

Optimize the Dispensing Process with True 3D Inspection: An Update on the Journey Towards Zero Defects

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ABSTRACT

Manufacturers increasingly rely on conformal coatings to enhance the reliability of their products in challenging environments. These coatings play a crucial role in protecting electronics from moisture, debris, corrosion, and mechanical stress, thereby reducing failure rates. However, ensuring the effectiveness of these coatings is challenging due to the limitations of current inspection methods.

The constraints of manual or 2D inspections prevent accurate measurement of critical aspects such as material thickness and coverage, especially for transparent materials. Consequently, today's conformal coating inspection processes lack the reliability offered by true 3D inspection.

Traditional laser-confocal and electron microscopes, although capable of measuring three-dimensional shapes, fail to inspect transparent materials due to their shallow penetration depth. Optical systems that use UV light are limited to simple 2D presence detection.

L.I.F.T. technology (Laser Interferometry for Fluid Tomography) provides a solution with non-destructive 3D inspection, enabling precise measurement of wet and dry fluids, including material thickness, at production speeds. This technology utilizes low-coherence interferometry and Near-Infrared Light (NIR) to capture images through multiple layers of a fluidic structure, regardless of transparency.

This presentation will consist of four sessions. It will start by examining the overall market situation, focusing on major applications in the SMT industry and highlighting several conformal coating inspection challenges. Following this, an update on potential solutions to overcome these challenges will be introduced. Finally, the presentation will explore updated methods to achieve a zero-defect process, surpassing current limitations.

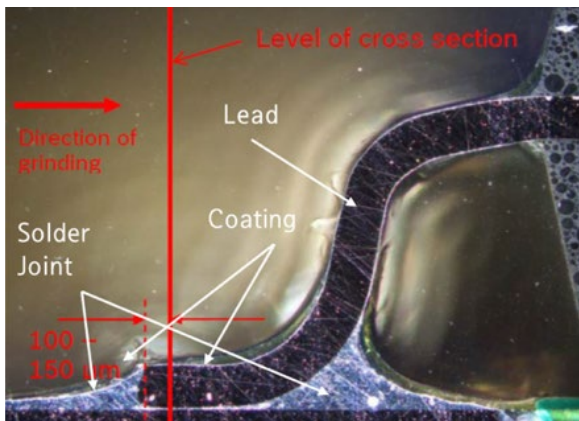
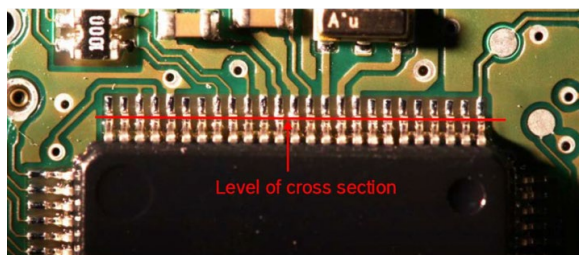
INTRODUCTION

In the pursuit of manufacturing excellence, the concept of "zero defects" has become a cornerstone for quality-driven industries. Achieving this ideal requires an intricate balance of precision, technology, and continuous improvement in production processes. Dispensing processes, such as conformal coating, underfill, and overcoating, play a crucial role in protecting electronic components and ensuring product reliability. However, these processes present unique challenges, particularly in terms of inspection and quality.

True 3D inspection technologies have emerged as a transformative solution in this domain, offering unparalleled accuracy and reliability in detecting defects that traditional methods might miss. This whitepaper explores the advancements in 3D inspection technologies, highlighting how they optimize dispensing processes and contribute to the journey toward zero defects.

CRITICAL ROLE OF DISPENSING PROCESSES

Dispensing processes, including conformal coating, underfill, and overcoating, are integral to the protection and performance of electronic components. Conformal coating, for example, involves applying a thin, protective film over a printed circuit board (PCB) to shield it from environmental factors such as moisture, dust, and chemicals. Similarly, underfill is used to distribute stress in electronic assemblies, while overcoating enhances the durability of medical devices and other specialized applications. A cross section of an IC lead is shown in picture 1.



Picture 1: Cross-section of IC lead

The reliability of these coatings directly impacts the longevity and functionality of the final product. However, ensuring consistent and defect-free application is challenging, particularly given the complexity and variability of modern electronic assemblies. Traditional inspection methods, which often rely on 2D imaging, may fail to detect subtle defects such as bubbles, splashes, and thickness variations, leading to potential failures in the field.

