

Due to the fact that UV light can be shadowed by tall components, a secondary cure process is required. The chemical cure of a 2K material is achieved within six hours at a constant and reliable rate without any requirement for an additional oven process.

Unlike traditional single coating systems, 2K materials have a different flow, which can provide improved edge coverage and resolves any issues regarding areas to be left uncoated such as connectors and BGAs. 2K can be applied by selective coating spray and needle dispensing to provide maximum coating accuracy to users.

With coating applications, controlling the flow rate at a suitably low level whilst also maintaining the correct mix ratios, is the key challenge and has recently been overcome by the use of specially developed, low-volume progressive cavity pumps. The pumps accurately control the flow rates of the individual components of the formulations within ±1%, maintaining control of the volumetric mix ratio and ensuring correct curing and properties of the dispensed materials. Additionally, the spray head velocity can be up to three times faster than traditional 100% solid material spray applications, significantly reducing coating cycle times.

What Types of Products Feature Within the 2K Range?

Electrolube's 2K conformal coating range fundamentally combines the tough, resistant properties of an encapsulation resin with the easy application of a coating. Examples of products within the range include 2K550, 2K850, and 2K750 conformal coatings.

2K550 is a flexible, high-performance coating, which has excellent clarity and resistance to discolouration, humidity, and condensation. The UL94V-0 compliant polyurethane coating is characterised by greater coating thickness and enhanced edge coverage, and shows improved adhesion, hardness, and scratch resistance. 2K550 also features a fluorescent trace to aid inspection.

The 2K850 UV cure coating combines the speed and convenience of UV cure with the benefits of Electrolube's 2K system. The 2K850 offers a faster processing time while still delivering high levels of protection. The polyurethane coating is a significant development to help speed up production, providing an immediate tack-free coating and enabling complete cure at room temperature within 24 hours compared to the industry moisture cure average of 8–14 days. Featuring a wide operating temperature range of -40 to +130°C with good thermal shock performance, 2K850 provides a consistent chemical cure and strong protection against water, moisture, salt mist, and condensation, making it ideal for tough electronic applications exposed to harsh conditions.

Electrolube has also developed a new silicone 2K conformal coating, 2K750. The UL94V-0 compliant coating provides a wide operating temperature range of -40 to +220°C with a high continuous use temperature of 200°C. The tough, low-stress coating has an extremely fast thermal cure time of 10 minutes at 80°C, in addition to curing at ambient temperature, and provides excellent adhesion to most solder resists and metals. The transition to implementing Electrolube's 2K conformal coatings range couldn't be simpler with a straightforward valve modification, such as PVA's VPX-2KS or Nordson ASYMTEK's AM range.

What Testing Procedures Have the 2K Products Been Through, and What Are the Results?

All of the 2K materials have been tested to comply with the BMW GS95011-5 automotive standard and meet the requirements of the IPC-CC-830. The testing procedures for the BMW GS95011-5 automotive standard includes sequential thermal shock, salt spray, corrosive gas, temperature, and humidity cycling. In addition to the BMW standard, the materials have been subjected to a minimum of 1,000 thermal shock cycles (-40° to +130°C) on populated, no-clean assemblies to ensure there is no tendency to cracking at the higher film builds (Figure 4).

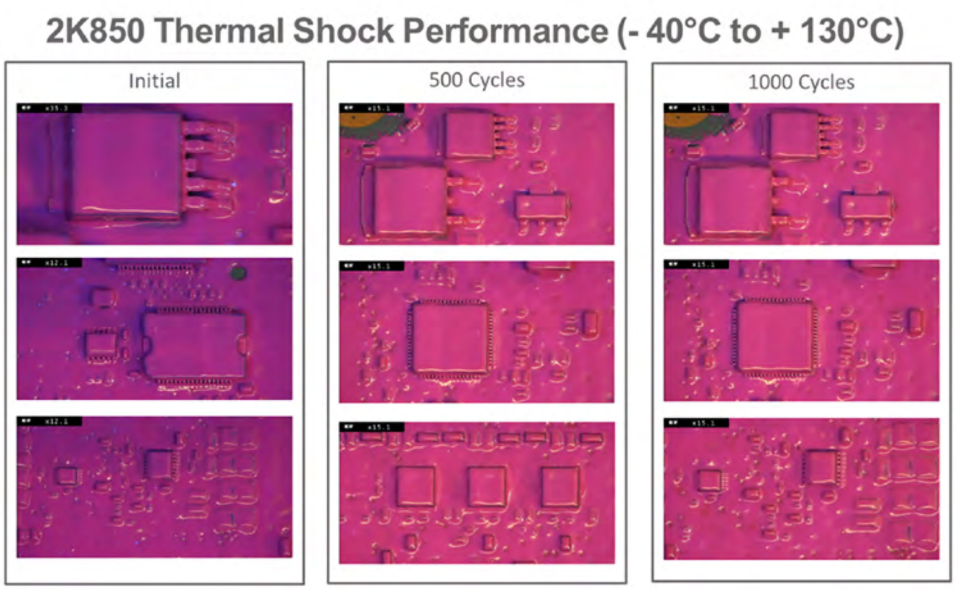
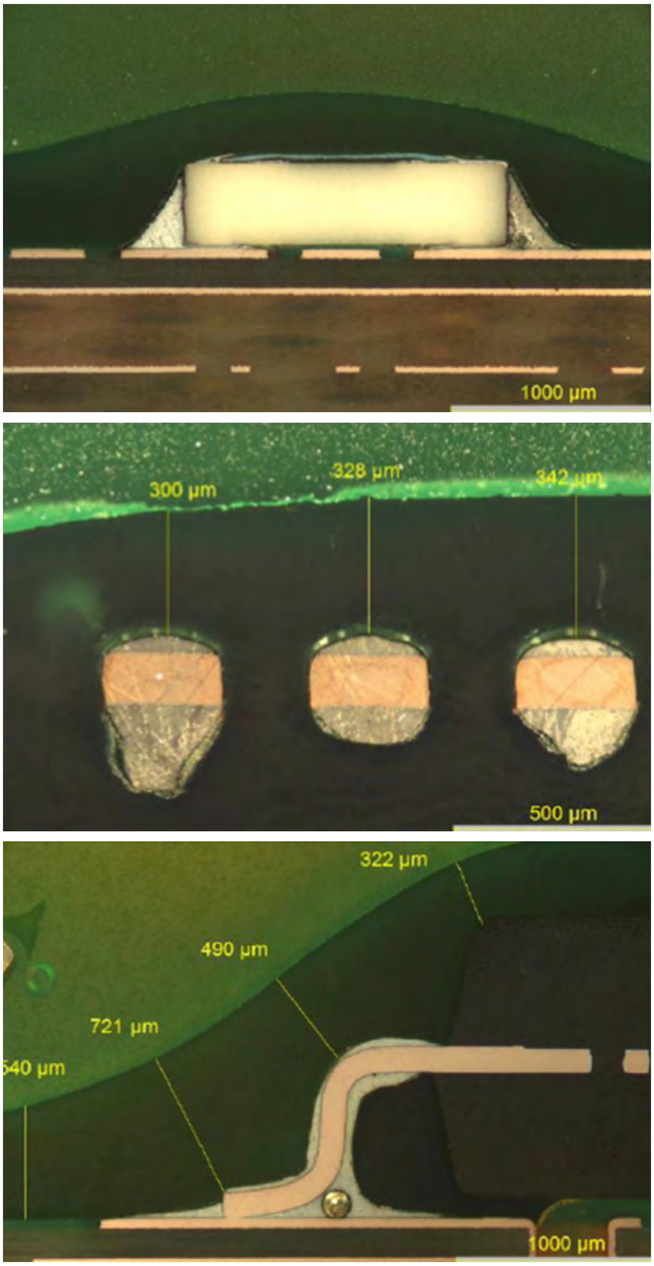


Figure 4: 2K850 thermal shock performance (-40° to +130°C).



Figures 5–7: Examples of cross-sections of PCB components/component legs showing coating coverage.

Many boards have been cross-sectioned after selective coating to ensure coverage and thickness requirements are achieved (Figures 5–7).

Following intensive powered condensation testing on automotive and aerospace assemblies, Electrolube's 2K300 demonstrated outstanding protection compared to the next best coating. The 2K materials have also undergone the BMW dewing test and the NPL's new condensation test on SIR test boards with particularly positive results and with little difference between damp and dry conditions in the cycling test (Figures 8 and 9). Higher insulation resistance values are desirable, as is recovery to similar levels between wet and dry conditions. Low insulation resistance values that remain low are indicative of corrosion or electrochemical migration (ECM).

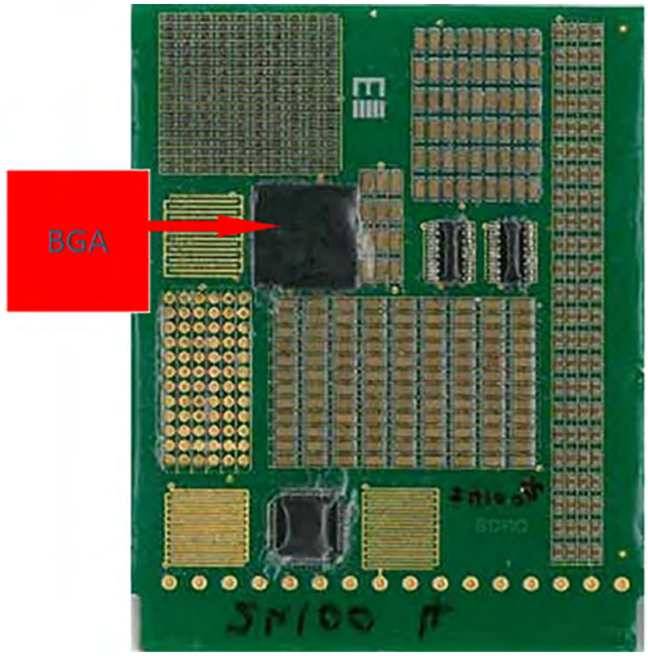


Figure 8: SIR test board used for BMW Dewing and NPL condensation tests.

Which Applications Are Most Suitable for 2K?

2K materials are ideally suited for harsh and demanding applications. The coatings are particularly suitable for automotive applications where the combination of high-temperature resistance, long-term flexibility to survive thermal shock cycling, and an unsurpassed ability to withstand corrosive gases, aggressive media—such as transmission and brake fluids—and powered salt spray. Condensation/dewing tests take their protective capabilities to the next level. The materials also provide resistance to total immersion in saltwater whilst under load for at least 30 hours.

However, 2K materials have also been beneficial to military and aerospace customers, as well as industrial controls and white goods manufacturers, with 2K improving resistance to

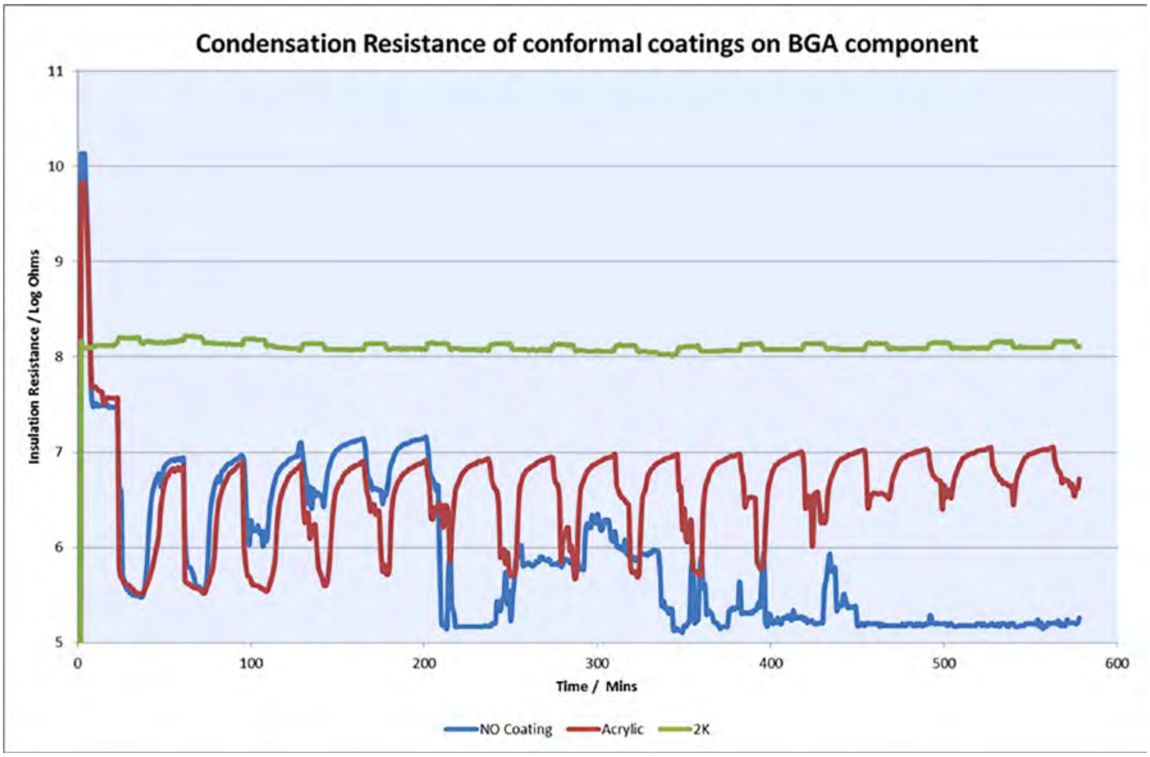


Figure 9: Condensation resistance of conformal coatings on a BGA component.

condensation, damage resistance from insects, liquid water ingress, and corrosive gases.

For example, 2K materials are commonly used in high-performance industrial applications, such as adhesives, paints, and even potting materials. The systems consist of a resin portion and a cross-linker portion that are reasonably stable when kept separate. However, once mixed in the correct ratio, an unstoppable chemical reaction begins, which continues until a solid polymer is formed. By adjusting the nature of the resins and the hardeners, a wide variety of polymers can be produced from soft rubber-like materials to high-strength glass-like materials. Many of these materials are diluted with solvents, which increases the usable life of the system and enables the use of existing application methodologies. However, with the restrictions on solvent usage, it was decided to focus on generating a solvent-free solution.

Do I Need to Make Any Changes to My Existing Selective Coating Equipment?

Electrolube has collaborated closely with popular selective coating equipment suppliers—such as ANDA, PVA, and ASYMTEK—to ensure that the thicker 2K formulations are fully optimised for application using commercially available dispensers. Together, they have developed and tested 2K applicators that provide customers with a retrofit upgrade to their existing and new equipment. The minor modification consists of metering pumps and controllers to ensure the correct volumetric mix ratio of the materials and a new spray applicator that mixes the materials immediately before spraying.

For precision work, it is possible to apply via a needle dispenser also. For instance, PVA's new two-component spray valve—VPX-2KS—has proved to be a highly successful modification for users of selective coating systems (figure 10), adapting easily into their existing equipment to ensure excellent control of material flow, improved edge definition, and easier regulation of dispensing starts and stops.

Conclusion

In comparison to single coatings, two-part (2K) conformal coatings can achieve impressive full coverage of components at higher film thicknesses, which results in unparalleled

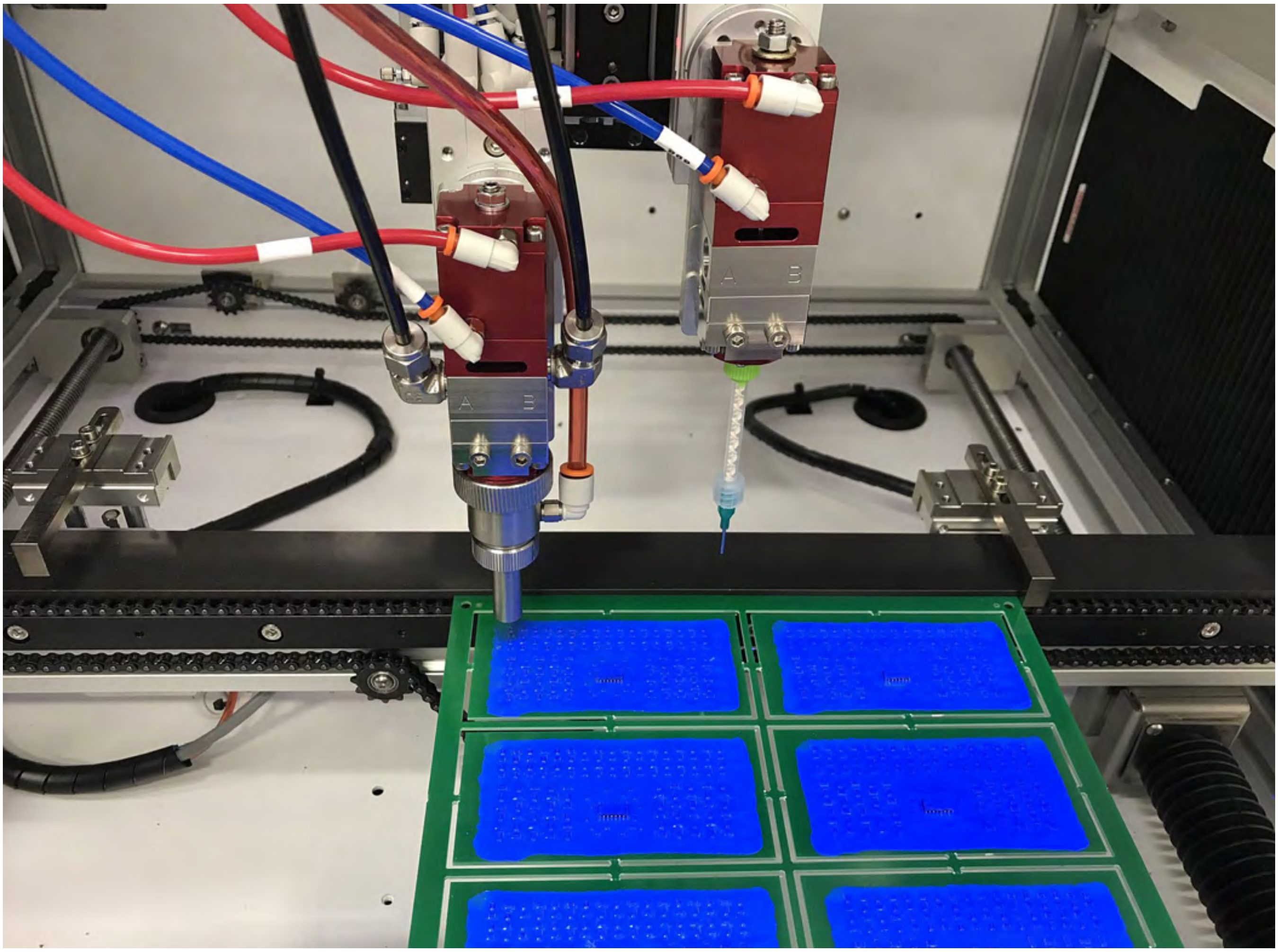


Figure 10: Effortless application of 2K coatings using PVA "VPX-2KS" spray valve.

resistance to condensation, corrosion, tin-whisker mitigation, and dielectric re-enforcement. 2K coatings are also hydrophobic, which gives improved humidity and moisture protection—including salt mist—making 2K an excellent choice for automotive electronics as well as other tough outdoor applications.

Some 2K materials can be reworked with comparative ease despite their greater thickness and enhanced chemical resistance. There are materials within the range that are formulated to be opaque and coloured to both improve machine AOI recognition and manual inspection but can also be used to hide board designs. 2K coating materials will still give significantly improved protection at lower-film builds compared with traditional materials due to their improved ability to cover component leads and other sharp edges.

The solvent-free range of 2K materials significantly improves the reliability of assemblies in automotive, aerospace, and industrial applications whilst simultaneously offering faster curing characteristics, lower odour, and improved health and safety characteristics than other 100% solids technology, such as UV-curable acrylated materials. **SMT007**

Phil Kinner is the global business and technical director of conformal coatings at Electrolube. Kinner is also the author of *The Printed Circuit Assembler's Guide to... Conformal Coatings for Harsh Environments.* Visit I-007eBooks.com to download this and other free, educational titles.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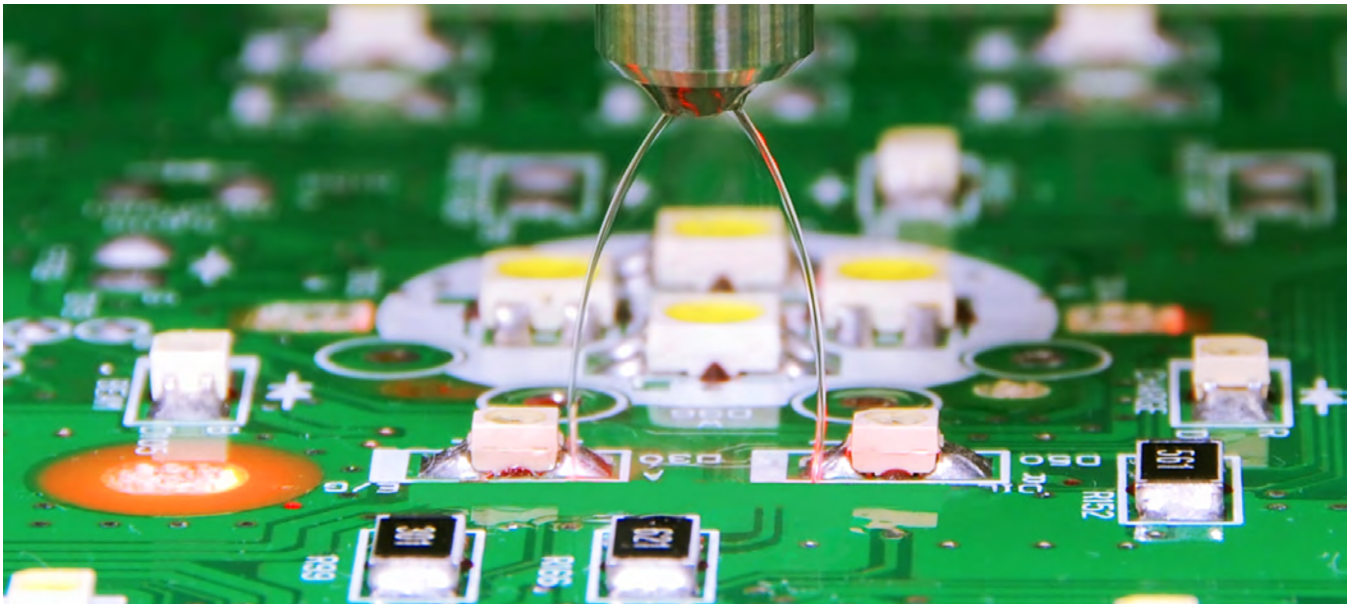


Conformal Coating Processes and Trends

Feature Interview by Nolan Johnson
I-CONNECT007

The I-Connect007 editorial team spoke with one of Nordson ASYMTEK's conformal coating experts, Camille Sybert, to discuss where the coating industry is trending and, with the rise of Industry 4.0 and automation, how it is much less about providing the right applicator and more about addressing the entire conformal coating process.

Nolan Johnson: Camille, can you tell us a little bit about yourself?

Camille Sybert: I'm a product marketing engineer, and I've been with ASYMTEK for about seven years. I started in applications supporting both our precision dispensing and conformal coating. I ended up focusing on the conformal coating. Now, my responsibilities cover the product management aspects of our conformal coatings product lines as well as addressing our EMI spray solutions.