MATERIAL CLASSIFICATION

The industry classifies conformal coatings by type according to their chemical makeup:

Acrylic Resin (AR)

This coating is easily applied and removed, is easy to work with, and is affordable. However, it has low resistance to chemicals, solvents, and abrasion, and is not ideal for high-temperature and harsh environments.

Urethane Resin (UR)

This coating offers excellent chemical, humidity, and mechanical wear resistance, but suffers from long cure times with a risk of peeling. It is also difficult to remove.

Epoxy Resin (ER)

This coating provides excellent protection in harsh environments due to its resistance to abrasion, moisture, chemicals, and humidity. However, it is difficult to remove and may shrink during curing.

Silicone Resin (SR)

This coating performs well in extreme temperatures and has excellent humidity, corrosion, and chemical resistance. It also adheres well to most PCB materials and components. However, it is the most difficult coating to remove, requiring chemical solvents or aggressive abrasion.

Parylene (XY)

This coating offers the best resistance to extreme temperatures and solvents, has high dielectric strength, and is transparent. It forms at room temperature and does not require curing time but is difficult to remove and must be scraped off. It also requires chemical vapor deposition equipment and is not highly rated for prolonged outdoor exposure.

There are several options for coating technologies, and the best choice for your application should primarily depend on the level of necessary protection. The application method and the ease of rework are also crucial factors but should be considered secondary to the required protective performance.

INSPECTION STANDARDS

A global association that helps electronics manufacturers, cable and wire harness manufacturers and electronics industry suppliers build electronics better, commonly known as IPC, has established standards governing the capabilities and requirements of conformal coatings:

IPC-CC-830

This is the primary standard for conformal coatings. It was created to provide an alternative to the older MIL-I-46058C standard when it was deactivated. IPC-CC-830C is used to qualify different conformal coating products and includes sections on materials, shelf life, curing, chemical resistance, viscosity, and appearance requirements. It also contains standards on fungus, moisture, and flammability resistance, as well as dielectric withstanding voltage and other electrical specifications. This standard is actively maintained by IPC, which updates it as needed. Current standards are noted in Table 1.

Table 1: Thickness recommended by IPC-CC-830

Conformal Coating Material Types	Material Thickness
Type AR (Acrylic Resin)	0.03~0.13mm (30 to 130um)
Type ER (Epoxy Resin)	0.03~0.13mm (30 to 130um)
Type UR (Urethane Resin)	0.03~0.13mm (30 to 130um)
Type SR (Silicone Resin)	0.05~0.21mm (50 to 210um)
Type XY (Parylene)	0.01~0.05mm (10 to 50um)

IPC-A-610

This standard covers the acceptability of assemblies and includes requirements for coating coverage and thickness.

IPC-J-STD-001

This standard covers the requirements for soldered electrical and electronic assemblies and includes a section dealing with conformal coating materials and application.

There are other key standards that include specifications and requirements for coatings:

MIL-I-46058

This is the original military-grade standard for conformal coating. The industry deactivated MilSpec 46058 in 1998 and replaced it with IPC-CC-830. Since the two specifications are similar, the industry considers conformal coatings that have been qualified to 46058 as also meeting the requirements of IPC-CC-830. However, despite its deactivation, some military contractors still require compliance with this standard.

UL94

This is an Underwriters Laboratory standard that certifies the ability of a conformal coating to self-extinguish a flame on a circuit board substrate (FR-4).

UL746

This is another UL standard that covers test procedures for the physical, electrical, flammability, thermal, and other properties of the materials, including conformal coatings, used in printed circuit boards.

FAILURE MODES

Conformal coatings isolate and protect electronics from moisture, debris, corrosion, and shock while adding mechanical stability to reduce failures and improve reliability in harsh environments like automotive, LED, military, aerospace, medical, and mobile applications. But what if the coating is too thin or defective? Failure.

Here are some common failure modes that dispense process inspection (DPI) systems can detect:

Bubbles

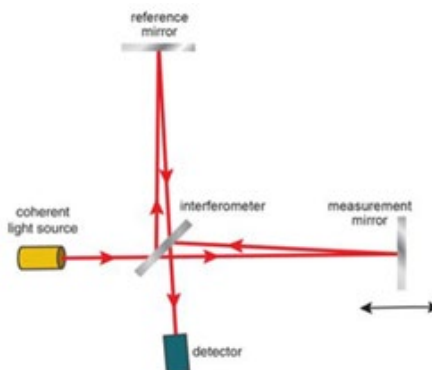
When entrapped air or solvents skin over, often caused during the drying process or multi-layer coating application, bubbles become trapped before settling out. DPI systems should be able to detect bubbles by measuring their length or the percentage of the affected area.