Johnson: Next, can you give us an overview of conformal coatings and the available technologies for applying them?

Sybert: Conformal coating is generally a process that's put in place because it's required as opposed to being a nice thing to have. Its function largely serves to increase product yields in the field and the reliability of products, especially in harsh environments. Conformal coatings protect electronics from external factors, such as extreme heat, humidity, moisture, and dust. They also protect from internal factors, such as circuit board corrosion, whisker growth, and shorts within the system. Overall, they serve as an insulation layer that makes sure that the different components stay focused and dedicated to what it is that they're doing as opposed to getting in trouble and causing premature failures on boards. As we start to see electronics in a variety of different applications, and as we incorporate some more into things like automobiles, then the need for higher reliability in these electronic products increases significantly.

Johnson: Do standards play a big role in why conformal coating is required rather than it being just "nice to have" for cars, etc.?

Sybert: Your question addresses a number of different items that are coming up as far as

what is required in the industry. The world's increasing dependence on electronics demands that these products need higher levels of performance and capabilities. The industry accepts this and defines what those requirements and standards are. In addition to the ability to put down conformal coating, there's also the requirement to add degrees of overall process tracking and traceability. Everything that goes into the development of these electronic components is recorded and monitored and can be researched retrospectively if an issue should arise. If there's a problem with an electronic component that comes up down the line, that can be addressed as well as similar issues. Then, the specific source of the problem can be identified too.

Johnson: That's an interesting point. The traceability requirement falls to the equipment, doesn't it?

Sybert: Right, there are many different factors that go into conformal coating, which is only one piece of the entire puzzle that goes together. Currently, people in the industry talk a lot about Industry 4.0 and IoT; much of that stems from data collection and traceability. Many systems involved in the process require closed-loop controls. Now, when we talk about conformal coating, the industry tends to focus on the conformal coating machine. But conformal coating is an entire process itself from board preparation to coating. Then, your coating quality has to be maintained by whatever curing process that you put in your manufacturing line. Inspection is another critical component to verify that your coating processes are within the target.

As we talk about closed-loop controls or the move to more automated operator-less factories, pieces of equipment must be more independent in the sense that they monitor themselves. They correct internally so that you don't require operators to intervene. With automated coating inspection, you can take out a lot of operator subjectivity by setting pass/fail criteria around what you're inspecting. You verify that you're putting the coating material where you need it to be. You're verifying that it's not where it shouldn't be and that your final product is within your accepted tolerance. The same is true with ovens and other systems having closed-loop controls to make sure that temperature is being appropriately regulated. You don't want an incomplete cure that may potentially cause other concerns and considerations.

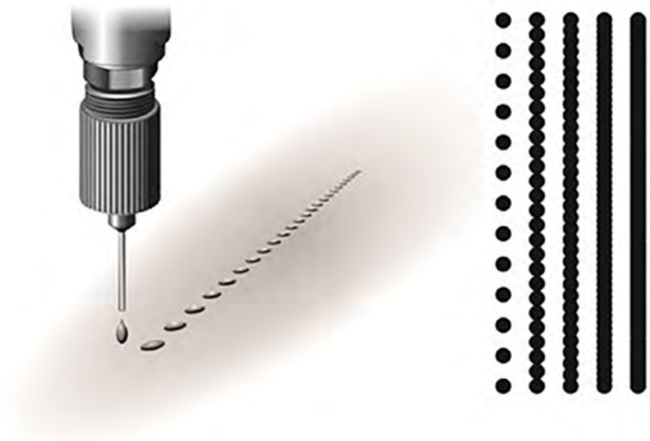
A lot of what's required around these pieces of equipment is that they can collect data and gather information, but also that they're able to share it and take action on that information. Nordson ASYMTEK has been big on process controls for decades. For conformal coating, we came up with laser fan width control to make sure that the coating fan pattern is within tolerance and can make adjustments. Monitoring and controlling flow rate is critically important as well as making sure that fluid temperature remains consistent, so the coating pattern is not affected by the environment; changes in environmental temperature can negatively impact your material viscosity, which would then change how your fluid comes out of the applicator.

Johnson: Clearly, there is a lot going on with inter-machine communication and data capture and reporting. That information then becomes useful up and down the manufacturing flow. You're coordinating with other pieces of equipment, such as the reflow oven and curing process. To make sure that the systems work correctly, has that required a lot of mechanical development work over the past couple of years?

Sybert: That level of communication is where the industry is trending, especially once you start referring to conformal coating as the entire process from beginning to end and not just what each individual machine is doing. The first step to making sure that the entire process is running smoothly is to verify that each individual part is still maintaining what they're supposed to be doing and that they are functioning within the realms that they're supposed to. Individual machine process control is still critically important as well as being able to use the information from one machine to help with another system, similar to the coating system and automated coating inspection (ACI) system. Using the results from the ACI system helps the operators understand what's going on with their process and allows them to make adjustments on their conformal coating programs, for instance, to ensure that areas that need more rework can be addressed.

Sybert: One thing I was looking forward to during this discussion is the equipment used to apply conformal coatings. The process is effective when you have the right pieces of equipment applying the materials. When we talk about these pieces of equipment, we're not talking only about the specific conformal coating machine, but also all of the other pieces of equipment that go into the entire process. The objective is not just achieving correct coating requirements but meeting throughput requirements. Both of those are major concerns for our customers as well. When we talk about equipment, it's important to focus on what the overall result is that you're looking for. Sometimes, we can get distracted by specific mechanics and details. For example, what are the accuracy and repeatability specifications of a system not running fluid? But if we're talking about conformal coating, the application of liquid matters.

It comes down to what is the equipment is able to do. In that case, the valve or applicator is critical to fluid dispensing because it's the last machine part to touch the fluid. The start and stop timings of the applicator can significantly affect placement. In other words, if you have the most expensive mechanics available on a system but incorrect applicator timing, that machine still might not meet the needs of your coating application. As a result, in conformal coating, we have a number of different technologies that we use to apply the material, including film coating; spray; monofilament, which is a non-atomized process where you take a bead of material and rotate it; jetting; and needle dispensing. Depending on the wide range of fluids that you're placing, each technique has its own nuance.



Ultimately, applicator timing and performance achieve uniformity and consistency. Accurate programming is also important. If the system does not allow for operators to program well, then your fluid is still not going to go where you intend.

Dan Feinberg: What are the most commonly used methods of application?

Sybert: That's an interesting question because the answer varies by region. Method of application largely depends on the type of fluid that's being dispensed. Europe tends to use largely solvent-based instead of silicones. With a lower viscosity, solvent-based type applications lend themselves well to film coating for large board applications as well as some jetting for more precise applications. But in the Americas, we also see silicone-type applications. Silicone applications lend themselves to either an atomized spray or a monofilament process. The monofilament approach creates a path that's about 10 millimeters wide; it's intended to cover a broad area. But as a non-atomized process, it gives you better control compared to a spray process.

Feinberg: When you say a film coating, is it a liquid-film coating, a dry-film coating where it would be laminated on or applied to some other way, or are or both being used at times?

Sybert: The term "film coat" refers to a specific type of wet coating in which the fluid exits the nozzle in a fan pattern. If you look at the nozzle head-on, the spray broadens out as it goes, creating either a fan- or a leaf-like curtain of material that dispenses a straight wall of material. Film coat tends to have a fairly high flow rate, but if you take that fan and rotate it 90 degrees, you use a very narrow knife edge.

Some applicators may atomize more efficiently and give you overall better edge definition and uniformity, even at different speeds. Some applicators may be designed so that they have better applicator shut-offs, giving you cleaner starts and stops, etc. At Nordson ASYMTEK, we make sure that we clearly establish what those start and stop distances are such that we can get the correct placement of our fluid at the beginning and end of the line. That is pretty unique to us.

As we mentioned earlier, it's a closed-loop system. When you just put an applicator onto a piece of equipment, it can dispense, but you would not get the feedback, accuracy, or reliability. When you're building millions of products, like mobile devices, or require high levels of reliability, like for automotive or medical electronics, then the line has to keep running, and throughput is very important. You don't want a lot of rework and stopping or operator interference.

And to take it up one level, at Nordson ASYMTEK, we provide an overall conformal coating solution, which is more than the applicator, process control, and machine; it's the entire process. This includes equipment for coating, curing, and inspection. From a large line perspective, a customer can interact with one partner to develop their entire process. We're able to provide an overall solution where we have expertise across the entire suite of production equipment. We can address the coating, take into account the curing, and verify everything with the inspection. Within those individual pieces of equipment are individual solutions.

For example, do you want one, two, or numerous applicators? If you're concerned about throughput, are you doing dual simultaneous, dispensing two applicators at the same time? Do you have multiple fluids that you're putting down and need different applicator technologies to do that? Are you combining a jet with a spray to make sure that you get the coverage requirements that need? How are you maintaining that overall production process?

What closed-loop controls do you have in place for that? From an ease-of use-perspective, what does the software look like? That's mainly where operators are interacting with the equipment. Is the programming easy for them to visualize and work with? Does the system help the operator set up the process? Can the operator decide limits around when these process controls get activated? Is it after every 10 boards, every half hour, or when the process starts to trend outside of what their specified limits are? Having features to deliver that level of control and capability allows manufacturers to holistically address the entire conformal coating process.

Johnson: There are low-mix, high-volume contract manufacturers, and then there are high-mix, low-volume contract manufacturers; they

optimize for slightly different things. How does a CM adjust the equipment to line up with those mixes?

Sybert: It's important for customers to work with somebody who has an array of equipment that is flexible to meet their needs. We offer a variety of solutions, and we create customized solutions to make sure that we address specific needs. We cover the gambit of applicator technologies, and our overall system can be customized based on the application. Do you dispense a urethane material and an acrylic material, meaning you should have two different applicators on the same system for different fluid types? There are a lot of production accessories too, such as barcode scanning, that can access the correct programs and make automatic adjustments to conveyor width for each board coming down the line.

One of the advantages of automated equipment is the flexibility to adjust on the fly as needed. Within the software, can you account for those different requirements, organize your valve capabilities, and provide many flexible options on what each application requires. For instance, if you have two different boards—one with many tall components and one that's flatter—you can teach different patterns with the same applicator. Default settings for each pattern are varied: the applicator coating a flat substrate can coat at a high velocity, and the velocity may change when coating a more populated board for contouring around those components. Options like these are associated with the specific program that's developed and associated with a specific board through the barcode. As soon as the board is scanned by the barcode reader, the system automatically makes adjustments to compensate for what this new board requires, such as a wider conveyor, narrower conveyor, switching off between different applicators, and adjusting the fluid pressure to what the specific board requires.

Johnson: That sets up my next question as we talk about applicators and fluids. There's a lot of innovation going on right now, including many new types of solutions that provide greater extreme environmental protection. With the long-term effects in lead-free, there's a lot of attention on environmental protection. From your perspective, who's the dog and who's the tail? Are you in a place where you're working hard to keep up with different kinds of fluids, or are the new developments in conformal coatings lining up with existing tips and applicators in a way that you don't need to do much?

Sybert: We see a lot of the same players. Ultimately, the concern of the equipment supplier and fluid manufacturers is to help the customer be successful, whatever their application. As we're working on developing these new fluids and the technology to apply those fluids, we see a lot of collaboration between different fluid manufacturers and equipment suppliers to make sure that we're able to provide a holistic solution that will enable our customers to be successful.

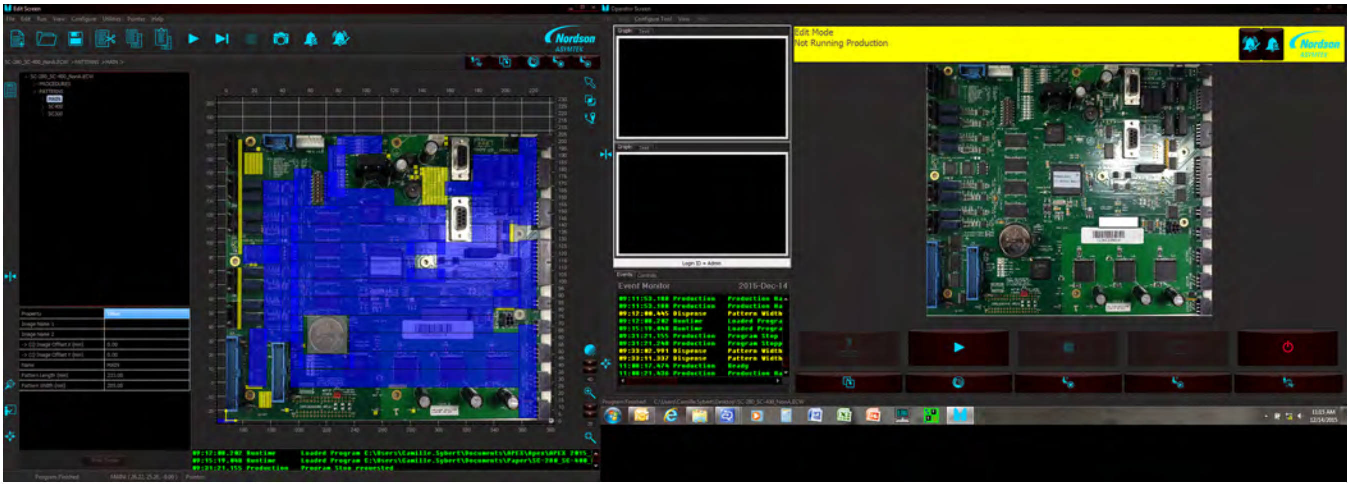
Johnson: So, you're working back and forth with that a lot?

Sybert: Yes, and often, it's iterative. A new process requires iteration both on the fluid side and the equipment side. We're both adjusting and evolving to provide the solution that meets the final customer needs.

One great example of collaboration most recently falls within what we're working on for EMI. In the past few years, Nordson ASYMTEK published a couple of different white papers partnered with different fluid manufacturers to address new developments with EMI-type applications. This is a collaborative effort with many iterations and a lot of research behind it. As a company researching new technologies, it is critical to the industry's ongoing success that we dedicate a significant amount of our time and resources to investigate those solutions.

Johnson: What are the differences you're seeing in the regions that you're identifying?

Sybert: In general, we see all applications and fluids in different regions. In Europe, the focus



largely has been on solvent-based materials and not as much with silicone-type fluids. We see silicone fluids more often used in other regions. But as the world becomes a smaller and smaller place, then we will continue to see shifts in the fluids that are being used. The trends in what we're protecting from evolving and dictate fluid types we will be applying.

Environmental impact is also a consideration; many of the solvent-based materials have higher volatile organic compounds (VOCs). And there's an effort to make conformal coating a safer and more environmentally friendly process. The equipment needs to handle those volatiles and take them away or manage them. Having a whole system where you can help the environment is also trending and very important.

Johnson: So, globally, conformal coatings seem to be trending toward less and less regional variation?

Sybert: Potentially. I think the other consideration is that we have new and evolving requirements from our fluids as well. With the introduction of gels and two-component materials, we're going to see an emphasis on the coating fluid more specific to what the application itself requires.

Johnson: As an equipment manufacturer, what's one of the more exciting new developments in conformal coating that you're looking forward to?

Sybert: Conformal coating has evolved as a process from "good enough" and "somebody with a spray can" into a much more sophisticated, automated process. I am looking forward to the significant knowledge gains that we're making with conformal coating and understanding the fluid dynamics behind conformal coatings so that we can move it to be more of a science as opposed to an art. We want to take this knowledge base and incorporate it in a way that helps our customers set up their processes faster and more efficiently for better results. We want to elevate conformal coating and gain a lot more knowledge on how the process functions and share that expertise.

Johnson: And there's a lot of work going on at Nordson ASYMTEK in research and development as well.

Sybert: Yes, we have a strong team of applications engineers all over the world who both contribute to new product development but also are there when customers need their support. And we have some fun activities going on that we're looking forward to sharing with the rest of the world later this year.

Johnson: Thank you so much. This has been very productive.

Sybert: Nice talking to you. Thanks for including us. We really appreciate it. **SMT007**

Sealing Your Fate

Quest for Reliability

Feature Column by Eric Camden, FORESITE INC.

According to a quick internet search, the process of conformally coating an electronic assembly goes all the way back to I don't know when; I couldn't find that information. Sorry. But I was able to contact an industry colleague that works for one of the major chemical manufacturers. Their company has strict restrictions about being cited in publications, so they will remain nameless, but "the man" can't keep me from telling you what their thoughts are. Here's what they had to say.

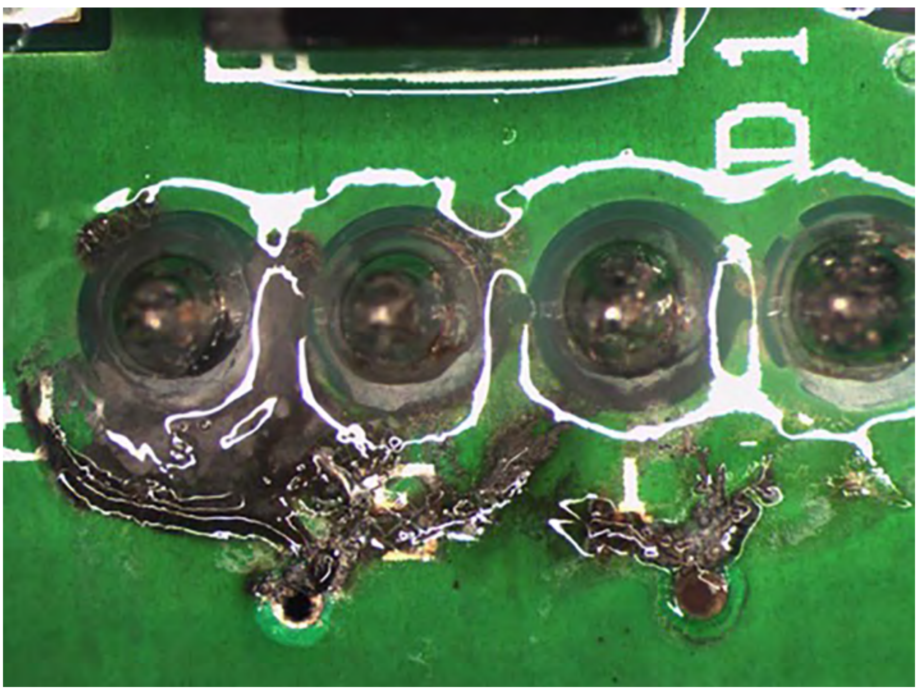
"Conformal coatings being used to protect printed circuits dates back to before the 1960s when the Department of Defense authored specification MIL-I-46058. A general industry standard IPC-CC-830, has more recently carried the industry forward. Conformal coatings can be used to protect printed circuits from current leakage/short circuits (arcing/corona), corrosion, solder joint fatigue, mechanical stresses, such as shock and vibration, along with protection from dust and dirt debris."

So, there's that bit of history that pretty much sums up what a good coating is used for. Now that we've cleared that up, let's talk about my favorite part—how CMs continue to do it wrong. Remember, I work for an analytical lab.

Four Main Types

There are several types of coating material available, and it normally comes down to the end-use environment when deciding which one is best for your product. In general, the choices are acrylic, silicone, urethane, and Parylene. There are probably some exotics out there as well, but for most of what we see, those are the big four.

Out of those four, the one we see the least amount of issues with is Parylene because it is applied with a vapor deposition process that requires the substrate to be extremely clean for proper adhesion. When that process is properly done, the residues that can normally facilitate electrical leakage or electrochemical migration are removed. On top of that, Parylene creates a near hermetic seal when compared to other coating materials.



The drawback for Parylene is the cost and the time it takes to apply it. We don't see Parylene used in high-volume production, such as

consumer electronics, but more often for high-end reliability product, such as medical devices and aerospace applications. The remaining three materials are more of the focus for this month's column as they do not require the precleaning of the surface before application, which is where we see the problems start.

We regularly receive failures in our lab from people who are astonished that coating didn't stop dendrite growth on their product.

We regularly receive failures in our lab from people who are astonished that coating didn't stop dendrite growth on their product. Conformal coating is sometimes thought to be some magical application that stops all electrical leakage, but that's simply not the case. In the past, I have discussed at length the risk of leaving elevated levels of ionic residues from any part of the process, and that's no different when coating is involved. Coating is good at keeping out most dust and debris, but given enough atmospheric moisture, in conjunction with active/hydroscopic ionic residues, it will eventually penetrate through and can cause electrical leakage.

Application and Curing

There are multiple ways to apply conformal coating, including manually by brush, dipping, or aerosol cans, and automatically by spray equipment using air pressure and nozzle delivery. Any manual method effectiveness is normally driven by the operator's competence and experience level. Manual methods may also include proper masking of areas designed to not be coated, which is most often done with polyimide tape. This may prohibit some assemblies from being dipped based on keep-out areas that are hard to mask. Automatic spray systems are among the most repeatable methods for coating application. This is the most prevalent method we see in the industry and is normally used in high-volume processes. Spray systems are the easiest to diagnose and optimize if something should go wrong.

Coating over no-clean flux residue is now a common practice, and there are a few different points of view on this process. In general, we see fewer problems with coated boards that have been properly cleaned before coating, like the Parylene application. We have seen adhesion issues with this practice when the flux residues are not fully processed to create a firm outer shell for the coating to adhere to. If the flux is not properly processed, the soft outer shell can blend with the coating and won't fully cure. Adhesion is also an issue on assemblies processed with no-clean flux that incorporates a cleaning process. Many times, the bulk of the flux is removed with the cleaning process, but there will be a monolayer of residue left behind that isn't readily visible. The residues you can't see can cause as many problems as the ones you can, so it is imperative to qualify the wash process to ensure that all of the residues have been removed.

Then, there are two cure methods: thermal and UV exposure. Thermal exposure curing takes more time than UV but can take as little as 10 minutes to tack dry for further assembly processes while it continues to cure. UV cure is far quicker, but there is a risk of coating in shadowed areas never to cure. This is most commonly found on high-density assemblies. If UV coating migrates under components, it will never fully cure, and it will remain wet for the life of the product. Coating in this state can hold the dust and debris it is intended to block out. If the debris is metallic, you may be at an even higher risk of failure than not using a coating at all.

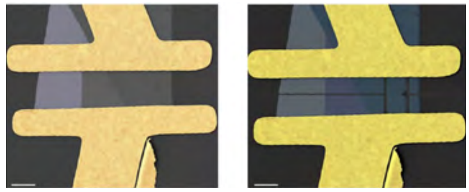
The good news is that UV coatings are much easier to inspect due to the addition of a luminescent property. This will allow the inspector to determine exactly where the coating is on the assembly and determine if the UV cure process is adequate to reach all the areas of the coating. UV-cured coatings also make it much easier to determine consistency with thickness. In general, the brighter the coating, the thicker the application. Dewetting of coating is common when residues are present, and many times, on sharp edges of leads and component bodies. This may leave some areas more vulnerable to the operating environment.

Determining the level of adhesion can be done using IPC TM-650 2.4.1.6. This method uses a 10 x 10 grid of 1 mm x 1 mm squares etched into the coating with subsequent application of tape and removal of the tape with a steady motion at a 180° angle. Inspection after the tape pull is based on how many of the grid pieces were removed with the tape. The remaining grid area is judged on a scale from zero to five with zero being more than 65% removed and five having none of the coating removed. This is primarily done on test coupons during process evaluation and not on actual product. We recommend this test on the actual product if possible because that will give you a much better idea of what to expect when the coating is combined with the chosen material set.