Cracks

Cracks leave an area exposed and less protected from moisture and dust. They usually occur when the curing temperature is too high or when curing happens too quickly. If combined with a thick coating application, this can cause the coating to fracture into sections. If a crack expands into a larger area, delamination can occur, which can also be caused by PCB cleanliness issues. DPI systems should detect cracks or delamination defects by measuring their length or calculating the affected area as a percentage.

Thickness Variations

Conformal coating thickness can present two problems: being too thick or too thin. Measuring thickness can identify common defects caused by incorrect coating thickness, including capillary flow, de-wetting, and uneven coating. These are challenging defects to detect with traditional measuring technologies and are usually addressed through destructive testing. However, a patented technology—L.I.F.T. (Laser Interferometry for Fluid Tomography)—can accurately measure coating thickness at full production speed without damaging the product. (Picture 2)



Picture 2: Non-destructive L.I.F.T. inspection

Foreign Material

Poor coating application can leave particles that may result in a short circuit or reduce PCB protection from environmental contaminants like dust, moisture, and corrosive vapors. In some products, conformal coating is applied to provide structural integrity.

If coating defects are not adequately detected, PCBs as part of a final assembly can have a reduced lifetime or, even worse, malfunction during regular operation. For example, consider modules in a car that are composed of several PCBs and require strong bonds. These modules might use conformal coating to protect against vibration and mechanical shocks. If this protection is inadequate or defective, it could cause a life-threatening accident due to an electronic module malfunction that was supposedly protected by the conformal coating.

Therefore, measuring thickness is a critical quality assessment tool that must be performed through non-destructive test at production speed.

DISPENSING INSPECTION CHALLENGES

So, what are the challenges with these parts? As you can see, manufacturers may use varied materials for conformal coating on the same product, leading to differences in thickness and color on the same type of board.

Traditional laser-confocal and electron microscopes only measure three-dimensional shapes and cannot inspect transparent materials due to shallow penetration depth. Optical systems use UV light but only for simple 2D presence detection.

Conventional 2D CCI's inspect according to UV color, making them susceptible to the board environment, leading to high false call rates. Addressing this issue requires the system to continuously adjust the region of interest (ROI). Finally, 3D thickness measurement of transparent material is challenging with existing technology due to the material's transparency.

Why is 3D thickness measurement of transparent materials difficult? In the case of IC components, as the coating flows down, it is thinner on top of the leads and thicker between the leads due to accumulation.

High False Call Rates in 2D Inspection

One of the most significant challenges in inspecting dispensing processes is the high rate of false calls associated with 2D inspection methods. Traditional 2D inspection relies heavily on visual contrast, often using UV light to detect the presence of coatings. However, this method can be susceptible to variations in the coating material's UV response, leading to false positives or negatives. For instance, bubbles within the coating can appear similar to non-defective areas, resulting in unnecessary rework and reduced process efficiency.

Difficulty in Setting Regions of Interest (ROI)

Another challenge lies in defining and setting Regions of Interest (ROI) for inspection. With complex and densely populated PCBs, manually setting ROIs for every inspection point can be time-consuming and prone to errors. This challenge is exacerbated when dealing with different board types or variations within the same board, as slight changes in color or reflectivity can require new ROIs to be drawn and adjusted, adding further complexity to the process.

Limitations in Measuring Transparent Materials

Measuring the thickness of transparent or semi-transparent materials, such as those used in conformal coatings and underfills, presents another significant hurdle. Traditional 2D methods struggle to provide accurate measurements of these materials due to their transparency and the variability in light transmission. As a result, even when 3D inspection is attempted, the measurements can be inconsistent, leading to unreliable data and potential quality issues.

THE EMERGENCE OF TRUE 3D INSPECTION

True 3D inspection technologies have been developed to address these challenges, offering a more reliable and accurate solution for inspecting complex dispensing processes. These technologies leverage advanced imaging techniques to capture detailed, three-dimensional data of the coated surfaces, allowing for precise measurement and defect detection.

Accurate 3D Thickness Measurement

One of the key advantages of true 3D inspection is its ability to measure the thickness of coatings with high accuracy. This capability is particularly important for ensuring that coatings are applied within specified tolerances, avoiding issues such as inadequate protection (if the coating is too thin) or stress-induced defects (if the coating is too thick). By providing a true 3D view of the coating, these systems can accurately assess the thickness at multiple points, ensuring comprehensive coverage and consistency.

AI-Powered Defect Detection

Incorporating artificial intelligence (AI) into 3D inspection systems has further enhanced their effectiveness. AI algorithms can be trained to recognize specific defect patterns, such as bubbles or splashes, and differentiate them from acceptable variations. This reduces the incidence of false calls, allowing for more efficient inspection processes and minimizing unnecessary rework. Additionally, AI can adapt to different inspection criteria based on customer requirements, ensuring that the system is tailored to specific quality standards.

Simplified and Intuitive Programming

Modern 3D inspection systems are designed with user-friendliness in mind, offering intuitive software interfaces that simplify the programming and setup process. Users can quickly define inspection parameters, set ROIs, and review results through a single, cohesive platform. This reduces the time and expertise required to implement and maintain the inspection process, making it accessible even to teams with limited technical backgrounds.

CASE STUDIES: ACHIEVING ZERO DEFECTS WITH INSPECTION

Several industries have successfully implemented true 3D inspection technologies to optimize their dispensing processes and move closer to achieving zero defects. The following case studies illustrate the impact of these technologies in real-world applications.

Automotive Electronics

In the automotive industry, the reliability of electronic control units (ECUs) and transmission control units (TCUs) is paramount. These components are often coated to protect them from harsh operating environments. However, traditional 2D inspection methods struggled to detect defects in the conformal coating, leading to field failures. By adopting true 3D inspection, manufacturers were able to accurately measure coating thickness, identify bubbles and splashes, and ensure consistent quality across all units. This resulted in a significant reduction in defect rates and improved overall reliability.

Semiconductor Manufacturing

Semiconductor devices, particularly those using flip-chip or ball grid array (BGA) technology, often require underfill to manage thermal stress. Ensuring the correct application and thickness of underfill is critical to the device's performance and longevity. True 3D inspection allowed manufacturers to measure the fillet height and width of underfill with precision, ensuring that the material was applied correctly and consistently. This not only improved yield but also reduced the likelihood of device failure in the field.

Medical Device Production

In the production of medical devices, such as continuous glucose monitors, overcoating is used to enhance the device's durability and biocompatibility. The application of these coatings must be precise to avoid compromising the device's performance. True 3D inspection technologies provided the necessary accuracy to measure the height of overcoating, detect any bubbles or voids, and ensure the coating was applied uniformly. This level of control was essential in maintaining the standards required for medical devices, ultimately contributing to better patient outcomes.

THE FUTURE OF DISPENSING INSPECTION

As manufacturing processes continue to evolve, the demand for more advanced inspection technologies will only grow. True 3D inspection represents a significant step forward in this journey, offering the tools needed to achieve zero defects in dispensing processes. However, the future holds even greater potential, with ongoing developments in AI, machine

learning, and sensor technology poised to further enhance the capabilities of 3D inspection systems.

Integration with Industry 4.0

The integration of 3D inspection systems with Industry 4.0 initiatives will play a crucial role in the future of manufacturing. By connecting inspection systems to a broader network of sensors and data analytics platforms, manufacturers can gain deeper insights into their processes, enabling real-time monitoring, predictive maintenance, and continuous improvement. This will not only enhance the effectiveness of inspection but also contribute to more agile and responsive manufacturing operations.

Expansion into New Applications

While true 3D inspection has already proven its value in areas such as automotive, semiconductor, and medical device manufacturing, its potential applications are vast. As technology continues to mature, it is likely to be adopted in a broader range of industries, including consumer and renewable energy. Each of these sectors presents unique challenges and opportunities for 3D inspection, further driving the development of specialized solutions.

Enhancing Resolution and Speed

The advancement of sensor technology and processing power will enable 3D inspection to achieve even higher resolutions and faster processing speeds. This will allow for more detailed inspection of increasingly complex boards, as well as the ability to inspect at higher throughputs without sacrificing accuracy. Such improvements will be critical in meeting the demands of modern manufacturing, where speed and precision are equally important.

CONCLUSION

The journey toward zero defects in dispensing is challenging but achievable. True 3D inspection technology has emerged as a powerful ally in this quest, providing the accuracy, reliability, and flexibility needed to ensure the highest quality levels. By overcoming limitations of traditional inspection, 3D inspection enables users to detect defects early in the process, reducing waste, improving yields, and ultimately delivering better products to market.

As technology continues to evolve, it will play an increasingly central role in the future of manufacturing, driving the industry closer to the ideal of zero defects. For manufacturers committed to quality and continuous improvement, the adoption of true 3D inspection is not just an option—it is a necessity.