Now, it's time to circle back to the title of this month's installation: "Sealing Your Fate." After you apply your coating of choice, that is normally the end of the process with no easy way to make repairs if necessary. You can certainly remove coating with a wide range of chemistries or dry ablation processes, but these are time-consuming and have their own inherent risk of introducing failure opportunities. The important lesson to take away from this column is that coating does not always prevent failures; it is just as important to look at your cleanliness levels just as you would with an assembly that is not bound for coating. If you have a dirty assembly, you might be buying a little time, but ultimately, you've sealed your own fate. **SMT007**

Eric Camden is a lead investigator at Foresite Inc. To read past columns or contact Camden, click here.

Direct After-fabrication Tailoring of MoS2-FET Transistors



Transition metal dichalcogenides are discrete, 2D, atomically thin layers bound together by Van der Waals forces. They exhibit thickness-dependent variations in their physical properties that can be exploited in distinct optoelectronic applications. For example, the band structure of molybdenum disulfide (MoS_2) has a direct bandgap of 1.8 eV in a single layer that narrows down with thickness, being 1.2 eV indirect bandgap in bulk.

The atomically thin layers of MoS_2 can be separated by micromechanical exfoliation; nonetheless, the fabrication of optoelectronic devices from mechanically exfoliated MoS_2 is an intricate process. The geometry of the device is limited in all cases by the shape of the exfoliated flake, even when a deterministic stamping method is employed.

Thus, developing techniques to tailor the device geometry after the fabrication steps are completed is of great interest. The group led by Professor Daniel Granados at IMDEA Nanociencia has come to a smart solution to modify the geometry of several field-effect transistors (FET) fabricated out of exfoliated MoS_2. The proposed method uses a variation of focused electron beam-induced etching (FEBIE) with a pulsed electron beam. The beam scans the surface into a designed geometry, employing a pattern generator, modifying the conduction channel between the source and the drain of the transistor, and allowing a tailor-made device performance.

This method presents several advantages. It combines patterning and etching into a single step, allows electronic and optical characterization before and after the tailoring step, and the pulsed-FEBIE method has an electron beam energy lower than other studies, reducing the sample damage and prevents the distortion of the MoS_2 lattice.

(Source: IMDEA Nanociencia)

The Role of Parylene Conformal Coatings in Next-gen Electronics

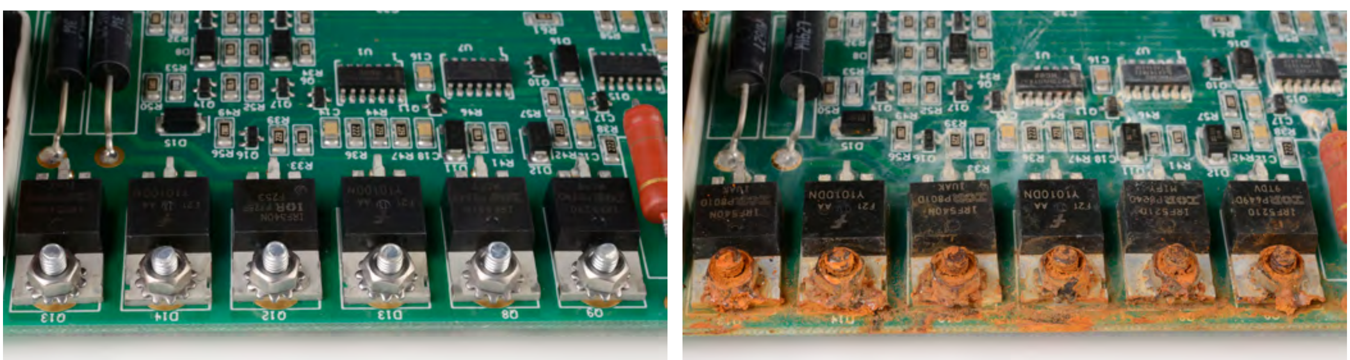
Feature by Tim Seifert
SPECIALTY COATING SYSTEMS (SCS)

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.

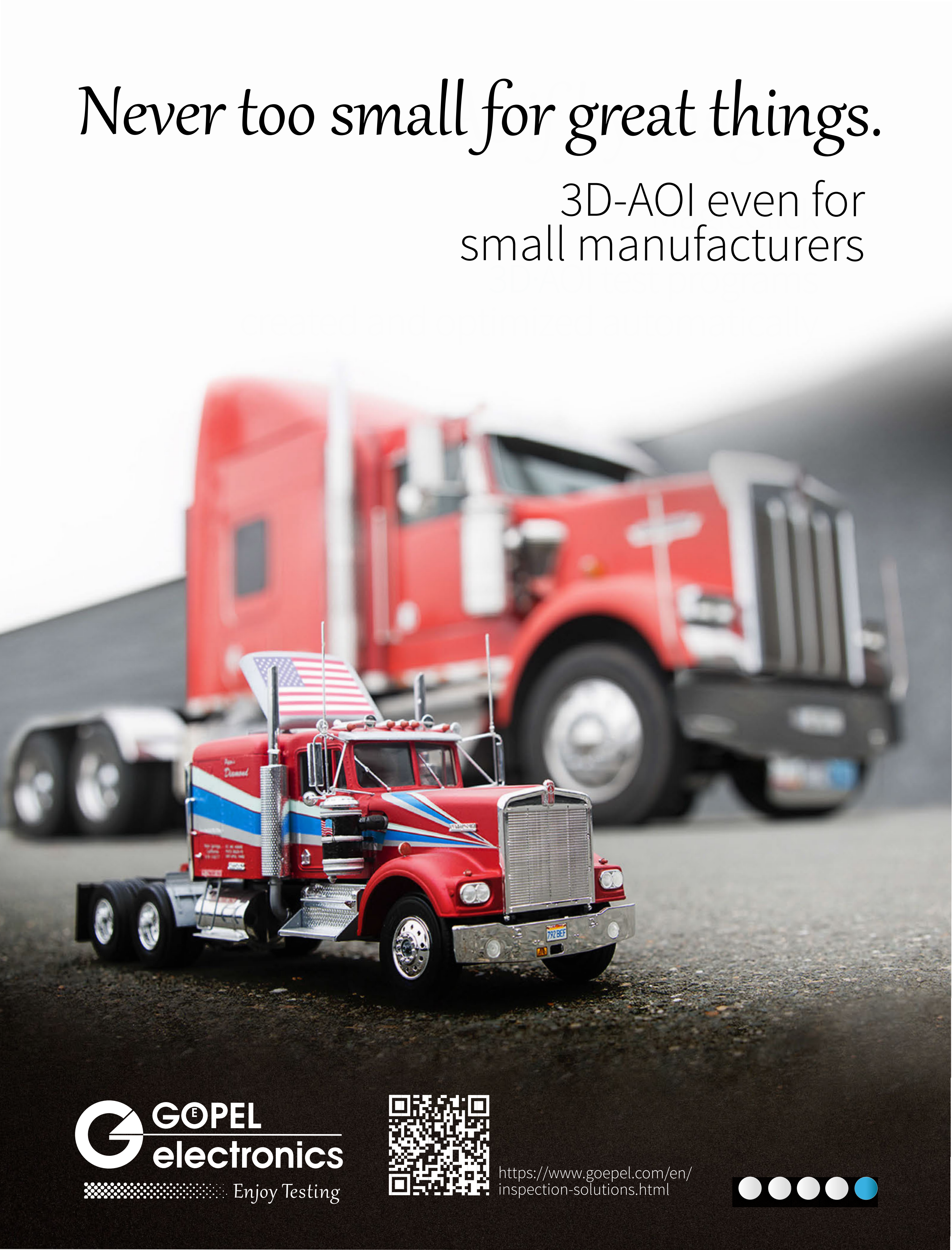
Developed by Union Carbide scientists in the late 1950s, Parylene is the generic name for a unique series of polymeric organic coating materials. They are polycrystalline and linear in nature, possess useful dielectric and barrier properties per unit thickness, and are chemically inert. Parylene coatings 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.


Never too small for great things.
3D-AOI even for
small manufacturers
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electronics
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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-paraxylylene 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

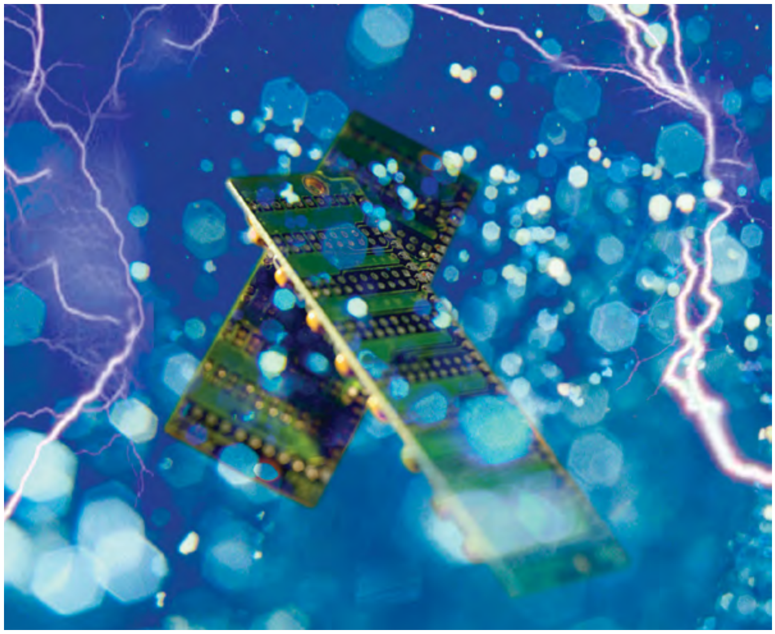
		Parylene N	ParyFree	Parylene C	Parylene HT	Acrylic (AR)	Epoxy (ER)	Polyurethane (UR)	Silicone (SR)
Dielectric Strength V/mil		7,000	6,900	5,600	5,400	3,500	2,200	3,500	2,000
Dielectric Constant	60 Hz 1 KHz 1 MHz	2.65 2.65 2.65	2.38 2.37 2.35	3.15 3.10 2.95	2.21 2.20 2.17	– – 2.7 – 3.2	3.3 – 4.6 – 3.1 – 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.

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.



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

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 conditions 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.

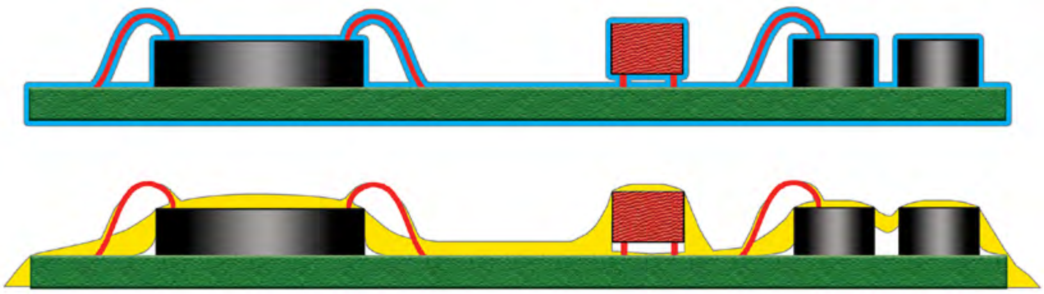
Stability to Endure Thermal Cycle Extremes, Pressure, and Vibrations

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**

Tim Seifert is an aerospace and defense market manager at Specialty Coating Systems.

SMTA

Additive Electronics Conference: PCB Scale to IC Scale

October 24 - 25, 2019

DoubleTree by Hilton San Jose
San Jose, California, USA

About the Conference

From smartphones to implantable medical devices, electronic designers and fabricators are continuously challenged to miniaturize the size of their products. The SMTA Additive Electronics Conference brings together practitioners looking at the SMT-SEMI convergence. Targeted at substrates with line space/width down to 5um, this conference will showcase substrate design and manufacturing technologies that will enable the next generation of electronic products.

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Solder Mask Evolves into a Truly Additive Process

Feature by John Fix
TAIYO AMERICA INC.

As I write this article, it is the eve of high school graduation for my oldest son, Tom. It's easy to reflect on his life that spans just short of 18 years. As parents, we all remember the milestones of our child(ren): when they were born and their first words, steps, days of school, etc. His high school graduation means he now embarks on the specialized educational path of his choice. For my wife and I, we have fantastic memories and look forward to seeing what Tom's future holds.

I started with Taiyo America 18 years ago. And yes, 18 years can be a lifetime for some (like Tom), or short for others, like my wife and me. It's all just a perception of time.

Of course, technology can change significantly in a short period of time as well, which is not a perception; it's a reality that we see every day. Changing technology has a dramatic effect on how we live our lives. As a young parent, I thought it was incredible to have a video baby monitor. Now, the norm is to have an app to monitor your baby's every move from your smartphone. In the electronics world, 18 years have delivered changes from flip phones to smartphones, 2G to 5G, and plated through-holes to blind vias. In the automotive world, Tesla didn't even start development until 2004; now, we have self-driving vehicles.

However, the 5G era is creating quite a bit of work for many PCB engineers as the materials required to keep up with the speed, frequency, and latency requirements need to be defined

Figure 1: 5G era.

and qualified. Solder mask, for example, now becomes a truly additive process. There are several solder mask properties to investigate, including digital solder mask technology, process step removal, environmental extremes, heat management, crack reduction, and via filling, just to name a few. In this article, I will begin to explore the "hows" and the "whys" involved in making solder mask a strictly additive process.

Going Digital

One of the most important ones was the property function of imaging the material. PCBs have much tighter space requirements as devices get smaller and more processing is required that pushes PCB manufacturers to implement some form of digital printing into their process. Taiyo has spent several years in developing not only laser direct imaging (LDI) solder mask for the very popular Orbotech Paragon machine, but we have also designed direct imaging (DI) solder mask for various other DI equipment options that are now available. These LDI/DI solder masks offer excellent advantages over traditional liquid photo-imageable (LPI) solder mask processes with regards to registration, tight tolerances, and fine dams.

PCBs have much tighter space requirements as devices get smaller and more processing is required that pushes PCB manufacturers to implement some form of digital printing into their process.

However, the true leap in digital solder mask technology is inkjet solder mask. For the past several years, Taiyo has worked with inkjet equipment manufacturers such as Orbotech and Notion Systems, just to name a couple, pushing this technology into the marketplace. Inkjet solder mask allows you to enjoy the many advantages of LDI/DI, such as registration, no artwork generation or the waste/cost associated with it, and the capability to do fine features. You also gain the benefit of not leaving solder mask in the hole or on the pad because inkjet solder mask will never leave residue on pads or in the plated through-holes. This new solder mask application method truly becomes an additive process.

Process Optimization

In becoming an additive process, solder mask can now remove multiple steps in the current process. No more waste development solution that must be deposed of and no more artwork generations waste disposition. Tack drying and the associated solvent that is dissipated into the environment is gone. Thus, inkjet solder mask not only saves you money in processing cost, but you are making the environment greener. When would you have ever thought you would have heard that statement before—a PCB process that is environmentally friendly? Although the cost savings will vary from PCB manufacturer to manufacturer due to labor cost, markets served, board technology, etc., it is obvious there is money to be saved and opportunities to be taken.

New Performance Requirements

As if 5G wasn't a harsh enough new requirement for engineers to deal with, the automotive industry is certain to keep the printed circuit manufacturing industry awake at night thanks to the continual new thermal cycling requirements. With each new vehicle model, the PCB footprint inside the vehicle increases. The electronic functionality of a vehicle increases as features—such as lane control, massage seats, cameras, and energy-recycling alternators to charge your batteries—become more and more common. Figure 2 suggests the rate at which these features will continue to grow.

Heat Management

Many of the PCBs required to introduce these new features are built with higher layer

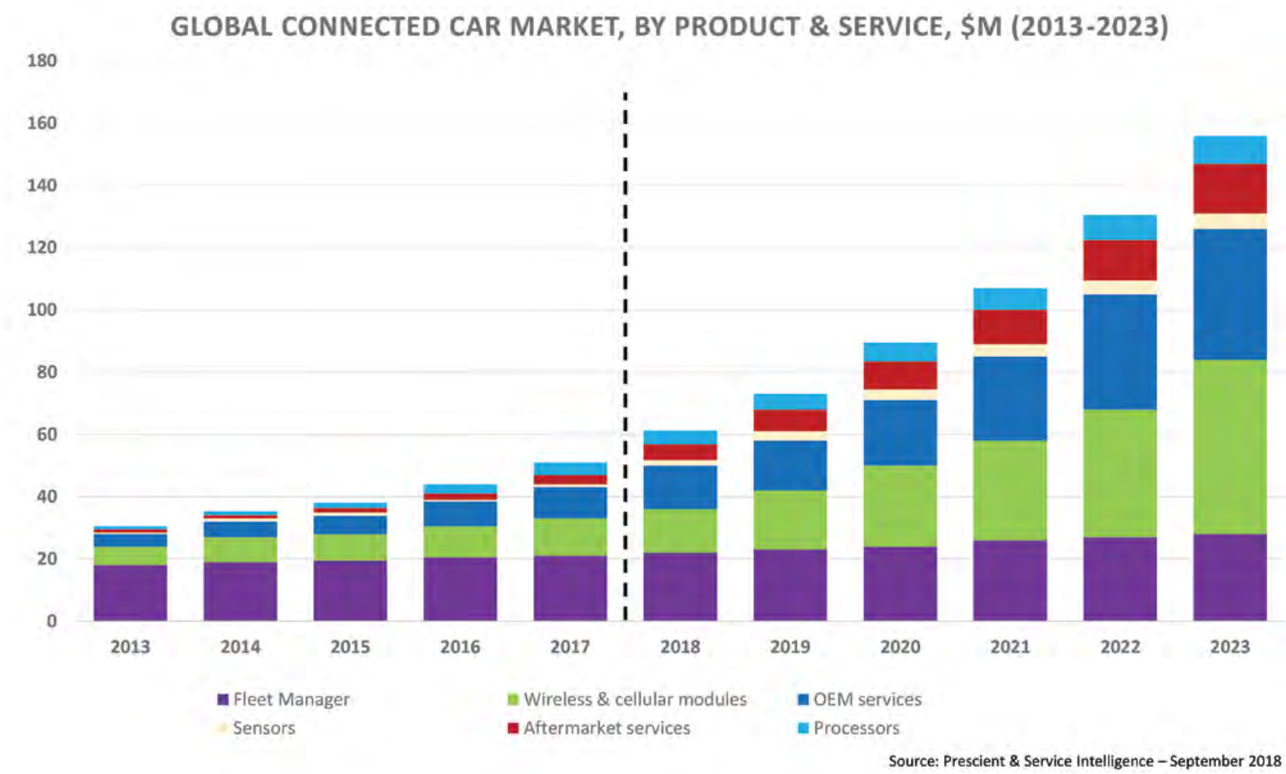


Figure 2: The global connected car market and 5G, propelling each other forward.

counts and heavier copper plating. This creates more energy, and more energy creates more heat. The added heat can lead to deformation or wear on the parts. Thermal management and overall better performance of materials are required. Therefore, thermal management has been a key area of research and development at Taiyo. As the market leader in solder mask, Taiyo has seen the trend for thermal cycling requirements increase, and we have responded with a series of solder mask products specifically for the automotive electronics industry.

To deliver better thermal management, Taiyo America has designed PSR-4000 CC01SE, showing excellent thermal properties at temperatures at or above 180°C for 2,000 hours. Currently, Taiyo is working to push this beyond the 200°C mark. Another product designed for the automotive industry is PSR-4000 CR01MW, which addresses the white LED segment's concerns about crack resistance. The CR01MW product also meets the same higher thermal cycling requirements as its counterpart, CC01SE.

Via Filling

With a growing demand for high-density interconnect (HDI), via filling is a critical new process in a PCB manufacturer's facility. Filling vias has come a long way over the past 18 years. It used to be a simple process of screen printing an epoxy material over a drilled hole to fill the vacant space. With the growing need to fill blind vias, back-drilled vias, and high aspect ratio vias, you need specialized equipment. Equipment suppliers—such as I.T.C. Intercircuit, the German equipment manufacturer—offer sophisticated equipment that creates a vacuum environment for blind vias so that they can be filled air-free. This also works for back-drill and high aspect ratio vias (Figure 3). This type of equipment is critical so that the vias can be filled with no air bubbles inside.

With the new growth of 5G networks and continuous new thermal cycle requirements from the automotive industry, the materials needed for via fill must be improved on a regular basis by suppliers like Taiyo. Taiyo has designed several via fill products that focused

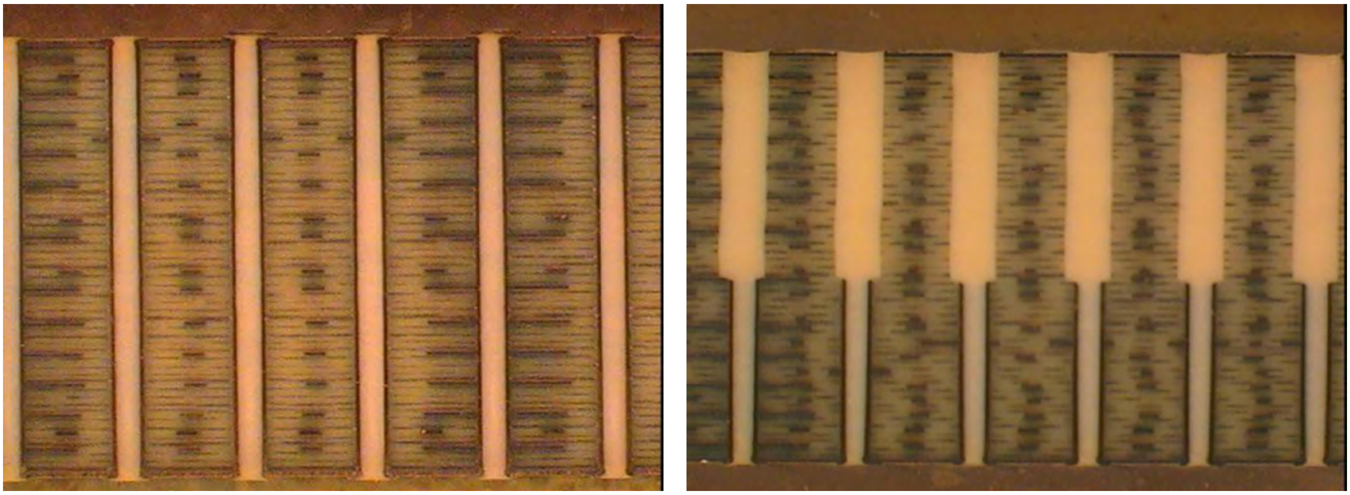


Figure 3: Over the years, via fill has developed from simple screen printing to vacuum environments.

on higher Tg and lower CTEs both working to solve these new technology challenges. Taiyo America currently offers THP-100 DX1 HTG that has the highest Tg (173°C) and the lowest CTE (19 ppm/56 ppm) available to the market today. In development, we have even better products on the verge of going to market soon. These products will offer even lower CTEs that will alleviate the back-drill cracking issue that many PCB manufacturers are dealing with today. Having a lower CTE will allow the via fill material not to expand or shrink as much during the various harsh temperature conditions, thus reducing the tendency for cracking in the back-drilled via. Improving the reliability of the via fills is one of Taiyo's main goals in designing new products for the HDI market.

Taiyo has also worked for several years to develop improved thermally conductive materials. Our product portfolio in the past has featured 2–3 W/m·K of thermal conductivity, but the market needs even more conductivity. As a result, Taiyo will be delivering a product later this year which demonstrates more than 10 W/m·K. Taiyo thinks that a heat-spreading product with this capability can greatly enhance the longevity of the PCB's life and reliability—especially in our emerging 5G, IoT, and automotive markets. It is well known that heat is the enemy of electronics and semiconductors. If we can design products that can reduce/eliminate or move heat away, we can extend the life of these devices that we so love in our everyday lives.

Looking Elsewhere for Inspiration

To keep up with all these changes in mobile communication, networking, and automotive, Taiyo also invested in multiple areas of R&D to cover the diversity we see today. Taiyo America is very fortunate to have four other sister companies that also do R&D to support the electronics industry. As a supplier of materials, Taiyo is looking into all types of technologies to accommodate new growth areas. We must provide products that meet today's technological needs while also continuing to develop new products that will be there for the next generation of great gadgets.

As we look back at the past 18 years, there's no doubt we enjoyed a world of new toys and gadgets that grow by the day. With this growth comes many changes that tend to drive our industry. We must develop a new product to hold up to new thermal cycle requirements so that we can enjoy more functionality for a more pleasurable and safer drive.

New technology forces us to look at new material changes so that we can implement 5G, such as new photo initiators for LDI and DI products or new fillers and resins to lower the CTE and increase the Tg for via fill products. These material changes in our products allow these new technologies to expand as the real estate of the PCBs become smaller and tighter and exposed to harsher environments.

However, a lot of these new technologies like LDI/DI and inkjet will require PCB manufacturers to invest in new equipment to run these new products. Also, to take full advantage of the advancements made in our new via fill products, equipment purchases for vacuum-assisted via filling are required to maximize the highest of quality HDI products. But some new materials, such as head spreading technology, do not necessarily require new equipment and offer other advantages, including longer reliability of devices. In the end, these higher-quality PCBs can be made with technology that can be an additive process, such as inkjet solder mask. This will offer many cost-saving opportunities and promote a greener environment. **SMT007**

John Fix is manager and director, marketing and sales, for Taiyo America Inc.

Window Film Could Even Out the Indoor Temperature Using Solar Energy

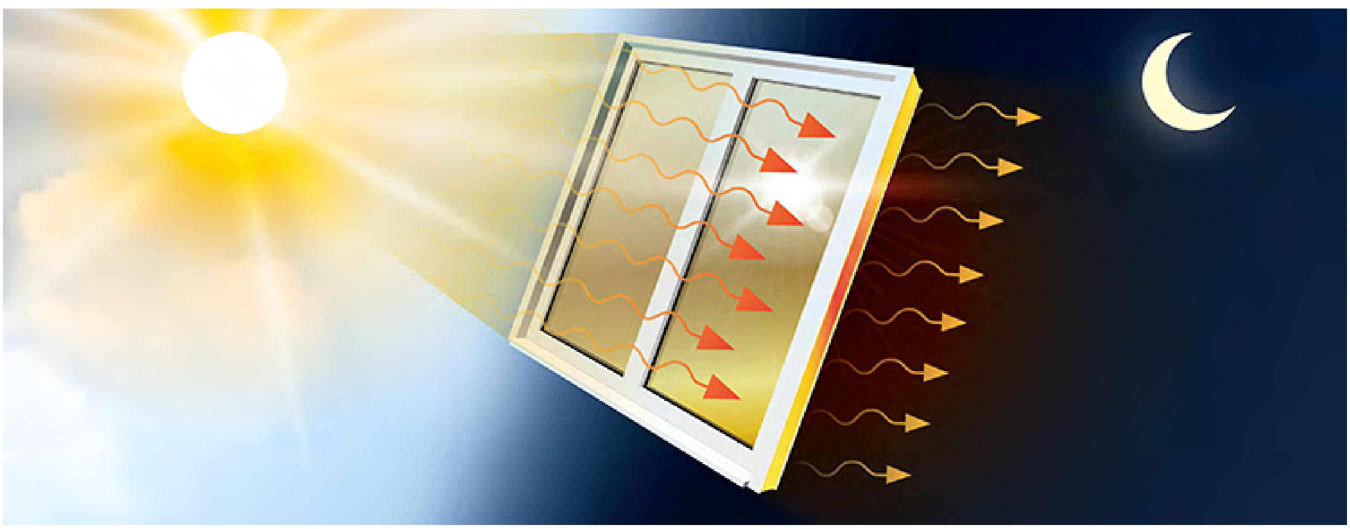
Researchers at Chalmers University of Technology are proposing a method that utilizes heat and distributes it evenly over a longer period instead. When their specially designed molecule is struck by the sun's rays, it captures photons and simultaneously changes form; it is isomerized. When the sun stops shining on the window film, the molecules release heat for up to eight hours after the sun has set.

At dawn, when the film has not absorbed any solar energy, it is yellow or orange. When the molecule captures solar energy and is isomerized, it loses its color and becomes entirely transparent. As long as the sun is shining on the film, it captures energy, which means that not as much heat penetrates through the film and into the room. At dusk, when there is less sunlight, the heat starts to be released from the film, it gradually returns to its yellow shade, and it is ready to capture sunlight again the following day.

The molecule is part of a concept the research team calls molecular solar thermal storage (MOST). Previously, the team presented an energy system for houses based on the same molecule. In that case—after the solar energy had been captured by the molecule—it could be stored for an extended period, such as from summer to winter, and then used to heat an entire house. The researchers realized that they could shorten the step to the application by optimizing the molecule for a window film as well, which would also create better conditions for the slightly more complex energy system for houses.

The researchers still have to increase the concentration of the molecule in the film while also retaining the film's properties and bring down the price.

(Source: Chalmers University of Technology)



Supplier Highlights

Standard of Excellence: Choosing the Right Replacement Vendor ▶

What happens when you have all of the suppliers you need, but a larger firm acquires one of them all of a sudden, and there is only one qualified supplier left when there used to be two. As a smart PCB user, you always want to keep your options open in case you are going to have to qualify another supplier to buy your PCBs from.

Altus' Axis: Why Are Data Analytics so Important to R&D Within Inspection Businesses? ▶

Any sales professional operating in the inspection space will tell you that the market is flooded with competition when it comes to SPI and AOI machines. Although I have no doubt their preferred solution will be the market leader, unless you are knowledgeable about the differences in provider and the array of technologies available today, you can soon fall into a trap of not selecting the correct platform for your application.

The Mannifest: First Time With In-house SMT Assembly? Start With a Great Design ▶

One of the best ways to eliminate possible production issues when you handle your SMT work in-house is to ensure that you have a manufacturable design. Thus, there are several factors to keep in mind when reviewing your designs before bringing your production in-house or starting your first run of in-house prototypes.

Goepel electronic Solutions, Webinar Series, and Trends ▶

Barry Matties catches up with Matthias Müller to chat about the wide range of test and inspection solutions currently being offered by Goepel electronic as well as the informative webinar series produced by the company to help further educate their customer base and promote technical discussion on a number of topics.

3D Optical Inspection Provides 'Eyes' for Process Improvements in Industry 4.0 ▶

Automated 3D solder paste inspection (SPI) and 3D automated optical inspection (AOI) systems have become an integral part of the printed circuit board assembly (PCBA) process because they help ensure high-quality production. As today's board complexity is increasing, inspection technology becomes even more critical.

KYZEN's Chelsea Jewell Recognized by Products Finishing 40-Under-40 ▶

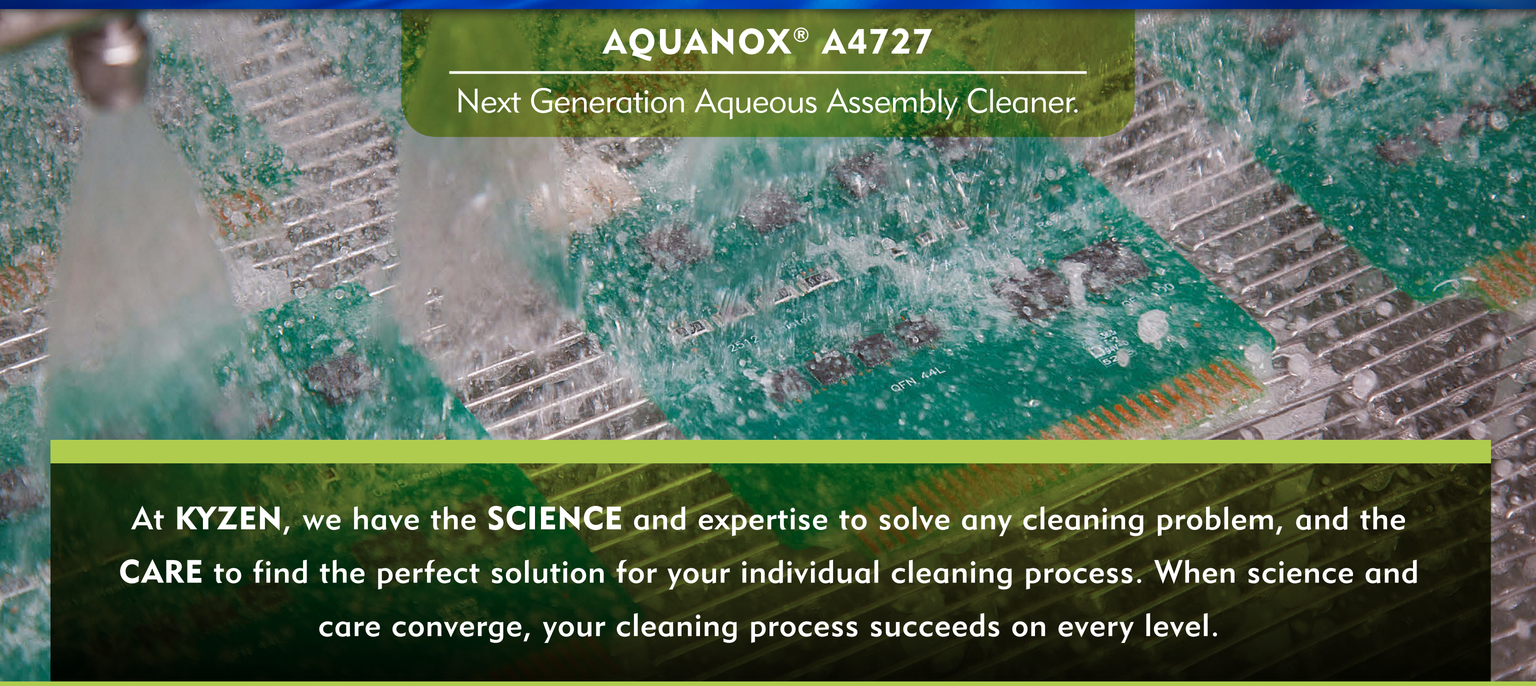
KYZEN, the global leader in innovative environmentally friendly cleaning chemistries, is pleased to announce that Chelsea Jewell, application lab manager, has been selected to the Products Finishing 40-Under-40 class for 2019. Jewell was recognized at the NASF Sur/Fin Show on June 4, 2019, in Chicago.

Naprotek Purchases a Nordson SELECT Selective Soldering System ▶

Naprotek Inc. has purchased the Nordson SELECT Cerno 103IL selective soldering system. The robust system provides the company with an exceptional combination of versatility and productivity.

Low-temperature SMT Solder Evaluation ▶

Until recently, the use of Sn/Bi-based SMT solder materials has been investigated with negative consequences for high strain rate (drop-shock) applications; thus, these alloys have been avoided. Recent advances in alloy doping have opened the door to revisit Sn/Bi alloys as a possible alternative to SAC-305 for many applications.



Custom Reflow Ovens and Curing

The Mannifest

Feature Column by Chris Ellis, MANNCORP INC.

It seems that a lot of companies in today's market are buying specialized ovens for curing. Did you know that most SMT reflow ovens can be modified by the manufacturer (and quite easily too) for curing applications? In most cases, these ovens will also still work for SMT reflow, eliminating the need to waste precious floor space on a second oven.

Typically, when converting a reflow oven for curing, manufacturers simply replace gearing. This allows the oven's belt to run slowly enough for the long profile required in most curing applications. Some oven manufacturers do not even charge, or have minimal charges, for these types of changes.

Granted, you will still need a separate oven for curing if your SMT line is at maximum capacity. Depending on volumes, you can go with a smaller, more compact oven to save floor space. For example, some freestanding four-zone ovens are only about 80 inches in length. With custom gearing, they can have belt speeds that allow a product to be in the oven for anywhere from 7 to 30 minutes or even longer.

Now, imagine if you have a very high volume line for curing. Here, you could go with a two-in-one solution like a 10-zone reflow oven that is about 220 inches in length. This gives you the flexibility to run a longer profile in the close-to-90-minute range when required, and you would still have a 30-minute tunnel time available and get three times the volume of the four-zone oven.

There are also conformal coating applications that can be used in standard ovens. The only caveat is you need to use a heat-cured conformal coat rather than UV-cured. Changing to a heat-cured conformal coat eliminates the need for expensive UV ovens, which do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not handle any applications other than conformal coat curing. Again, this allows you to maximize your investment in a single piece of equipment while reducing capital expenditures. A lot of people still buy ovens as separate, standalone units for heat-cured conformal coatings due to the "messiness" of conformal coating. In a lot of these cases, I have seen the mesh belts totally eliminated since almost all conformal coating applications require just the edge rail, which supports the product by its edges to ensure an even coating and curing.

Other options for custom ovens can be for photo optics, component manufacturers, etc. Typically, for some of these applications, it is as simple as removing edge rails for double-sided SMT and changing the belts to a finer diamond mesh belt versus the standard mesh belt. Clearance heights can also be changed to accommodate taller items. I have seen applications where a tunnel opening greater than 5 inches is required. In the case of most manufacturers, the oven can easily be modified for items like this.

Most ovens come with or can implement a SMEMA interface, which is a standard form of communication between machines that sends "board available" and "machine ready" signals back and forth, so the machine knows when to release another board to the reflow oven. This also ensures the line will stop in the case of any down situations.

As you can see, standard SMT reflow ovens can be adjusted to accommodate a number of multifunction situation, at a much lower price and within a smaller footprint than an expensive specialty oven. **SMT007**

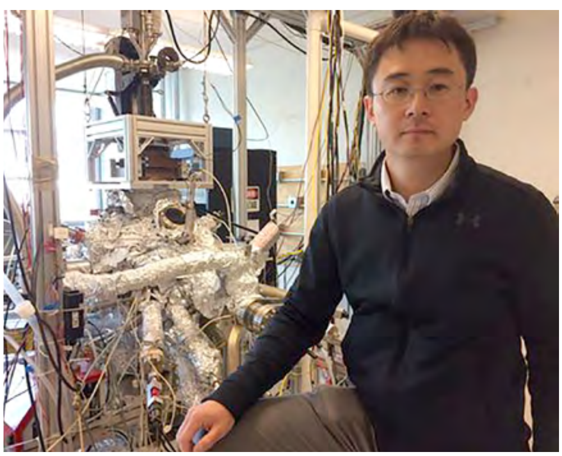
Chris Ellis is a sales manager/ engineer for Manncorp Inc. To read past columns or contact Ellis, click here.

New Material Shows High Potential for Quantum Computing

A joint team of scientists at the University of California, Riverside (UCR) and the Massachusetts Institute of Technology (MIT) is getting closer to confirming the existence of an exotic quantum particles called Majorana fermion, one of the most sought-after objects in quantum physics because they are their own antiparticles.

Majorana fermion can split the quantum state of an electron in half and follow different statistics compared to electrons. Though many have claimed to have identified them, scientists still cannot confirm their exotic quantum nature.

The UCR-MIT team overcame the challenge by developing a new heterostructure material system based on gold that could be potentially used to demonstrate the existence and quantum nature of Majorana fermions.



The Majorana fermion, considered to be half of an electron, is predicted to be found at the ends of a topological superconductor nanowire. Interestingly, two Majorana fermions can combine with each other to make up one electron, allowing the quantum states of the electron to be stored nonlocally—an advantage for fault-tolerant quantum computing.

In 2012, MIT theorists predicted that heterostructures of gold could become a topological superconductor under strict conditions. Experiments done by the UCR-MIT team have achieved all the needed conditions for heterostructures of gold.

The research paper shows superconductivity, magnetism, and electrons' spin-orbit coupling can co-exist in gold—a difficult challenge to meet—and be manually mixed with other materials through heterostructures. The research paper also shows the electron density of superconductivity in the surface states of gold can be tuned.

(Source: UCR)


The universe is a harsh place.
Here's how you can protect critical components that operate in adverse environments.
Written by Phil Kinner of Electrolube's Conformal Coatings Division, this book simplifies the many available material types and application methods, and explains the advantages and disadvantages of each.
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Selecting the Proper Flex Coverlayer Material

Feature by Dave Lackey
AMERICAN STANDARD CIRCUITS

Introduction

What is a flex coverlayer? What's its purpose? Are they new or have they been around a while? Why do they matter to my design?

Coverlayers are polymer materials used to cover and protect the copper traces of the flex circuit product. As implied, there are a number of different options available for protecting the circuits, and they serve different design requirements in terms of cost, performance, and flexural endurance optimization. When specifying the choice, it is critical to call out not just the type of coverlayer material but also the thickness requirement. This can be very important in certain types of constructions, especially when a flex circuit will experience dynamic flexing during use.

It is also important to know and understand that there are different types of materials available for use as coverlayer materials and that there is no single, ideal solution. The appropriate material choice will be based on a number of factors, such as application, cost, projected life, etc. Coverlayer selection requires a thorough analysis that balances both cost and performance to ensure the proper choice. Key considerations include how much will the flex circuits be bent in the field (install or dynamic), can a hybrid approach be taken (solder mask in SMT locations and coverlayer everywhere else), and is the performance improvement of laser machined coverlayers worth the significant cost increase (and potentially lead-time increase). In any case, due diligence is required to make the proper coverlayer technology choice.

Machining Options for the Coverlayer

Both mechanical and laser machining are common fabricating processes used in today's printed circuit industry. Each method employs its own distinct equipment set and has its own advantages and disadvantages. Preference for coverlayers among the two typically depends on the application, volume/lead time, and cost.

Mechanical Machining

Certainly, mechanical machine is the tried-and-true historical method of fabricating coverlayers. The primary benefit of mechanical machining is that the fabricator can use their

existing equipment set used for PCB drilling and fabrication. It is fast, has multiple stations (4–6), there is no learning curve, and every PCB fabricator already has the equipment. Hole quality depends on the drill tool, and there are minimum hole-size limitations to mechanically machining.

Laser Machining

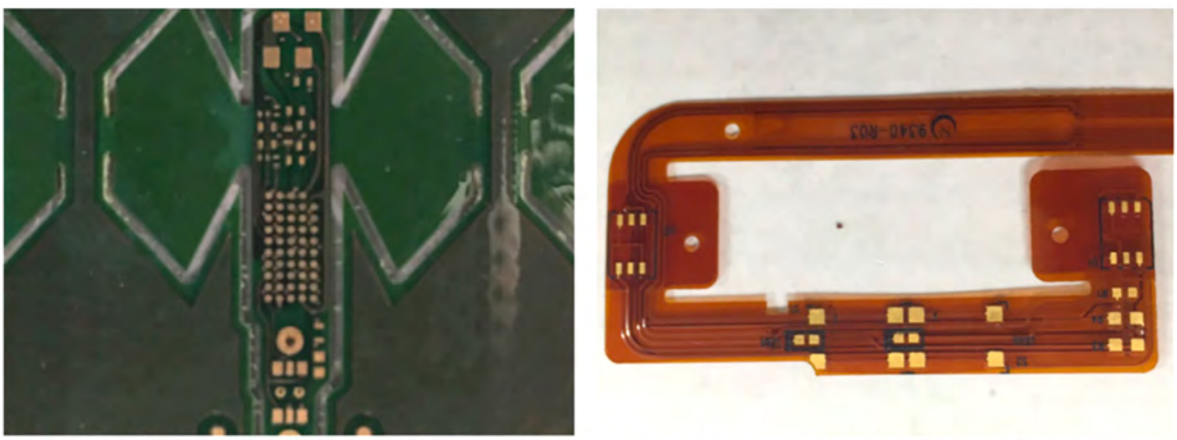
Requires a capital investment for a laser drill; however, the equipment will primarily be used for laser drilling the raw PCBs. Many PCB fabricators do not have existing laser equipment and the cost is much higher than mechanical machines. The actual lasering is faster per hole, but it is a single station. The laser produces a precise hole and has virtually no minimum hole size.

Flex Coverlayer or Flexible Solder Mask

In terms of cost, a flexible solder mask is generally the least expensive. Some one- or two-layer flex circuits that will not be subject to multiple flex cycles or extreme radius bends can be coated with an epoxy-based solder mask that is designed to flex without cracking. However, this is not recommended when the design requires any dynamic or extreme flexing. The other option is a laminated flex coverlayer. These are typically materials that have a makeup that is identical to the flex core material and are best suited for dynamic flexible circuit applications.

The flex coverlayer material is a polyimide sheet with acrylic adhesive on one side. It is usually pre-machined to create openings in the sheet where the final finish is required. The coverlayer sheets are typically applied in a lamination press using special pads to ensure conformity around the copper features on the flex layer. For rigid-flex circuits, the coverlayer is generally cut to only protrude into the rigid portion by no more than 50 mils. The purpose of this is to allow all the plated holes in the rigid-flex to be void of any acrylic adhesive, as it can affect the hole wall plating integrity. Figure 1 shows an example of flexible solder mask and coverlayer being used in flex circuits.

It is worthwhile to note here that the bond ply used to laminate flex layers together is like a coverlayer, but it has adhesive on two sides. It is further worth noting that prepregs (glass cloth, which has been pre-impregnated with a thermosetting resin) used for making rigid circuits are used in the construction of rigid-flex circuits where they serve in the role of bond ply. It is also important to note that coverlayer material can come in typical thickness intervals from 0.5–5 mils (12–125 µm) of polyimide and 0.5–3 mils (12–75 µm) of adhesive. Based on the design and application, the adhesive thickness requirement is typically decided by the copper thickness to which it is being bonded. The higher copper weight, the more adhesive is needed. There are various thicknesses of coverlayer coatings, and a general rule of thumb



Solder mask on flex circuit

Coverlayer on flex circuit

Figure 1: Flexible solder mask and coverlayer used in flex circuits.

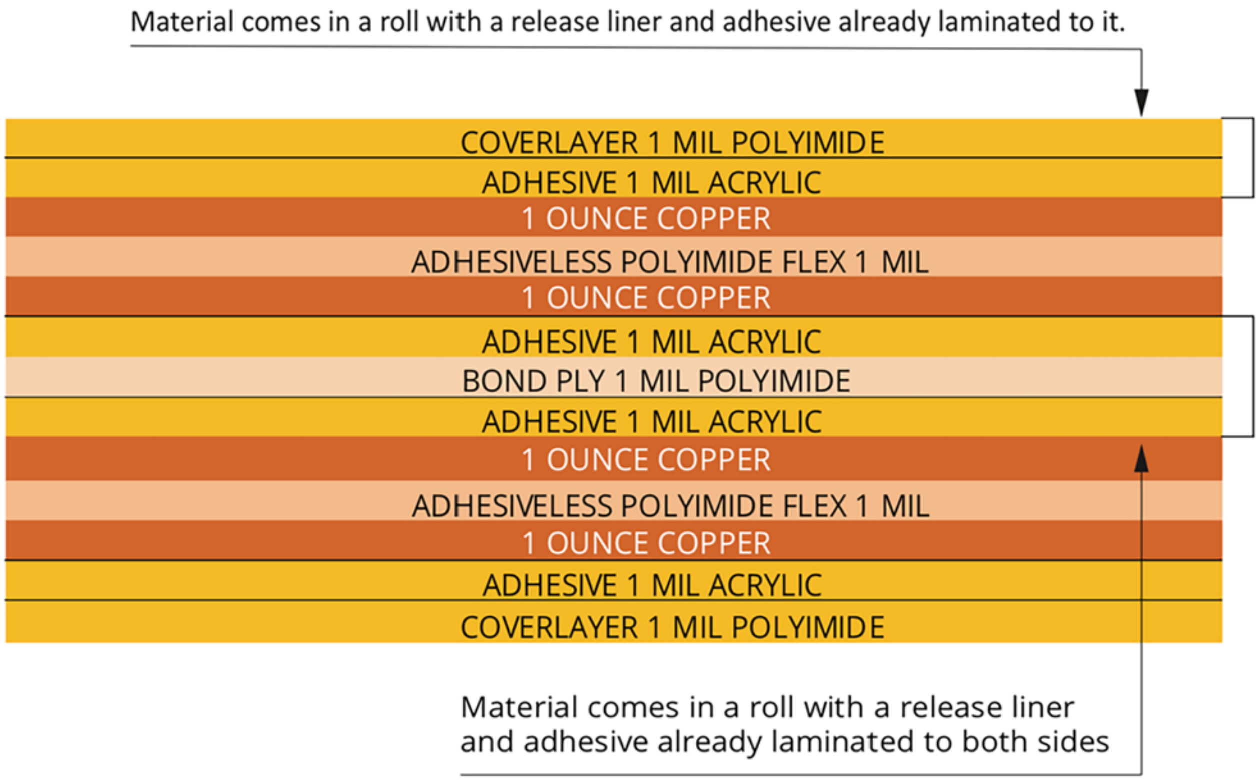


Figure 2: Four-layer flex circuit with coverlayer and bond ply.

is one mil of adhesive (coverlayer) for every ounce of surface copper it is covering. The same holds true for bond ply. Figure 2 illustrates a four-layer flex circuit and demonstrates the use of coverlayer and bond ply.

Matching the Coverlayer to the Application

Coverlayer and cover coat are terms normally reserved for flexible circuit constructions, and by default, they are a defining structural element of both flex and rigid-flex circuits (Figure 3). Coverlayers serve as a flexible coating of sorts that protect the delicate surface traces from physical damage and potential wicking of solder along circuit traces. The coverlayer offers protection while leaving open access to design features where interconnections are to be made to components by soldering. It is important to determine the thickness of a coverlayer as a balance needs to be made between allowing for maximum flexibility while also ensuring a sufficient amount of adhesive on it to accommodate the copper weight (the more adhesive, the less flexible).

This is where it is critical to understand the application and working environment the flex board will be subject to in the field. The coverlayer choice will depend on how the flex circuits are utilized; will the circuit be bent just one-time during installation, intermittently, or dynamically millions or even billions of times over its useful life? In the latter case, the dimensions and make of the flexible circuit coverlayer are critical. In dynamic flex circuits,

Figure 3: Flex circuit coverlayer.

there is a need to balance the amount of flexible materials on the sides of the conductors where flexing is to occur.

As in many PCB decisions that need to be made, the optimum solution may be a hybrid or blend of multiple materials. These material choices include materials that are laminated to the copper circuits using heat and pressure; materials that can be laminated and then photoimaged, like solder mask, to define points of connection; and materials that are simply screen printed on to seal traces while leaving open features of interest for further processing or for making interconnections.

Conclusion: Due Diligence

The best advice I can offer is to talk with your PCB supplier to discuss the proper coverlayer to use for your specific application. When preparing for this discussion, the following questions will help arrive at the proper coverlayer choice:

- What is the final product application?
- What are the bend requirements (how many, how often)?
- Are there any cost constraints?
- Are there any lead-time constraints?
- How many holes need to be machined per board?
- What is the smallest size needed in the coverlayer?
- Does the fabricator have laser machining capability?
- What is the copper weight on the surface layers?

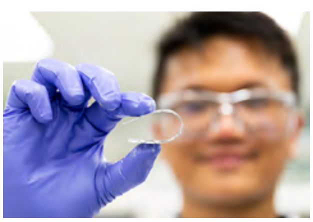
This early engagement will eliminate costly mistakes and position your design for the best possible result the first time. **SMT007**

Dave Lackey is VP of business development at American Standard Circuits. Lackey is also a co-author of The Printed Circuit Designer's Guide to... Flex and Rigid-Flex Fundamentals. Visit I-007eBooks.com to download your free copies of American Standard's books, including The Printed Circuit Designer's Guide to... Fundamentals of RF/Microwave PCBs, as well as other educational titles.

Energy-harvesting Nanomaterials Created Using Low-temp Process

Some of the vast amount of wasted energy that machines and devices emit as heat could be recaptured using an inexpensive nanomaterial developed at King Abdullah University of Science and Technology (KAUST), and turned back into useful electricity.

Waste heat emitted by machines and devices could be recaptured by thermoelectric materials. Until now, though, thermoelectric materials have been made using expensive and energy-intensive processes. Researchers from KAUST have developed a new thermoelectric material made by spin-coating a liquid solution of quantum dots. The team spin-coated a thin layer of lead-sulfide quantum dots on a surface and then added a solution of short linker ligands that crosslink the quantum dots together to enhance the material's electronic properties.



After repeating the spin-coating process layer by layer to form a 200-nanometer film, gentle thermal annealing dried the film and completed fabrication. The quantum-dot-based thermoelectric material is only heated up to 175°C. This lower processing temperature could cut production costs and means that thermoelectric devices could be formed on a broad range of surfaces, including cheap, flexible plastics.

The team's material showed promising thermoelectric properties. One important parameter of a good thermoelectric is the Seebeck coefficient. The team was able to show that an effect called the quantum confinement, which alters a material's electronic properties when it is shrunk to the nanoscale and was important for enhancing the Seebeck coefficient. The discovery is a step toward practical high-performance, low-temperature, solution-processed thermoelectric generators.

(Source: KAUST)

MilAero007 Highlights

U.S. House Approves Measure to Promote Lead-Free R&D in Milaero, Automotive, Medical ▶

IPC is applauding the U.S. House of Representatives for approving a measure that would promote research and development into the performance of lead-free electronics in high-reliability sectors, such as aerospace, defense, automotive, and medical equipment.

NASA Invests $45M in U.S. Small Businesses for Space Tech Development ▶

These selections have an estimated value of more than $45 million and are part of NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

SAMI Buys Riyadh-based Advanced Electronics Company (AEC) ▶

The agreement signing took place at a Saudi Arabia–U.K. industry event in London in the presence of senior shareholder representatives, including His Excellency Ahmed Al-Khateeb, chairman of SAMI, and Sir Roger Carr, chairman of BAE Systems.

BAE Systems Calls for Nationwide Effort to Develop Skills for Industry 4.0 ▶

BAE Systems has called for a concentrated effort by the industry, government, and education sectors to ensure that the U.K. can fully benefit from the digital revolution and Industry 4.0.

Of Art and Satellites ▶

A quotation from The Golden Record 2.0—a play written for the NUS Arts Festival—and a high-tech quantum device from the NUS Centre for Quantum Technologies (CQT) is now orbiting in space together.

NASA's Dragonfly Will Fly Around Titan Looking for Origins, Signs of Life ▶

NASA has announced that our next destination in the solar system is the unique, richly organic world Titan. Advancing our search for the building blocks of life, the Dragonfly mission will fly multiple sorties to sample and examine sites around Saturn's icy moon.

Collins Aerospace's David Adams Earns Dieter Bergman IPC Fellowship Award ▶

In recognition of his ongoing leadership in developing and promoting IPC standards on a global basis, IPC—Association Connecting Electronics Industries—bestowed a Dieter Bergman IPC Fellowship Award upon David Adams, Collins Aerospace, at the recent IPC SummerCom.

NASA Invests in 3D Printing for Aviation ▶

Additive manufacturing (AM), also known as 3D printing, is a promising new technology for all areas of aviation manufacturing. Additive manufacturing's flexibility in design and customization, cost reduction, and speed in delivering finished parts make it a perfect fit for creating parts used in aviation contexts.

Raytheon, Northrop Grumman Sign Teaming Agreement on Scramjet-powered Tactical Missile Systems ▶

Building on years of collaboration, Raytheon Company and Northrop Grumman Corporation have signed a teaming agreement to develop, produce, and integrate Northrop Grumman's scramjet combustors to power Raytheon's air-breathing hypersonic weapons.

Becoming the Preferred Supplier, Phase 3: Re-engineer Your Quality System

In Search of Operational Excellence

by Alfred Macha, AMT PARTNERS

The final phase of becoming a preferred supplier is to apply a business process re-engineer approach to your quality system. Before you start with this phase, the company should have implemented Phase 1 and Phase 2, which are focused on changing its leadership mentality to embrace LEAN Six Sigma and the pillars of operational excellence. It's paramount to have the right mindset before you re-engineer your quality system.

Most organizations build their quality systems for compliance to ISO 9001 or industry-specific standards, such as AS9100, ISO 13485, TL 9000, or TS 16949. It's important to maintain these certifications to reassure existing and new customers that the manufacturing facility has implemented quality systems compliant to a recognized quality management standard. However, a mistake that is often made is to develop procedures and a structure solely focused on passing registration and surveillance audits to maintain these certifications.

The business objective when implementing a quality management system is to develop

closed-loop systems and practical procedures that enable employees to manufacture and consistently deliver quality products on time to customers. The quality management system certifications should not be your end goal; customer excellence should be the goal of an effective quality system.

ISO provides valuable guidelines on implementing quality management systems to the various standards. One document that every manufacturing leadership team should read is "Quality Management Principles" from the International Organization for Standardization (ISO) [1]. This document delivers practical information in establishing the fundamentals of a quality management system, including:

- Customer focus
- Leadership
- Engagement of people
- Process approach
- Improvement
- Evidence-based decision making
- Relationship management

These principles provide the basis of how an effective quality management system should be developed. The guidelines in the next paragraphs provide supplementary guidelines to these quality management principles. These are five practical and proven approaches that can help you re-engineer your quality management system for customer excellence.

1. Lowest Common Denominator: Less Is More

I once audited a printed circuit board assembly factory and asked for their document listing. The listing was impressive and had over 500 procedures that had been created over 15 years. These procedures had comprehensive instructions and technical information that gave the impression of assurance. However, as I asked operators and technicians in the production line to explain their process steps and point out the steps of the procedure, it was quickly apparent that they knew their processes well but were not familiar with the respective procedures. The process engineer knew where to find the information in the procedure, but the end user—the operator—was not so sure. To address this common issue, some companies have created work instructions as the least common denominator of information that every production line personnel should master. These companies have also created technical documents that support these work instructions for trouble-shooting and problem-solving purposes where engineering is involved.

As you evaluate your current quality systems, put yourself in the shoes of the end user, and create simple-to-read, value-added instructions. Also, your supporting technical documents should not be lengthy. Keep the most essential and useful information available to support your operations.

2. Redefine Your Training Philosophy

Is your training program built to satisfy the ISO auditor? Or is it built to elevate your company's performance into a world-class organization? Training can be a controversial topic in organizations. Defining the return on investment on hours trained can not always be quantified in accounting. How many hours can you let employees off the production line to invest in training? Is your training program ISO-compliant? Does the current training material provide value to your operations? Those are questions that are discussed in every organization.

Here is an approach that companies should consider taking. Don't make training a burden to operations; instead, make it part of the operations process. Training can be incorporated as part of your day-to-day operations and a deliverable for every employee during the day. Design a training system where your production supervisors, process engineers, or area trainers can allocate a small percentage of the time each day to carry out on-the-job training. The key component here is to make it simple so that you cover a small element of knowledge each day—possibly 5 to 10 minutes with each operator. During the year, you will have covered at least 1,200 minutes of one-on-one training per operator, which equates to 20 hours of essential, practical on-the-job training. The goal should be to bring the competence and knowledge level of each employee to a higher level on a daily basis.

3. Eliminate Bureaucracy

How many signatures are required to approve a procedure or process plan? How long has a corrective action been open for because you are waiting for a final signature? Is your quality system built on LEAN principles or hierarchical structure for it to function?

Do not confuse a comprehensive review of a document requiring every manager to sign a document before it's released. You need to clearly identify roles and responsibilities to review and approve documents in your quality system. There should also be a process to communicate and give the opportunity to others for informal reviews before a document is released. Here is an approach that works well in LEAN organizations:

1. Designated approvers of a controlled document should consist of your subject-matter expert, quality systems oversight, and a senior manager accountable for that process
2. Provide a 72-hour grace period where a pre-approved document is available for review by other subject-matter experts and managers in the organization. This gives the opportunity for anyone in the organization to identify a possible discrepancy or concern with the document. Ultimately, the accountable manager for that process determines what input(s) will be considered in the document
3. Once the grace period has passed without any further revisions, the document is released in the system as an approved document

This approach addresses the most common form of bureaucracy in an organization. There should not be situations where improvements are not taken because a document is paralyzed in a review and approval cycle.

4. Walk in Your Customer's Shoes

One of the defining elements of a quality system is the effectiveness of its corrective action and preventive action (CAPA) system. Customers understand that every supplier will experience product failures or shortcomings during the production and order fulfillment process. When a failure occurs, the customer will initiate a corrective action request to the supplier and this is where the supplier can shine or disappoint in the customer's eyes. Customers expect that a supplier will do diligent root-cause analysis and provide a technical approach in preparing a corrective action response. The customer will place faith that the supplier has taken the necessary steps to prevent the problem from reoccurring.

The moment of truth will occur in two stages. The first stage will during the initial review of the corrective action response. Three factors are evaluated:

1. Did the supplier respond on time to this corrective action?
2. Did the supplier provide a comprehensive root cause analysis, containment, and corrective action plan that addresses the issue? The quality of the response should be remarkable
3. Has the supplier outlined how will the actions be verified for effectiveness? This is one of the differentiators between average supplier and outstanding suppliers

The second stage will occur during the implementation of the corrective action plan and monitoring phase. This is where the supplier should proactively monitor and provide objective data to the customer demonstrating that the problem has been addressed and subsequent production runs don't show the failures. The customer will gain a higher level of respect and confidence with a supplier that has applied due diligence in preparing a response, implementing action plans, and providing objective evidence to prove the problem has been addressed.

When you re-engineer the CAPA system, put yourself in your customer's shoes and make sure that your CAPA system is best-in-class.

5. Leave a Lasting Impression

Customers have several options in selecting suppliers to fulfill their needs. Becoming a preferred supplier takes a concerted effort to be unique. The minimum expectation is for the supplier to deliver products with good quality and on-time. The differentiator will be the overall customer experience a customer has with a supplier. When you re-engineer your quality system, make sure that all processes that have customer-facing interactions have been designed to provide your customer with a positive, lasting impression. Make your organization stand out amongst your competitors with these two principles:

1. Constant communication with your customer
2. Proactively provide data, plans or technical reports before your customer asks for this; be one step ahead of your customer and two steps ahead of your competitors **SMT007**

References

1. "Quality Management Principles," The International Organization for Standardization, Edition 2, 2015.

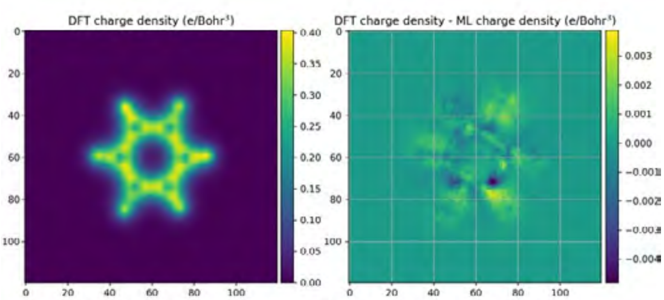
Alfred Macha is the president of AMT Partners. He can be reached at Alfred@amt-partners.com. To read past columns or contact Macha, click here.

Machine Learning Helps Create More Capable Capacitors

Researchers at Georgia Institute of Technology are using supercomputers and machine-learning techniques to find ways to build more capable capacitors.

The researchers focused on finding a way to more quickly analyze the electronic structure at the atomic level of two capacitor materials—aluminum and polyethylene—looking for features that could affect performance.

The researchers used the Comet supercomputer at the San Diego Supercomputer Center, an Organized Research Unit of the University of California San Diego, for early calculations, and the Stampede2 supercomputer at the Texas Advanced Computing Center at the University of Texas at Austin for the later stages of this research. Both systems are funded by the National Science Foundation under multi-year awards.



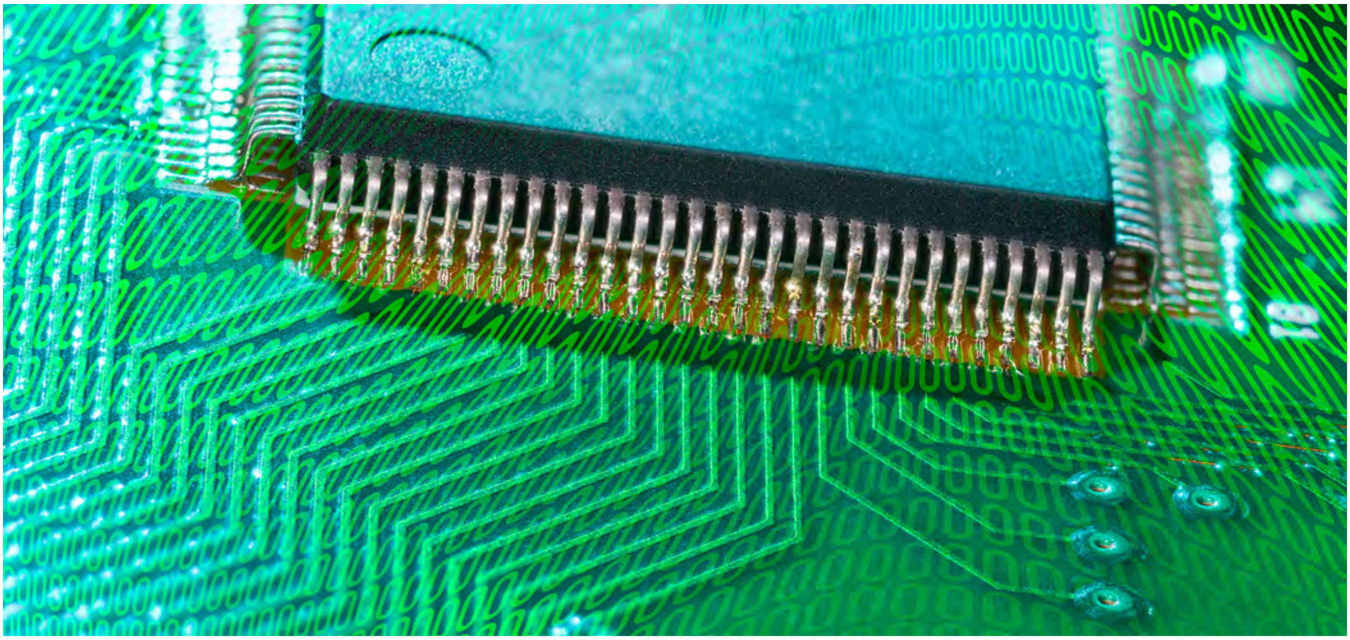
Using the new machine-learning method, the researchers produced similar results several orders of magnitude faster than using the conventional technique based on quantum mechanics.

While the study focused on aluminum and polyethylene, machine learning could be used to analyze the electronic structure of a wider range of materials. Beyond analyzing electronic structure, other aspects of material structure now analyzed by quantum mechanics could also be hastened by the machine-learning approach.

The faster processing allowed by the machine-learning method would also enable researchers to more quickly simulate how modifications to a material will impact its electronic structure, potentially revealing new ways to improve its efficiency.

The method was described in *Nature Partner Journal's Computational Materials.*

(Source: Georgia Tech)



Automated Conformal Coating of CCAs Using Polyurethane

Feature by Marissa Pati and Ana "Lety" Campuzano-Contreras
BAE SYSTEMS, AUSTIN, TEXAS

Abstract

The development of an automated circuit card assembly (CCA) conformal coating process using a low-outgassing polyurethane material was essential for meeting the increase in customer demand from 3,000 to 60,000 units per year. Low-outgassing polyurethane conformal coating is used for protection against humidity and tin whisker mitigation. When increasing production throughput requirements, it is necessary to eliminate variation and increase production capacity by automating processes. Manual processes in manufacturing can lead to defects, increased variability, and additional manufacturing time. To begin the process improvement of automating spraying a low-outgassing polyurethane conformal coating, several machine and material parameters were considered during the evaluation. A selective conformal coating machine was chosen and the following parameters were determined to be critical to the process: thinner-to-material ratio, atomizing air pressure, material syringe pressure, nozzle distance from the substrate, nozzle speed, material flow rate, number of coats, and curing requirements. These parameters were verified by performing an adhesion by tape test per ASTM D3359-17 (Standard Test Methods for Rating Adhesion by Tape Test) in addition to verifying conformal coat thickness and defects per J-STD-001 (Joint Industry Standard Requirements for Soldered Electrical and Electronic Assemblies) requirements. Implementing a selective polyurethane conformal coating spraying process has increased capacity capabilities and eliminated variations induced from the manual process.

Background

In the manufacturing of Class 3 circuit card assemblies, conformal coating can be critical to the lifespan of the circuit card. For circuit cards to withstand environmental factors

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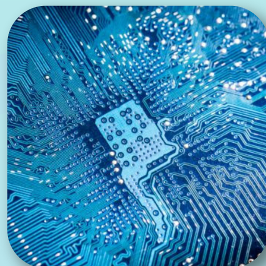

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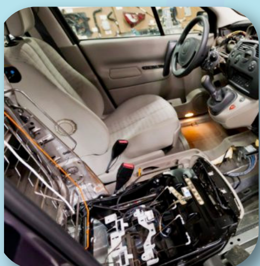

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in the field they must be properly protected, which typically requires the use of conformal coating. Polyurethane conformal coating is commonly used throughout the industry, but typically, it is used in lower volume production. Tin whisker mitigation is one of the most common reasons to use a low-outgassing polyurethane material.

Adapting to increases in production can be difficult. An increase in customer demand from 3,000 to 60,000 units per year can create many challenges in a manufacturing environment. Currently, a low-outgassing polyurethane material is applied to the circuit card assemblies via manually spraying using an atomizing handheld air gun. With any manual process, there is significant variation in the outcome due to many variables involved; therefore, the process is difficult to control. This variation may be acceptable in low volume production, but for mass production, this method is unsustainable and unreliable. Automating the process is the best way to achieve zero defects, eliminate variation, and accommodate the strict production schedule.

To develop an automated-spraying process for this polyurethane material, there were many factors that had to be taken into consideration and many variables that required process controls (Figure 1). There are J-STD-001 requirements that must be met; polyurethane conformal coating must be 0.03–0.13 mm (0.001–0.005 in.) [1]. No defects per IPC-A-610 (Acceptability of Electronic Assemblies) are acceptable. There is also the need to meet the customer and drawing requirements. Additionally, strict material requirements, such as pot life and cure time, needed to be considered. All of these factors played a major role in automating the manual hand-spray process, and it was necessary to understand all of the material requirements and restrictions, customer requirements, and IPC requirements before beginning the evaluation of equipment and development of the process.

The entire conformal coating process was evaluated during this experiment, which includes more than just the spraying of polyurethane material onto the circuit cards. The first step of the process is the preparation of

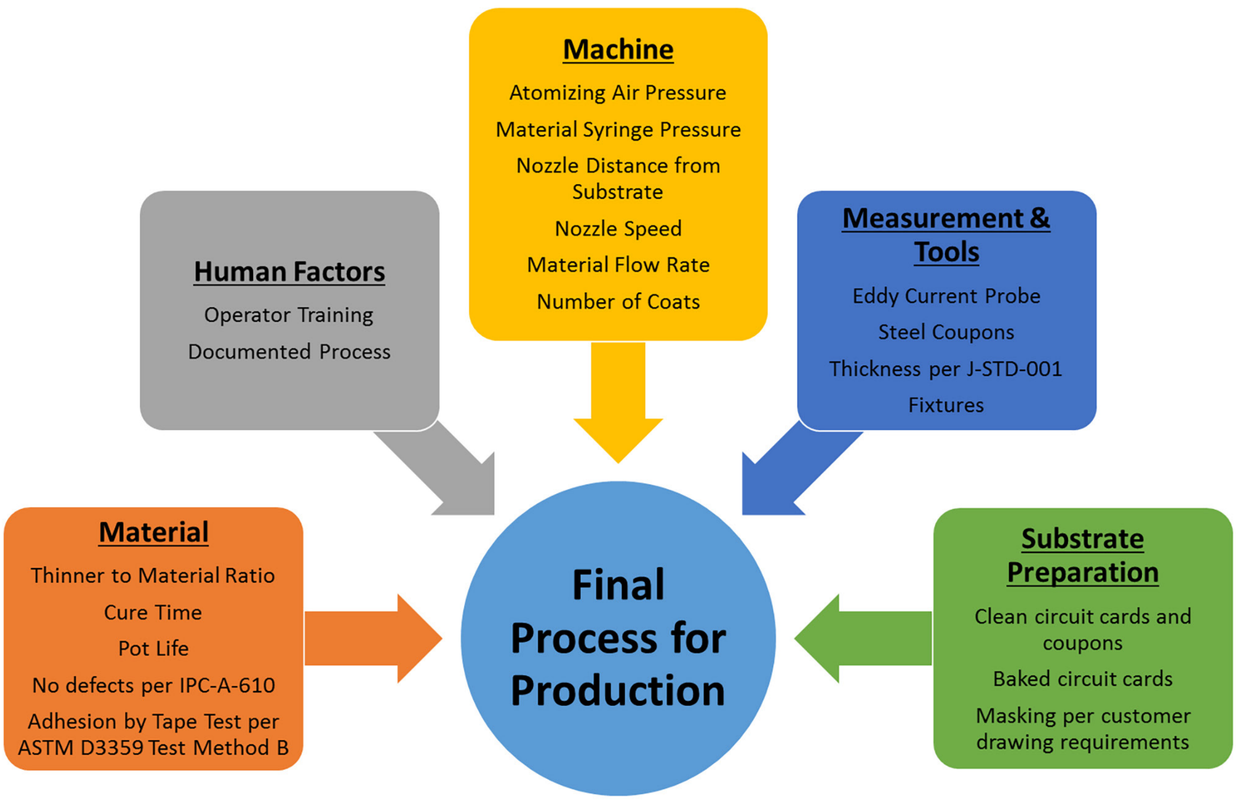


Figure 1: Important considerations for the final process.

circuit card assemblies, which includes cleaning, baking, and masking any areas that are required to be free of conformal coating per the customer drawing requirements. The coating process also includes preparation of the material used for spraying; this may be a mixture of two or more parts that must be weighed and mixed properly. The next step is the spraying and curing of the material onto the circuit cards and coupons for thickness measurements. The final steps of the conformal coating process are the removal of the masking materials and touchup of the coating. Preparation of the substrates, correct mixture of the material, proper curing, and accurate thickness measurements are important variables that could affect the output of the conformal coat spraying process. Therefore, it was necessary to ensure proper controls had been established for all of these aspects of the conformal coating process.

Materials and Tools

Preparation of materials and circuit card assemblies was a key factor to being successful in the transition from hand spraying to automated spraying of circuit card assemblies. Ensuring coupon substrates and CCAs were properly cleaned and baked before the coating was necessary for proper application of the coating material. If any IPC-A-610 defects were observed, it was important to know that the samples were properly prepared to eliminate cleanliness or moisture as a root cause for the defects.

It was crucial to understand the requirements and properties of the two-component, low-outgassing polyurethane material before beginning to research equipment to automate the spray coat process. For this experiment, the datasheet for the low-outgassing polyurethane material was the starting point to understanding the material pot life and cure times as well as the mix ratios, thinner ratios, and general material properties. An evaluation of the material showed that there is a very short pot life that needed to be taken into consideration when purchasing an automated machine. If the material ages while in the machine, it will create difficulties with the maintenance and could result in damage to the machine or defects when spraying the material.

It was also important to understand which material parameters can be changed and which cannot. For example, the ratio of a two-component material cannot be changed; however, additional thinner may be added to the mixture to change the viscosity to improve material flow. Additionally, the cure times cannot be changed without sufficient process evaluation to determine that the material properties are consistent. Another factor that was considered involved the number of coats being sprayed, which is another variable that may be changed. For example, it could be beneficial to spray multiple thin coats instead of one thick coat or a thin coat and cure to a tack-free state before applying a second coat.

Validating the measurement system in place was important when developing this new process.

Validating the measurement system in place was important when developing this new process. Thickness is a critical parameter for conformal coating and is required to be 0.03–0.13 mm (0.001–0.005 in.) per J-STD-001 for polyurethane materials [1]. Before this experiment, fiberglass coupons were being used for thickness measurements and were being measured with a digital positioner micrometer measuring tool. This tool was difficult to use and showed to have significant operator-to-operator variation when multiple operators were measuring the same coupon. A new measurement system using steel coupons, instead of fiberglass, measured with an eddy current probe, was evaluated.

To evaluate and validate the new measurement tool with the new steel coupons, 20 sample coupons were conformal coated and measured by four different operators. The variation in measurement results was compared between the digital positioner micrometer tool compared to the new eddy current probe. Figure 2 shows a comparison of the operator measurements for each coupon using the existing measurement tool. This shows clear inconsistencies between each operator using the digital positioner micrometer tool to measure the same coupon. Figure 3 shows the same four operators measuring the same 20 coupons but now with the eddy current probe, which shows clear improvement compared to the measurements in Figure 2.

The standard deviation was calculated for each coupon for each measurement tool used, and Figure 4 shows a comparison of the standard deviation of each measurement tool. The eddy current probe has a significantly lower standard deviation between measurements performed by multiple operators measuring the same coupon and therefore has proven to be a much more reliable measurement tool. Ensur-

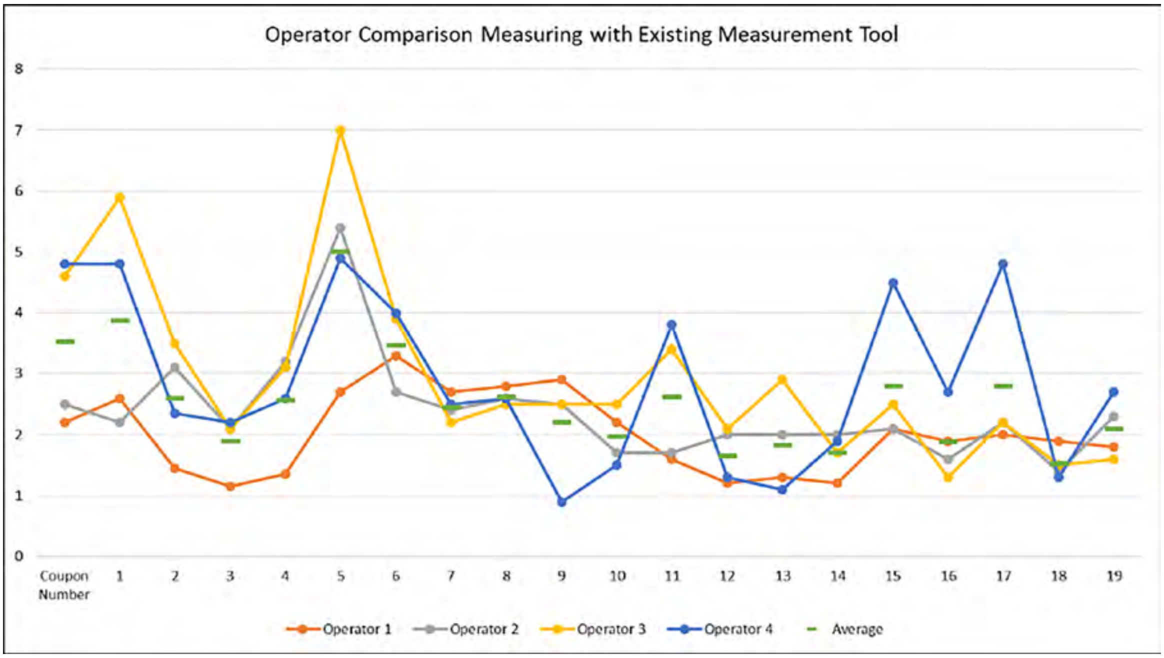


Figure 2: Operator comparison measuring with the existing measurement tool.

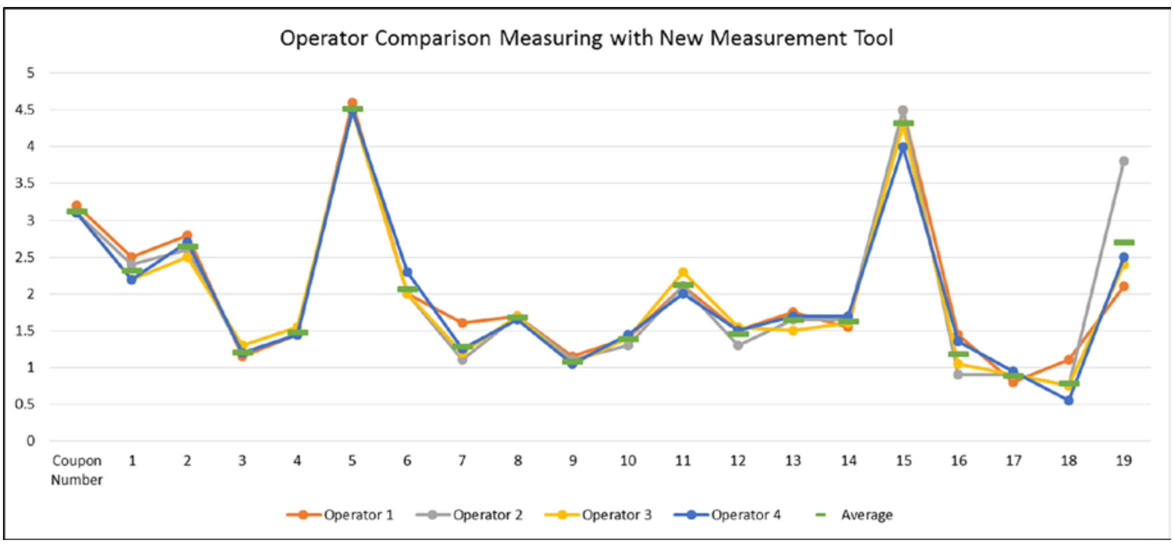


Figure 3: Operator comparison measuring with the new measurement tool.

Figure 4: Standard deviation of measurements.

ing a proper measurement system was necessary for setting up a proper automated-spraying process with good process controls since the thickness is a critical parameter of the conformal coating process.

In the early stages of process development, after the machine was selected and installed, a slight anomaly was observed in the conformal coating. As fiberglass coupons had traditionally been utilized, and the new steel coupons were beginning to be used, a slight fogginess on the steel coupons was observed. This fogginess did not appear on the fiberglass coupons, circuit card assemblies, or on the steel coupons that were being hand-sprayed. Fogginess only appeared on the steel coupons being used in the new automated coating machine. Additionally, it appeared that as the pot life aged using the automated machine; there was no fogginess observed on the steel coupons that were sprayed with the older material. After this observation, significant testing was performed to attempt to eliminate the fogginess.

A series of experiments were performed by adjusting spray-valve distance from the substrate, syringe material pressure, atomizing air pressure, thinner to material ratio, valve speed, number of coats, and material flow rate to determine if any of these improved or worsened the fogginess on the steel coupon, but none of these parameters had any impact. It was at this point that it was necessary to send samples to a lab for analysis. Five samples, as shown in Table 1, were sent for Fourier-transform infrared spectroscopy (FTIR) analysis. The samples sent for analysis included a representative sample of auto-sprayed foggy and clear coupons, steel and fiberglass substrates, and material used within and exceeding pot life. The concern was that on the foggy coupon (Sample 4) the material may not be properly mixed, or the thinner is not able to escape, or there was some reaction with the new steel coupon. The FTIR analysis was uti-

Samples for FTIR Analysis				
Sample Number	**Spray Process Used**	**Coupon Substrate**	**Appearance**	**Pot Life**
1	Auto	Fiberglass	Clear	Within
2	Hand	Fiberglass	Clear	Within
3	Hand	Steel	Clear	Within
4	Auto	Steel	Foggy	Within
5	Auto	Steel	Clear	Expired

Table 1: Samples for FTIR analysis.

lized to determine if the composition of the foggy material on the steel coupon was identical to the clear coating on the other coupons.

Luckily, there was no difference between the chemical composition of the hand-sprayed clear steel and fiberglass coupons (Samples 2 and 3) compared to the auto-sprayed foggy coupon (Sample 4) [3]. The slight fogginess that was observed was determined to be caused by the fiberglass coupons being an ivory color while the steel coupons were reflective, which caused the slight fog to be visible when the conformal coating was thicker. Meanwhile, Sample 5 appeared clear because the coat was much thinner at the end of the pot life due to the thickening of the material causing a reduction in material flow rate, which resulted in the fogginess being minimized. What was most interesting was that the FTIR analysis showed there was a difference between the clear end of pot life auto-sprayed coupon (Sample 5) and the rest of the coupons that were sprayed within the pot life limit [3]. This result from the FTIR analysis showed the importance of the pot life as a critical parameter that will require process control for the final automated-spraying process.

To allow for circuit cards to be processed through the machine, it was necessary to design fixtures that would be able to run on machine conveyor rails.

To allow for circuit cards to be processed through the machine, it was necessary to design fixtures that would be able to run on machine conveyor rails. The fixtures that were created allow multiple circuit card assemblies to be processed at the same time. Per the customer drawing requirements, certain areas of the circuit card assembly are required to be free of conformal coating. To meet the drawing requirements for these keep-out zones, a hand-masking process is currently used where operators manually apply tape, covers, or other masking material to the CCA in the areas that must be free of coating. When designing these fixtures, an easy way to reduce manual masking time and increase throughput capabilities was to incorporate as much of the masking requirements as possible into the fixture design.

The fixture is a clamshell type of design that covers certain areas as required per the customer drawing. The operator can easily place circuit cards into the fixture and secure a lid on top, and the fixture masks the majority of the required areas. By designing the masking into the fixtures, the operator time required for applying and removing masking was reduced by about half. Utilizing the fixtures that incorporate masking has been a significant improvement on the current masking process and reduced significant touch time to help increase production throughput capabilities at these critical conformal coating operations.

Analyzing the Current Process

Evaluating the current hand-spraying process to assess the material behavior was necessary to ensure a sufficient understanding of the material before selecting a machine. The material was being applied with high atomizing air pressure with a handheld air gun. The dexterity of the operator was essential for proper component coverage with the operator being able to maneuver around the circuit card assemblies to spray the sides of leads and components as necessary. This process was yielding very good results despite batch-to-batch and operator-to-operator variation.

During the evaluation of the current hand-spray process, the material began to thicken after approximately three-quarters of the datasheet recommended pot life and was typically being disposed of by the operator at that time. Understanding these important key facts about the current process was essential to determining what machine requirements would be necessary. The short pot life makes it difficult to automate the process, especially since most

automated conformal coating machines are equipped with a large pressurized material pot and long fluid delivery lines to the spray valve. With this low-outgassing polyurethane material having such a limited pot life, it was determined that long fluid delivery lines and a large material pot would cause significant maintenance issues in the long run. During the machine evaluation process, a more direct material delivery system would be required.

One option was to have the material directly fed to the spray valve by syringe; this is the best way to reduce maintenance issues that could have occurred if long fluid delivery lines were used. Also, it was necessary to evaluate machines that could mimic the dexterity of the operators; therefore, machines with X-Y-Z rotations, fourth-axis motion, and selective spray valves would have to be evaluated.

Machine Evaluation and Selection

After reviewing the current process and the material and customer requirements, the machine evaluation process began. At this point, preliminary research was done on automated conformal coating machine manufacturers. Manufacturers were contacted to determine their level of experience with the polyurethane material to be used in the machine. When evaluating the machines, it was important to thoroughly review the machine specifications and limitations. It was also important to review the machine software and determine how easy it is to program. Working with the manufacturer helped narrow down the machine selection before testing them.

After selecting machines, some were tested by the manufacturer using their recommended settings on coupons and with sample circuit card assemblies. It is best to perform the machine evaluation on-site with the manufacturer to validate the process being used. It was important when evaluating machines with the manufacturer to understand all of the machine and spray-valve parameters that can be manipulated. Parameters—such as valve distance from the substrate, atomizing air pressure, material syringe pressure, valve speed, and material flow rate—will need to be adjusted during the process development. While choosing the automated conformal coating machine, it was very important to understand the process, material, and customer requirements to ensure the proper machine and features are selected.

Process Development

Once the machine was installed, process development began. Using the machine manufacturer's recommendations as a starting point, multiple parameters were adjusted over several weeks of performing experiments to develop the process. To begin, before spraying any circuit cards, the process was tested on the flat steel coupons. Starting with the manufacturer's recommendations, individual parameters were increased or decreased and tested to see the effects on the coupons. For each coupon processed, the thickness data was measured.

It was at this time that the fogginess, as described previously, was observed and evaluated. Once the fogginess was deemed to be acceptable, process development continued with additional experiments to begin autocoating on assemblies. Some of the parameters that were adjusted were the material-to-thinner ratio, number of coats, valve distance from the substrate, material syringe pressure, atomizing air pressure, valve speed, and material flow rate. These parameters were adjusted and tested to develop a proper spray pattern. The spray pattern is important to guarantee component and surface coverage are sufficient. The most important parameter for proper spray pattern was the material flow rate. If there are gaps in the spray pattern caused by the width of the spray, then there will be voids in the coating that will require a touch-up. Once an ideal set of parameters were established, and the thickness was validated, sample circuit card assemblies were coated using the established process.

It was observed that the material moved differently on a circuit card while it appeared flat and smooth on the unencumbered steel coupons. Due to this, more experiments and adjustments were made to optimize the process after spraying populated boards. It is important to

test sample circuit card assemblies to ensure the chosen process will work on the product. Once the sample circuit card assembly was cured, it was inspected per IPC-A-610 and J-STD-001 requirements. Higher magnification was utilized during this process development to analyze the conformal coating quality and inspect more thoroughly for bubbles or other defects. The first process that was developed and tested during this experiment resulted in excessive bubbles around leaded components; the bubbles were bridging conductors and a defect per IPC-A-610 requirements, as seen in Figure 5 [2]. These bubbles could be caused by the material and process, but bubbles could also be caused by contamination or improper baking of the assemblies before application. When reevaluating the process to begin additional experiments, it was determined that the material was sprayed on too thick, which created bubbles when the entrapped air underneath components could not escape.

The next set of experiments included a reduction in material flow and an increase in the number of coats applied as well as ensuring the assemblies were properly cleaned and baked before coating. By decreasing material flow, less material is applied at one time and applying multiple coats allows the material a chance to settle before the next coat is applied. More sample circuit cards were sprayed with the new process to validate that the bubble defect was eliminated. Once this was confirmed, the new process with a lower material flow and multiple coats became the final process selected for use on production.

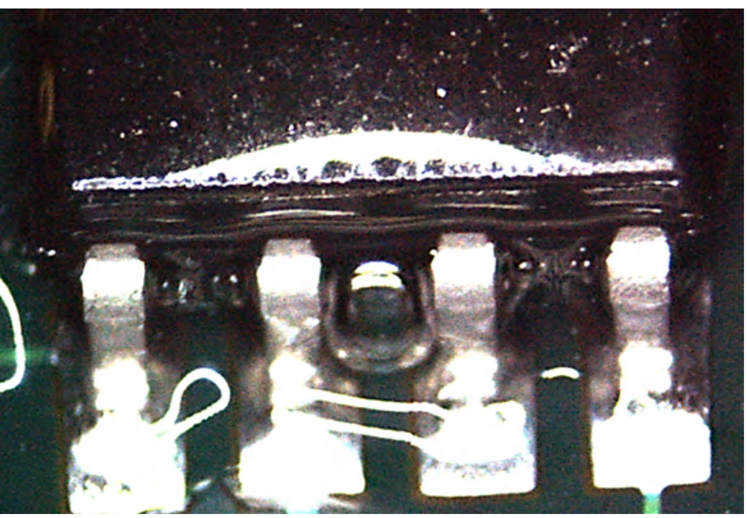


Figure 5: Example of the bubble defect.

The final automated process for production—with a lower material flow rate and multiple coats—has eliminated approximately one hour of coating processing time, including 10 minutes of manual spraying time per CCA. This improvement to the process has helped to increase production throughput capabilities and reduce cost by reducing the amount of time the operator is required to manually spray the circuit card.

Process Validation

Once the final process for production was established, it was necessary to perform a process comparison to ensure there was no degradation of quality from the manual hand-spray process compared to the new automated process. The parameters that were validated during this experiment were the thickness per J-STD-001 requirements, uniformity, and an adhesion by tape test per ASTM D3359 Test Method B (cross-cut tape test). To perform the adhesion by tape test, 10 sample coupons were used for hand spray and 10 were used for auto spray; stainless steel coupons and some sample unpopulated printed circuit boards were used. The coupons were conformally coated per the established process and cured per the datasheet requirements then after curing the adhesion test per ASTM D3359 Test Method B was performed.

The adhesion test consists of scoring the conformal coating using a clean sharp knife to cut the coating as the test requirements specify (Figure 6). After the cuts are made, the debris is removed, and tape is applied and smoothed over the cut area before the tape is pulled off. Once the tape is removed, the grid area is inspected and rated per the Classification of Adhesion Test Results listed in ASTM D3359 [4]. Figure 6 shows an example of a test before and after the tape is applied and removed. The goal of this test was to see no change in the adhesion to the same substrate type between the hand-spray and automated-spraying process. In this experiment, all results yielded a

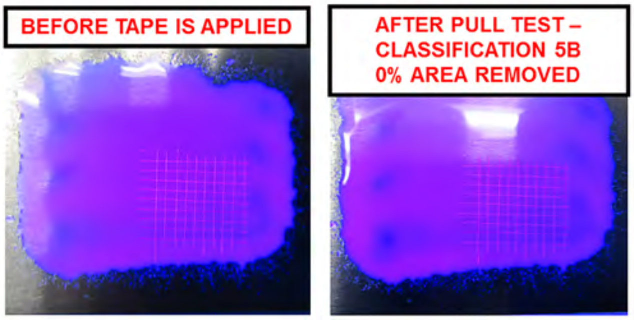


Figure 6: Adhesion by tape test (before and after 5B example).

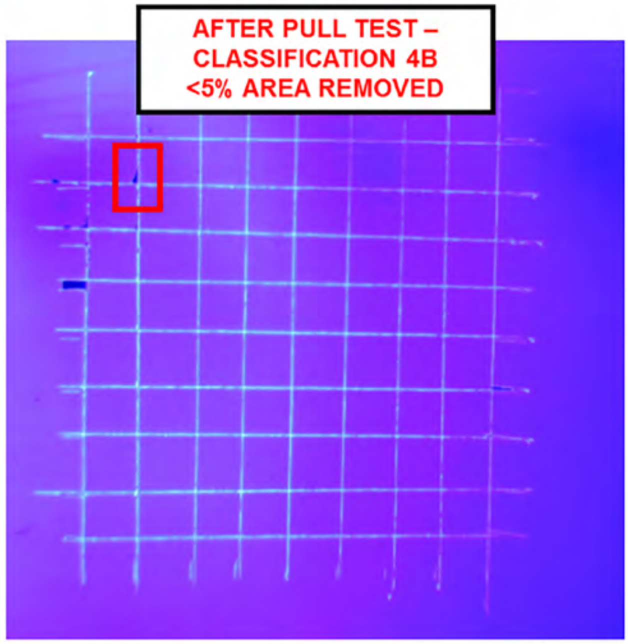


Figure 7: Adhesion by tape test (4B example).

5B, which is the best result. Figure 7 shows an example of what a 4B result would look like. This test presented a comparison of the hand-spray to the new, automated-spray process; it validated that there was no degradation between the old process and the new.

A thickness comparison between the hand-spray and automated-spray processes was also performed. Per J-STD-001, the thickness requirements for polyurethane materials is 0.03–0.13 mm (0.001–0.005 in.) measured on a flat unencumbered surface that was processed with the CCAs [1]. The thickness was measured using the eddy current probe on a stainless steel coupon. The automated-spraying process has proven to reduce the variation in thickness that is observed with the current hand-spraying process. Figure 8 shows the improvement and reduction of variation in the thickness measurements (measured in mils) from hand spray to automated spray. The process capability, Cpk, has also increased from 0.82 with the hand spray to 1.98 with the automated spray.

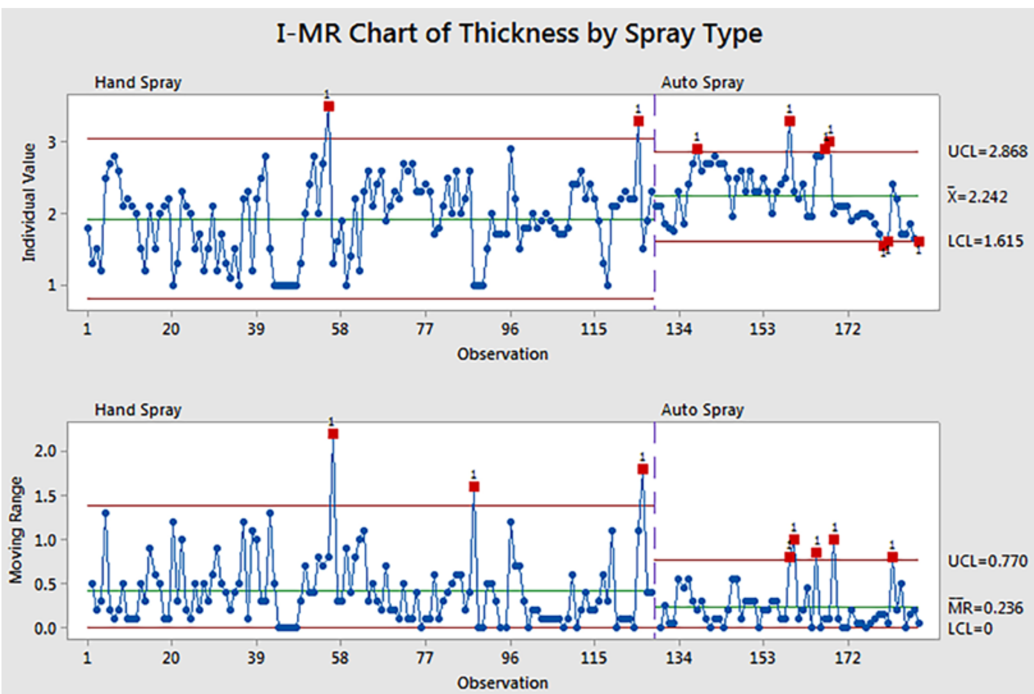


Figure 8: Control chart comparing hand spray to auto spray.

Process Controls

Once the process was established and validated, the next step was to set up process controls for the critical parameters. A properly documented process and properly trained operators are important factors for process control. It is important that all of the critical parameters are documented in a process control document. Most parameters in the automated-spraying process are values stored in the machine programming, such as the nozzle distance from the substrate, nozzle speed, number of coats, and curing profile. These values cannot be changed on the equipment and are also documented for reference in the process control document. Some parameters are manually adjustable—such as atomizing air pressure and material syringe pressure—but are monitored by the machine and set up to have machine alarms if they are out of specification. Some critical parameters—such as thinner to material ratio measurements and maintaining the material pot life—while still documented, are left to the operator training and discipline.

One of the critical parameters that required well-documented controls was material pot life. As it was discovered in the FTIR testing of the coating coupon samples, a difference in the material was observed when the pot life had expired. In addition, polyurethane materials have notoriously short pot lives, which makes them difficult candidates for automated processes due to the maintenance requirements. Setting up process controls to ensure materials are used within their pot life can help eliminate issues that could arise due to expired material. It is important that the operators are properly trained and understand the strict pot life requirements and that the process is properly documented.

It was expected that throughout the pot life the material would begin to thicken, which would cause the flow rate to decrease. This theory was tested by processing circuit card assemblies and coupons continuously through the automated process for the entire pot life to observe how the material was expected to change. It was observed that the material did begin to thicken causing the flow rate to slightly decrease. This resulted in the spray pattern slightly changing after about three-quarters of the pot life. This was consistent with the current hand-spray process that the operators had observed as well. Reduction in flow rate may cause a decrease in final coating thickness. Therefore, when the mixed material reached three-quarters of the pot life, it was necessary to purge all remaining material from the machine and completely remove and clean the valve.

To control this requirement, the process has been set up to spray a coupon with one coat and a coupon with the final process for production, which includes multiple coats with each set of circuit card assemblies. These coupons allow for visualization of the process, and if any abnormalities in the coating or changes in the spray pattern are observed, the visual difference signals the operator that it is time to change the material. Figure 9 is an example of how this coupon may look as the spray pattern begins to change; small voids will appear.

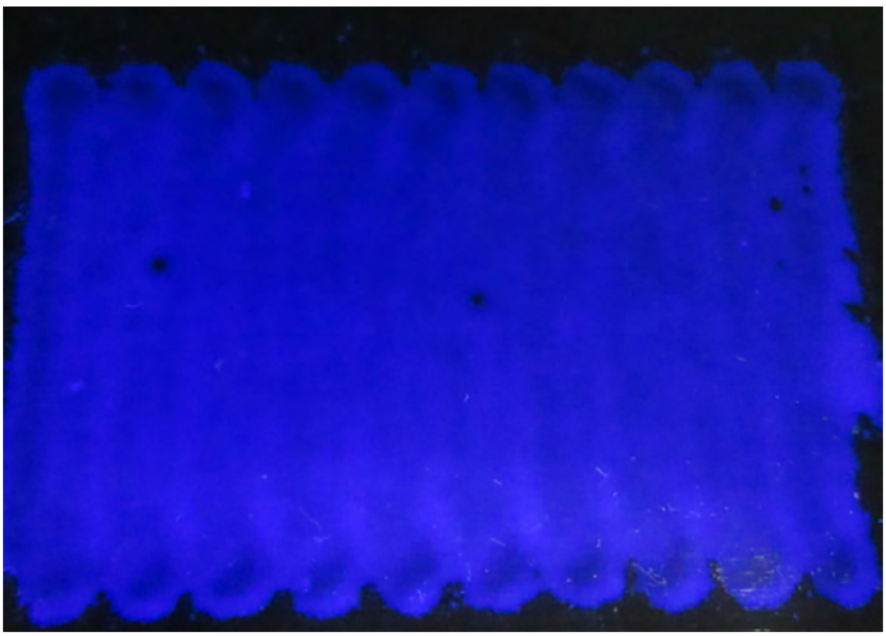


Figure 9: Example of a one-coat coupon as spray pattern changes.

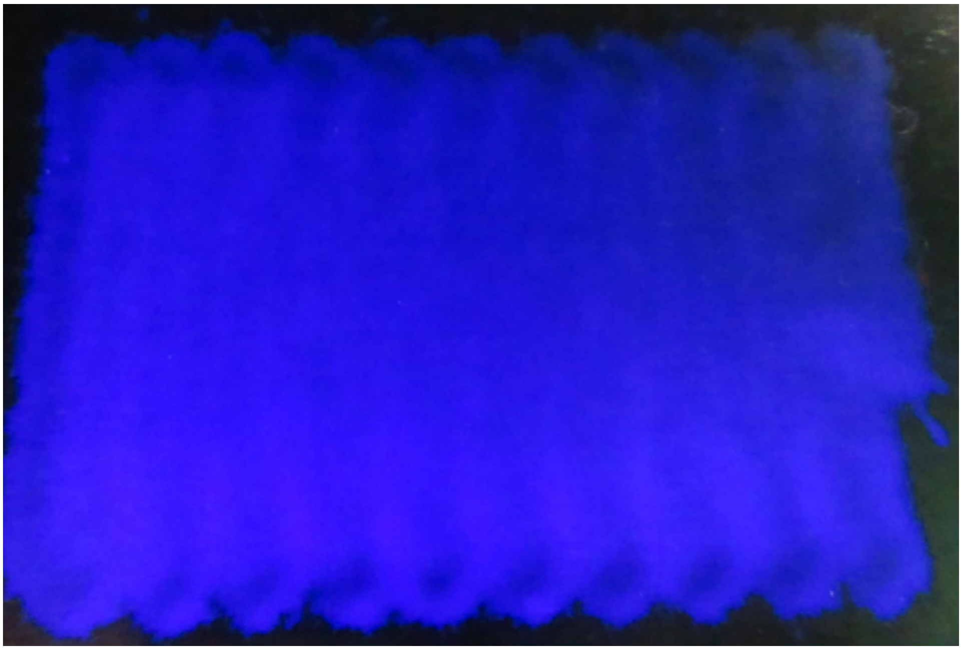


Figure 10: Example of a uniform one-coat coupon.

Figure 10 shows an example of how the one-coat coupon should look with no voids and uniform. It was necessary to run the separate one-coat coupon because it was observed that when spraying the final process for production—which includes multiple coats—any voids in the coating or changes in the spray pattern were covered up. Additionally, to control pot life, all mixed materials are labeled with the material name, date, time mixed, and pot life so that the operator knows when the pot life will expire. These process controls have been sufficient to ensure the material is not used after the pot life has expired.

Maintenance of the machine was also determined to be important for proper coating application. Polyurethane materials are very difficult to clean. This was observed with the hand-spraying process as well; the maintenance of the hand-spray gun and the auto-spray valve is critical. Any coating remaining in the valve will cure and can either clog the valve or will affect the performance of the next run. The best way to ensure consistent processing for each new pot of material is to completely remove and deconstruct the valve and clean all of the wet components individually.

It was also necessary to inspect the components under magnification to ensure they are clean before reassembling the valve. Purging the valve with thinner is required to ensure all material has been removed from the valve before disassembly and after reassembly. These experiments determined that it is a process requirement to run at least two coupons at the beginning of each material pot mixture to ensure the spray pattern is sufficient and that there are no abnormalities with the material before spraying any circuit card assemblies. By following these maintenance requirements, the process has performed consistently.

Curing

The curing process was also automated for this implementation by using an inline curing oven. Modifications to the oven were required due to the long material cure times. To ensure the oven is reaching the proper temperature for the correct cure times, a thermocouple profiling tool was used to adjust the temperatures as needed until the cure temperature was achieved. This inline curing oven process differed significantly compared to the current process of placing the circuit cards into an oven. The process also requires a period for air curing, so a staging area is required. During staging and before entering the inline curing oven, the circuit cards are inspected for any obvious defects and touched up as required before curing.

Conclusions

The development of an automated process to spray a low-outgassing polyurethane conformal coating material was essential for meeting an increase in customer demand. Manual processes in manufacturing lead to defects and increased variability as well as increased manufacturing time. Many parameters were taken into consideration when developing the process, as seen in Figure 1.

To validate the implementation of the new automated conformal coating process, a comparison of the manual hand spray to the new process was performed to ensure there was no degradation between the old and new process. An adhesion by tape test per ASTM D3359 Test Method B was performed using hand-sprayed and auto-sprayed coating samples; all coupons tested yielded a 5B result. A visual inspection of the circuit card assemblies sprayed with the automated-spraying process validated that the coated circuit card met all J-STD-001 and IPC-A-610 requirements. The thickness comparison proved that the new automated-spray process is more consistent that the hand-spray process. All thickness coupons measured within the J-STD-001 requirements of 0.03–0.13 mm (0.001–0.005 in.), and the variation has been reduced and process capability has been improved from a Cpk of 0.82 with the hand spray to 1.98 with the automated spray.

Designing fixtures to incorporate a majority of the masking required per the customer drawing has reduced operator masking time by about half. Automating the process resulted in a reduction in overall spray coat cycle time by about one hour, including approximately 10 minutes of manual spraying time per circuit card assembly. The automation of conformal coating using a two-component, low-outgassing polyurethane material has resulted in many significant successful improvements to the overall manufacturing of these circuit card assemblies.

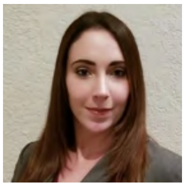
Next Steps

Process improvements will continue as an ongoing effort with a primary focus on increasing component coverage capabilities. **SMT007**

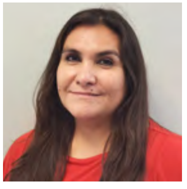
References

1. J-STD-001G (Joint Industry Standard Requirements for Soldered Electrical and Electronic Assemblies), IPC, 2017.
2. IPC-A-610G (Acceptability of Electronic Assemblies), IPC, 2017.
3. Analytical Report (FTIR Analysis of Coating Samples), Cerium Laboratories LLC, 2018.
4. ASTM D3359-17 (Standard Test Methods for Rating Adhesion by Tape Test), ASTM International, 2017.

This paper was first presented at the IPC APEX EXPO 2019 Technical Conference and published in the 2019 Technical Conference Proceedings.

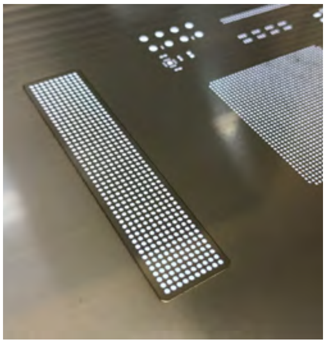


Marissa Pati is a senior process engineer at BAE Systems.



Ana "Lety" Campuzano-Contreras is a principal manager at BAE Systems.

SMT Stencils 101: What Are Industry-standard Stencil Designs?



If you've been in the SMT industry for any length of time and involved in ordering stencils, you may have instructed your stencil supplier to design your stencil to "industry standards" or per IPC standards. These are very loose terms and may be interpreted differently by different stencil manufacturers. Many parts of the IPC-7525B standard are only recommendations, and the recommendations are typically a range of size reductions and/or area reductions for different types of components. In this column, Greg Smith discusses how his company interprets these guidelines and look at general design principles that should be applied to every stencil. (Source: I-Connect007)

Read the column here.

Electronics Industry News and Market Highlights

Semiconductor Industry Capex Forecast to Slump in 2019 and 2020 ▶

The streak of strong ≥45% capital spending growth two years after spending cutbacks ended in 2015, with capital spending registering a 1% decline.

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DISPENSING EMI SHIELDING MATERIALS: An Alternative to Sputtering

Feature by Garrett Wong
NORDSON ASYMTEK,
and Jinu Choi
HENKEL ELECTRONIC MATERIALS LLC

Abstract

Shielding electronic systems against electromagnetic interference (EMI) has become a hot topic. Technological advancements toward 5G standards, wireless charging of mobile electronics, in-package antenna integration, and system-in-package (SiP) adoption are driving the need to apply more effective EMI shielding and isolation to component packages and larger modules. For conformal shielding, EMI shielding materials for exterior package surfaces have mostly been applied with a physical vapor deposition (PVD) process of sputtering, leveraging front-end packaging technologies to back-end packaging applications. However, sputtering technology challenges in scalability and cost along with advancements in dispensable materials are driving considerations for alternative dispensing techniques for EMI shielding.

The authors will discuss the development of a spray coating process to apply EMI shielding materials to the exterior surfaces of individual components on strips and larger SiP packages. Using newly developed and enhanced materials and equipment for this industry, a process was demonstrated that provided uniform coating on packages in the sub-10-µm thickness range with consistent coating thicknesses around package corners and package sidewalls, producing a top surface-to-sidewall thickness ratio of 1:1. Further investigation showed decreased production costs for applying EMI shielding to component packages by increasing spray-coating productivity and by selectively applying the coating to specific areas of packages. Additionally, low capital-equipment expense and shorter lead times for spray coating equipment improved the ability to scale up production capacity compared to sputtering equipment.

In mobile electronics packaging, several SiP-module manufacturers are challenged to isolate components within the SiP from each other and from their exterior for EMI shield-

ing. Trenches are cut around the interior components and conductive paste is dispensed into the trenches to form smaller Faraday cages within the package. As trench designs become narrower, it's imperative to control both the volume and placement accuracy of the material filling the trenches. The latest, advanced jetting products provide control of the volume while the narrow, in-air stream width delivers accurate trench fill. In a final step, the tops of these paste-filled trenches are connected by applying exterior EMI shield coating. Spraying overcomes challenges faced when using sputtering equipment and harnesses the improvements in both the EMI shielding materials and the equipment for depositing it so that SiP packages can be manufactured using efficient back-end packaging techniques.

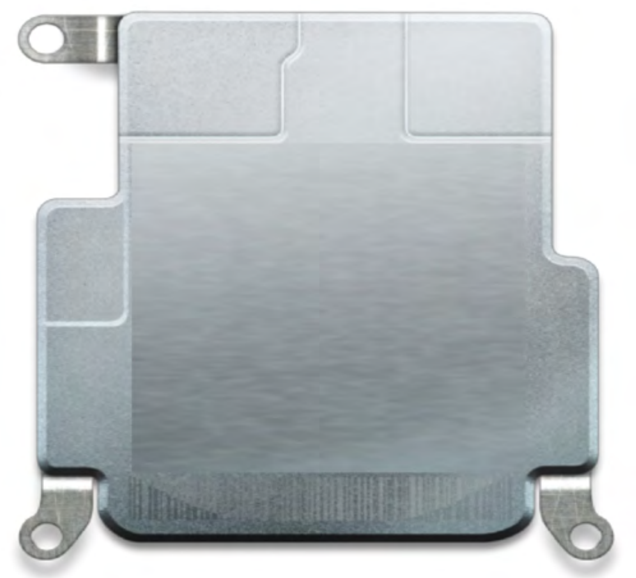

Figure 1: Example SiP unit with sputter coating and integrated EMI shielding structures.

Introduction: Growth of EMI Shielding

EMI shielding has become a topic of significant interest in recent years. As 5G wireless technology is approaching mass-market acceptance and the future capabilities 5G standards will enable for the internet of things (IoT) and mission-critical communications, there is a significantly increasing need to effectively shield electronics and components from EMI.

With the upcoming 5G wireless standards, signal frequencies of 600 MHz to 6 GHz [1] and mmWave bands will become increasingly more common and powerful as the technology is adopted. Some of the proposed uses and implementations include window panels for office buildings or public transportation to help deal with shorter range communications. Other proposed implementations include home and office building repeaters to provide adequate coverage due to 5G frequencies having difficulties passing through walls and other solid objects [2]. All of this activity will lead to an increased prevalence of signals in the 5G frequency range and a higher risk of exposure to EMI in these frequency ranges and their harmonics.

Fortunately, EMI can be shielded on component and system-in-package (SiP) devices through the application of thin coatings of conductive metal to the exteriors of such devices (Figure 1). Historically, EMI shielding has been applied through placing stamped metal cans around groups of components or by applying EMI shielding tapes to specific components. However, as packages and end devices continue to become miniaturized, such shielding methods become prohibitive due to size constraints as well as the flexibility to handle diverse, non-orthogonal packaging concepts that are becoming more common in mobile and wearable electronics.

Likewise, some leading-edge package designs are moving toward selective coating of only certain areas of a package for the EMI shielding rather than a complete shell over the full exterior of the package. In addition to the external coating for the EMI shielding, new SiP devices are further requiring additional integrated shielding to be built directly into the package to properly isolate individual components from each other in a single package.

Sputtering: A Method of Applying EMI Shielding

The predominant method for creating EMI shielding on molded component packages or molded SiP devices has been through sputtering multiple layers of metals over the surface. With sputtering, it has been possible to apply very thin, consistent coatings of pure metal or metal alloys to package surfaces in the 1–7-µm thickness range. With the nature of the sputtering process capable of depositing metals at the angstrom level, the electrical performance of its coating layer has been effective thus far for typical shielding application.

However, as the need for shielding grows, sputtering has significant inherent drawbacks for it to be established as a scalable method for manufacturers and designers. Initial capital equipment costs for sputtering equipment are very high—in the million-dollar range. Sputter equipment lines require significant floor space due to its multi-chamber process, and further increases the need for additional real estate with full in-line conveyorized systems. With the inciting of plasma to sputter material from a sputter target to the substrate, typical sputter chamber environments could reach into the 400°C range; therefore, cooling of a substrate with a "cold plate" mounting fixture to reduce the experienced temperatures is needed. The sputtering process deposits metal on a given substrate but typically only produces up to 60% thickness coverage on the vertical sidewalls of a three-dimensional package compared to the thickness of the top surface layer.

Lastly, due to the nature of sputtering being a line-of-sight deposition process, metal particles cannot be selectively applied or necessarily applied under overhanging structures and topology and can result in significant material wastage in addition to material accumulation inside of the chamber walls; hence, this requires intensive maintenance. It is also necessary to pre-apply masking to substrates if there are specific areas of a given substrate that must remain exposed or do not require EMI shielding.

Spray Coating: An Alternative Process to Sputtering

Spray coating is an established conformal coating method commonly used in the automotive and printed circuit board assembly (PCBA) markets to protect substrates from harsh environmental factors, including moisture and dust. Using similar spray technologies, thin layers of flux material have also been applied to PCBs before ball grid array (BGA) component attachment and reflow. Military applications use spray technology to apply extremely thin coatings to substrates, at times involving highly customized and expensive fluid formulations. Today's EMI spray coating equipment has evolved from these markets and applications, leveraging successful designs to achieve high productivity, long service life, and low capital costs.

Spray coating for EMI shielding started to gain attention in the 2000s as a result of extensive use in industrial and automotive markets and military applications. By 2012, spray coating EMI shielding fluids to coat the top surfaces of semiconductor packages was in mass production. However, at that time, sidewall coverage and fluid adhesion to vertical surfaces were significant challenges toward wider adoption of the process. Furthermore, initial formulations of EMI shielding materials based on conductive silver inks required moderate to high thicknesses to provide adequate shielding effectiveness and had limited adhesion property than recent formulations.

As discussed in a previous publication [3], the application of tilt spraying with a spray applicator has led to notable improvements in overcoming the prior sidewall coverage limitations from earlier implementations (Figure 2). Recent spray applicator design enhancements have also delivered greater selectivity and refined edge definition in the spray pattern.

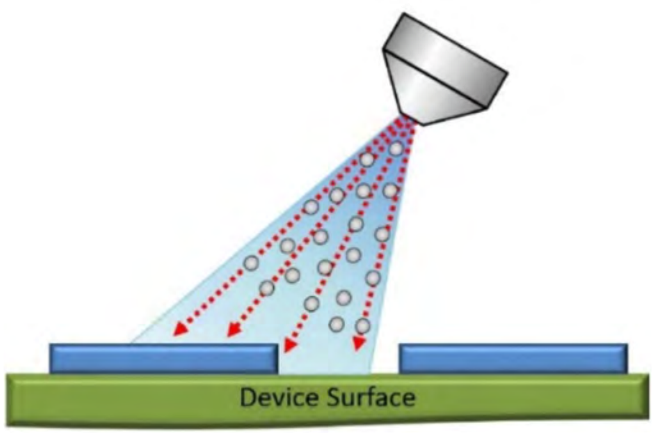

Figure 2: Tilted spray coating applies fluid at an angle to the top and sidewalls of component surfaces.

Such improvements further enabled capabilities of selective patterning or coating coverage desired in various leading-edge packages where full conformal shielding is not required. Sprayed material's adhesion compatibility to different substrates was also required for spray shielding to be considered as a viable or superior alternative to sputtering.

EMI Spray Shielding Material Improvements

Initially, EMI shielding materials for spray coating were silver-based conductive inks. These modified inks were adopted for mass production in a very limited market segment due to concerns with the material thickness required (≥ 25 µm) to achieve adequate shielding performance and lack of ability to adequately coat the vertical sidewalls of the substrates. However, new conductive material formulations have recently been developed to address adequate shielding performance and coverage consistency.

These formulations were initially focused on providing superior conductivity performance compared to conventional materials. As seen in Figure 3, shielding performance was improved by up to 80% and allowed reducing from 25-µm thick coatings to coatings in the 3–6-µm thickness range while achieving comparable shielding performance as sputtering. With these novel EMI shielding material formulations, spraying can now achieve comparable performance and thickness as sputtering.

Another challenge with conventional spray coating materials was the tendency of the material to "slump" after being sprayed or applied to the sidewalls of the target substrate. These early materials would tend to run down the sides of component packages causing inconsistent thickness and non-uniform coverage on the coated substrates.

New material formulations of EMI spray shielding materials have eliminated slumping. In recent tests with this material, we were able to coat test samples with 100% sidewall thickness as top surface thickness (1:1 ratio). Through adjusting parameters of the spraying process, such as dispense distance from the substrate or motion-speed of the spray valve, the coating thickness and resulting sidewall-to top-surface thickness can be adjusted. Typical sidewall to top surface ratio is greater than 0.7:1 (Figure 4).

In addition to improved sidewall coverage, adhesion performance is a critical component of this solution. Industry standards call for a cross-hatch etch-and-peel test and coatings must adhere with a rating of 4B or 5B to pass (minimal or no loss of material apart from the etched areas). Figure 5 illustrates a limited set of the test results for a new material at time zero as well as after accelerated life cycle tests.

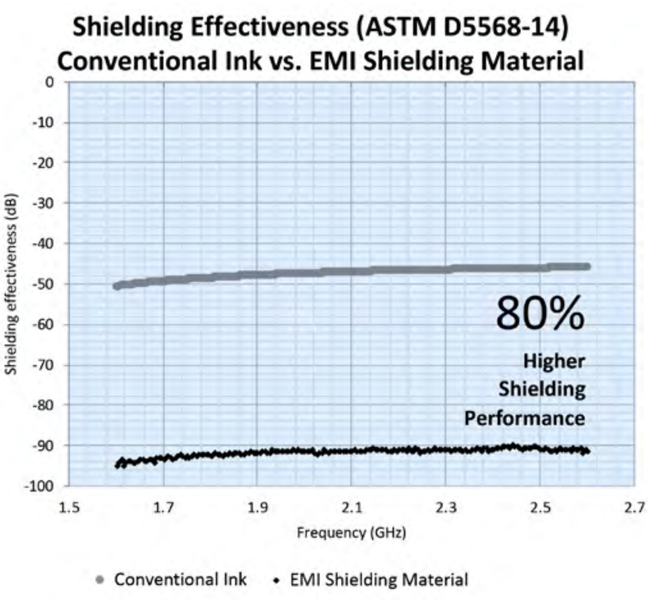

Figure 3: Shielding effectivity comparison between EMI spray shielding material and conventional silver ink.

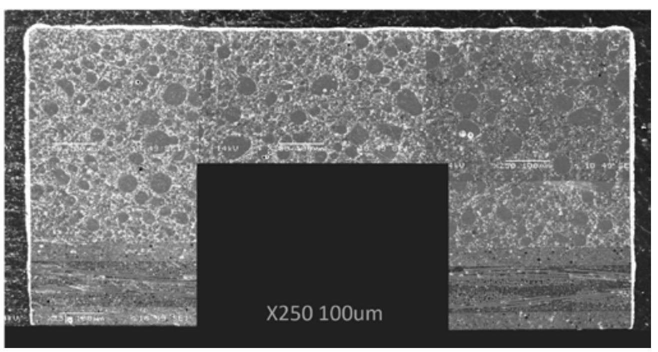

Figure 4: Spray shielding uniformity for top and sidewall surfaces with the new material.

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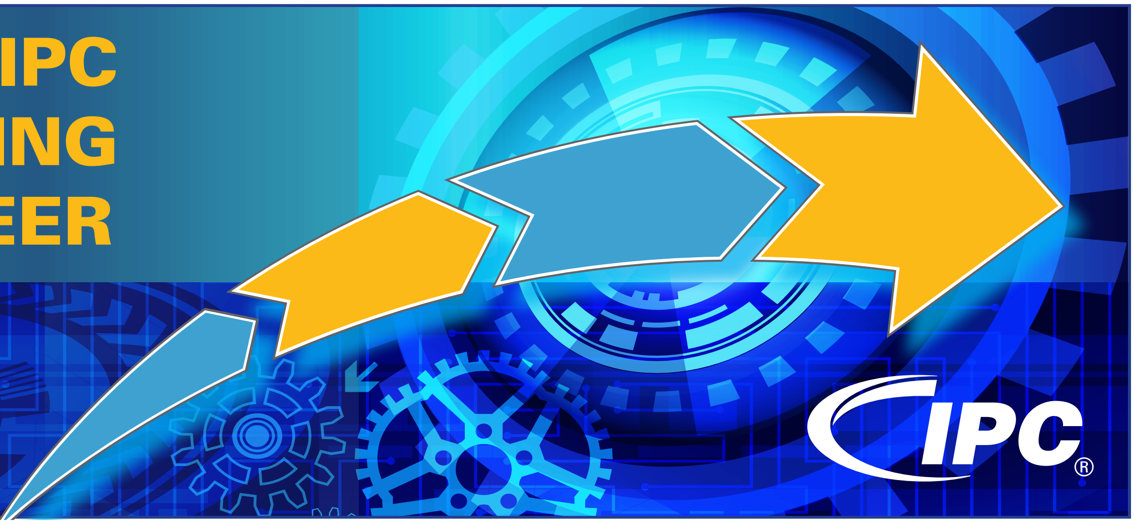

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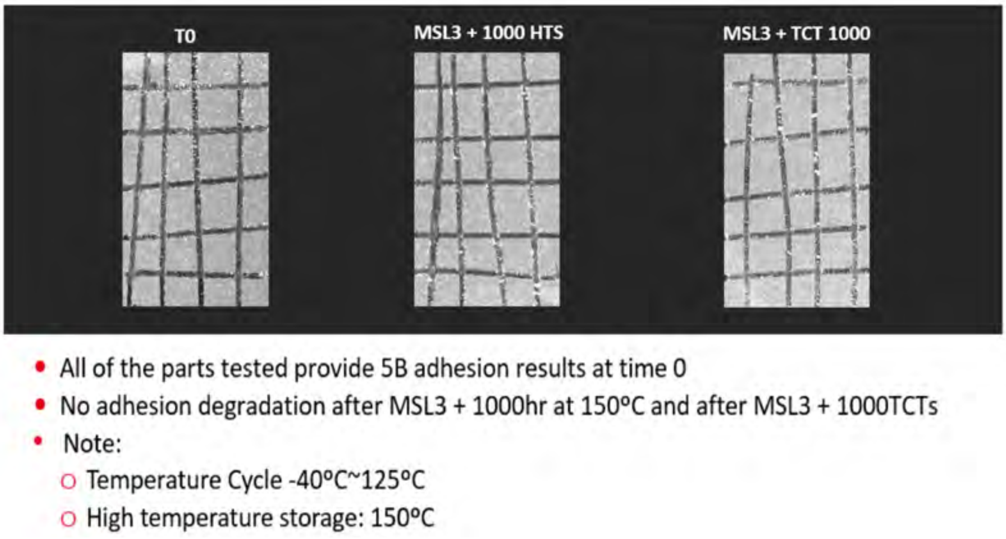

Figure 5: Adhesion testing and reliability of EMI spray shielding material.

Furthermore, as illustrated in Figure 6, new spray shielding materials from Henkel also provide robust adhesion on various substrates commonly used across a wide range of electronic design applications, including polyimide films used in flexible PCBs. Thus, spray coating for EMI shielding can further be applied to a broader scope of applications than could previously be considered.

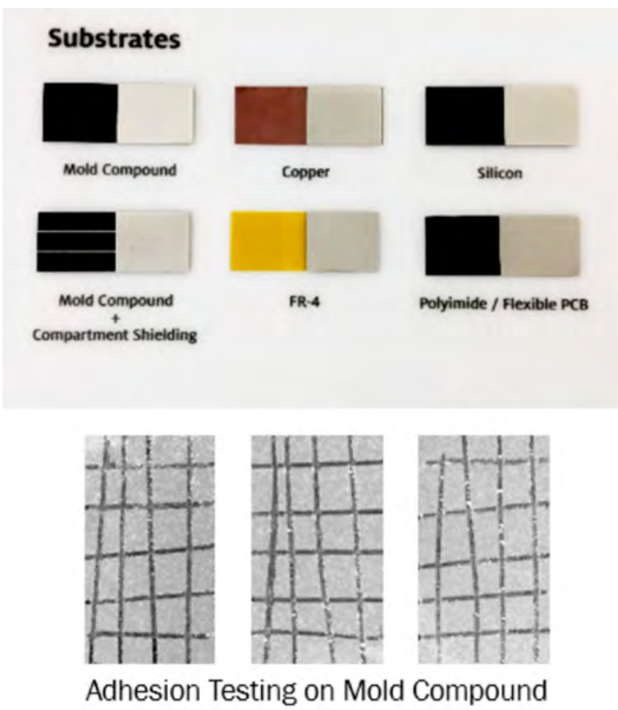

Figure 6: Substrate adhesion flexibility of spray shielding materials.

Cost Advantages of EMI Spray Coating

As EMI shielding continues to expand into wider markets and applications, manufacturers are paying close attention to the costs for starting EMI shielding production and weighing their options. One of the downsides of sputter coating is the significant cost of the capital equipment and associated floor space and operating cost. A typical sputter coating production line may require floor space on the order of 60 m^2. Productivity with such equipment for a package that is 25 mm x 25 mm can roughly reach 1,500 units per hour (UPH). With the price of the equipment into the million-dollar range, the initial capital expenditure to start a production line and to further add capacity can easily be problematic for contract manufacturers with varying production loading from their end customers.

By comparison, a spray coating process is far more scalable and flexible. A typical spray coating platform will require ~1 m^2 in floor space. A batch curing oven will typically run ~1 m^2 or an inline curing oven can be added for greater automation but at the trade-off of additional floor space. A single batch oven can typically serve curing parts from multiple spray coating platforms. Spray coating equipment with the batch oven can be sourced for a fraction of the cost of sputter coating equipment. A single spray coater can produce comparable or higher UPH for the same 25 mm x 25 mm package. With the low cost of the spray coater itself and the ability of the oven to serve multiple coaters, the equipment cost for starting a small coating production and increasing production capacity as loading increases is much more practical.

While the overall cost of ownership is lower for spray, consumable material costs for spray coating will naturally show a higher cost per unit. Sputtering for EMI shielding generally uses pure copper as the core shielding layer; therefore, the consumable cost is relatively low. Spray materials for EMI shielding can include different metals, including silver as well as other value-add technologies; this results in a relatively higher cost compared to sputtering pure copper. However, in large volume manufacturing conditions and with an optimized spray process, the overall cost per unit of spray coating is lower than sputter. Thus, optimized spray material consumption can further improve the cost advantage of spray.

Resulting from this study on reducing fluid consumption, there has been a further evolution of the spraying and dispense technology for applying the EMI shielding fluid to different substrates. Recently, modifications to the spray coating equipment have resulted in a marked improvement in the overspray conditions and width of the overall spray pattern. Current default spray patterns result in roughly an 8-mm wide spray area. The most recent design changes to the spray head have allowed the ability to adjust and control the width of the spray pattern (overspray condition) from the 8-mm width down into the 2-mm width range while maintaining target coating thickness and uniformity (Figure 7). Reducing the spray width has been a significant improvement in the process capability as it opens the door for more selective coating to only target areas, significantly reducing material consumption. In at least one case example, this ability to selectively spray-coat target areas of a substrate allowed for reducing the cost of the spray coating process by more than 50% of the cost of the end customer sputter process.

Jet Dispensing for Greater Selectivity

With the desire to further improve on selectively coating or compartment shielding structures, jet dispensing offers an attractive potential solution. Figure 8 shows an example process found in a growing number of SiP devices where an integrated EMI shielding structure creates partitioning within a single package. To fill such a trench, a highly con-

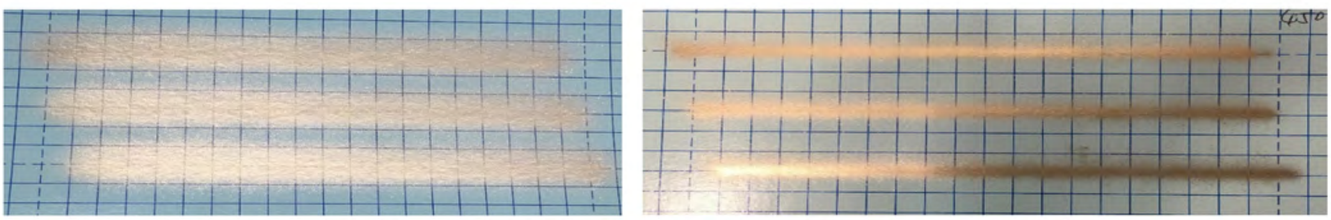

Figure 7: An 8-mm spray pattern (L) versus 2-mm spray pattern (R).

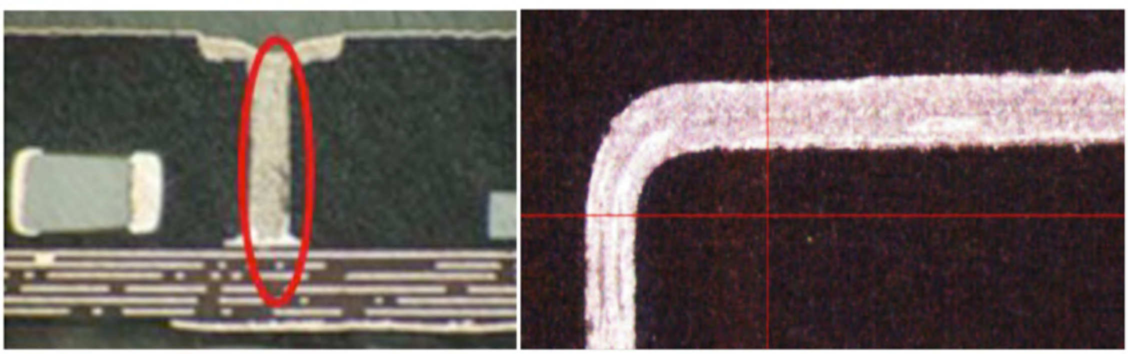

Figure 8: Cross-section example of a filled trench with Paste C.

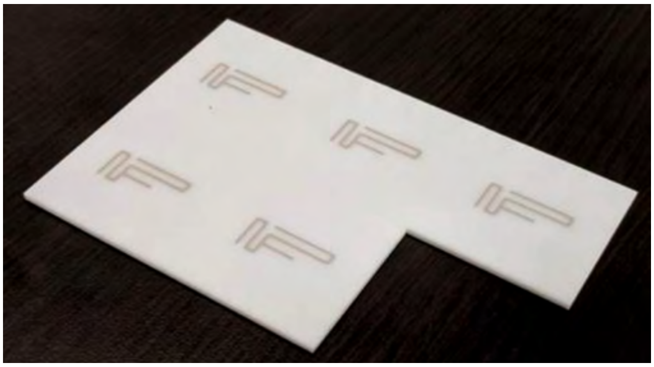

Figure 9: Jetted lines of conductive paste approximately 300 µm wide.

ductive paste with optimal rheology is jet dispensed (Paste C).

Jet dispensing offers some significant advantages in terms of process controls as well as productivity when compared to auger valve dispensing. In addition to increased productivity, jet dispensing also allows for smaller discrete dots of fluid to be dispensed. Leading-edge technology in jet dispensing provides excellent control for the in-air stream width of the fluid and better enables further improvements for new trench-fill applications as the SiP packages continue to narrow the trenches and increase the depth to width ratio.

With further improvements in fluid formulation to meet requirements for jetted line thickness, width, and surface adhesion, it is expected that jet dispensing will open the doors for further improving selectivity coverage and enabling new packaging structures. It is also possible that jet dispensing conductive pastes will allow for more additive manufacturing techniques and make possible for new applications such as flexible circuit trace printing or on-package antenna printing (Figure 9).

Conclusion

Sprayed EMI shielding has become a viable and attractive alternative to sputter coating. Advancements in material formulations, as well as the methods of applying these materials, allow for comparable performance and thickness as sputter coating. In addition, spray coating offers far more flexibility for different types of substrates that can be coated as well as allowing for greater selectivity for placement of the shielding material. Through optimizing the spray coating process and patterning, spray can achieve a comparable or better cost per unit when compared to sputter coating. Spray coating further offers superior scalability for growing production capacity with low capital investment. Lastly, further innovation in the dispensing of shielding materials is leading the way for highly precise shielded areas and conductive trace creation through jet dispensing.

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References

1. R. Urmi, N.J. Cho, Y.C. Kim, S.W. Yoon, W.K. Choi, P. Marimuthu, "Packaging and Integration Strategy for mm-Wave Products," IMAPS 14th International Conference and Exhibition on Device Packaging, 2018.

2. S. Djukic, "5G, From Anywhere: Overcoming The Challenges of Indoor Connectivity," *Electronic Component News*, May 7, 2018.

3. M. Szuch, A. Morita, G. Wong, M. Sakaguchi, H. Umeda, "EMI Shielding: Improving Sidewall Coverage With Tilt Spray Coating," IMAPS 13th International Conference and Exhibition on Device Packaging, 2017.

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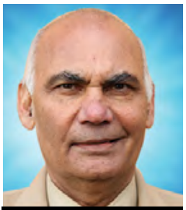
Editor's Picks from SMT007.com

1 SMT Solver: Benchmarking Defect Levels in Your Products ▶


Ray Prasad

In this column, Ray Prasad discusses why zero defects may be a desirable goal but not a realistic one. He also shares some industry data as proof, which you can also use to benchmark defect levels in your products. Finally, he also addresses the choices when selecting components that have a big impact on the level of defects you should expect.

2 Digitalization: Key to the Future of Electronics Manufacturing? ▶


Neil Sharp

Electronics manufacturers have long relied on automation to streamline their production processes. The concept of the smart factory takes this one step further with artificial intelligence (AI), robotics, analytics, big data, and the internet of things (IoT) promising an even greater level of autonomy, agility, and connectivity.

3 Zulki's PCB Nuggets: Three Die Attach Methods for Microelectronics Manufacturing ▶

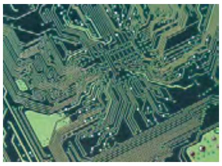

Zulki Khan

Die attach technology is increasingly being applied in PCB hybrid manufacturing (i.e., combining traditional SMT manufacturing with microelectronics) to comply with the requirements of small PCBs, especially rigid, flex, and combination rigid-flex circuit boards. These smaller boards are used in a variety of IoT, wearable, and portable applications.

4 Smart Manufacturing Roadmap: Data Flow Considerations for the Electronics Manufacturing Industry ▶

The 2019 iNEMI Roadmap features a new chapter on smart manufacturing. The chapter identifies key technology gaps and needs and offers recommendations to guide the electronics manufacturing industry in realizing the benefits of smart manufacturing. This article is based on information excerpted from the chapter.

5 Cavity Board SMT Assembly Challenges (Part 2)



This article describes the details of a study of assembling SiP BGA packages into a cavity. It points out the challenges involved in the board cavity design and assembly of components in a cavity. The authors discussed the board design challenge of having a cavity and defining the proper depth of the cavity to accommodate the board fabricator, the product design, and the SMT assembly.

6 The Government Circuit: IPC Promoting R&D on Lead-free Electronics, Streamlined Chemical Data Reporting, and More

For the most part, working in government relations is like running a marathon, not a sprint. It can take weeks, months, or even years to formulate an industry consensus position, educate the relevant policymakers in legislatures and executive branch agencies, build alliances and broad support, and ultimately push a final action over the finish line.

7 Help Build the Industry's Future: Become an IPC Emerging Engineer or Mentor

IPC's Emerging Engineer Program provides professionals early in their careers an opportunity to learn from industry mentors about IPC standards development, and to obtain education and training for professional development.

8 In Search of Operational Excellence: Becoming the Preferred Supplier, Phase 1—Transform Your Company's Culture with Lean Sigma


Alfred Macha

In the first part of this column series about becoming a preferred supplier to your customers, Alfred Macha provides the fundamental concepts to transform your company's culture with Lean Sigma. Read on.

9 Powerful Prototypes: The Ideal Bill of Materials


Duane Benson

A good portion of a quality electronics build is simply the result of clear information. Out of the set of files containing the information required by your manufacturing partner to ensure a quality build, the bill of materials (BOM) is deserving of extra attention.

10 National Circuit Assembly Appoints New President


Stephen Lehocky

National Circuit Assembly has appointed Stephen Lehocky as the company's new president.

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Career Opportunities

Career Opportunities

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NEPCON South China 2019 ▶
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Shenzhen, China

SMTA International 2019 ▶
September 22–26, 2019
Rosemont, Illinois, USA

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September 25–27, 2019
Delhi NCR, India

electronica India 2019 ▶
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