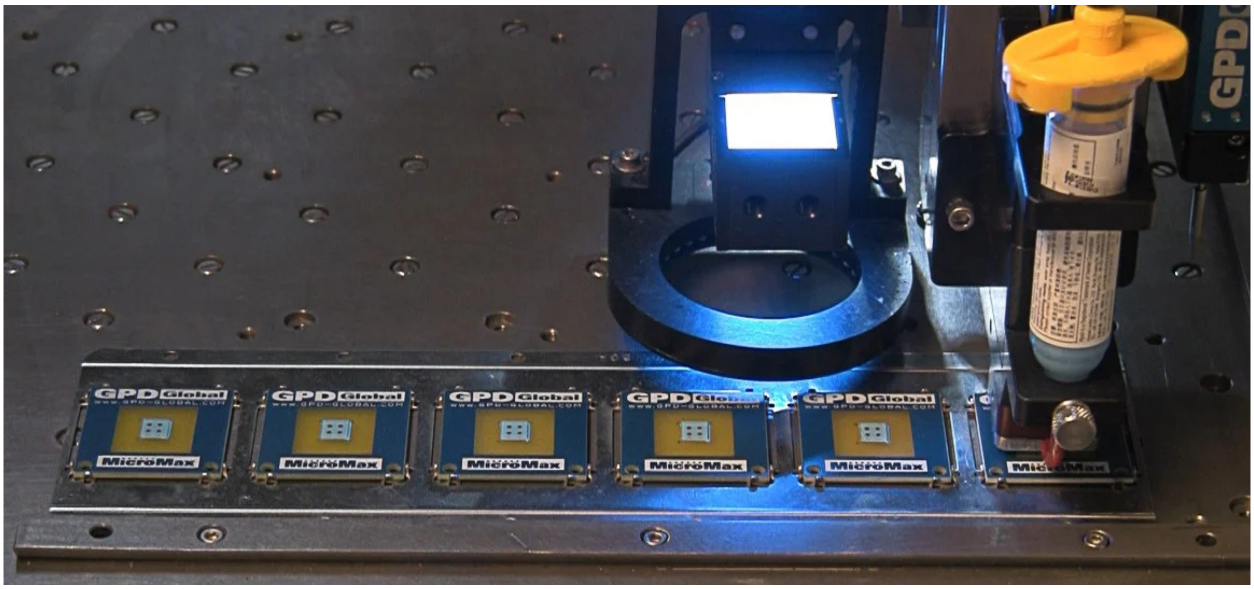
Underfill Materials Dispensing in Electronics Manufacturing Applications



In electronics manufacturing, "underfill" refers to a material that is applied to fill the gap between a semiconductor device, such as flip-chip assemblies, Ball Grid Arrays (BGA), or Chip Scale Packages (CSP), and the substrate, such as a PCB or flex circuit. It is also important in 3D ICs and advanced packaging technologies that involve stacking multiple chips or integrating multiple functions into a single package.

Underfill materials are essential in modern electronics manufacturing and are used extensively to enhance the reliability, performance, and longevity of electronic assemblies. These materials improve mechanical strength by enhancing the mechanical bond between the chip and substrate, reducing the risk of solder joint failure due to mechanical stress.

In applications where it is important for the assembly to withstand thermal cycling, underfills improve thermal cycling performance by reducing the risk of failures due to thermal expansion and contraction. Another key benefit of underfills is their ability to provide a protective barrier against moisture, contaminants, and other environmental factors.

Underfills can be categorized into four different types: capillary flow and no-flow underfills, as well as molded and wafer-level underfills. This article will focus on capillary flow and no-flow underfills in dispensing applications.

Dispensable Underfill Materials for Electronics Manufacturing

Capillary flow underfills (CUF) are dispensed along the edges of the component after reflow soldering. The material flows by capillary action to fill the space between the chip and substrate and is typically thermally cured, depending on the resin system. Capillary flow underfills usually show excellent thermal cycling performance and are a good choice for high-reliability applications.

No-flow underfills (NFU), on the other hand, are applied before component placement. During the reflow process, the underfill flows and cures simultaneously with the solder joints. By combining the soldering and underfilling steps, it streamlines the process, reducing the overall assembly time. However, they also come with disadvantages such as increased process complexity, potential for voids and incomplete coverage, limited material choices, and potentially lower thermal and mechanical performance compared to capillary flow underfills. Capillary flow underfills, while requiring an additional process step, generally provide better control, flexibility, and reliability for high-performance applications.

No-flow underfill is preferred over capillary flow underfill in certain applications where its unique characteristics and benefits align well with the manufacturing process and performance requirements. In high-volume production environments where throughput and efficiency are critical, no-flow underfill can simplify the manufacturing process by reducing the number of process steps and handling operations. In highly automated assembly lines, this can lead to significant time and cost savings. Where space is at a premium, such as in mobile devices, wearable electronics, and other compact consumer electronics, the ability to apply underfill in a single step can be advantageous since the reduced handling and processing can also help maintain the integrity of small and delicate components. For BGA and Chip Scale Package components, no-flow underfill can also be a benefit. Its ability to flow and cure in the same step ensures that all fine-pitch connections are properly encapsulated without additional process complexity.

The mechanical strength and excellent thermal cycling performance of capillary flow underfills make them often the first choice for environments with extreme thermal and mechanical stress, such as automotive applications, aerospace, and defense electronics, where reliability under harsh conditions is critical. For high-density interconnect (HDI) applications where components are closely spaced, resulting in numerous small gaps, capillary flow underfills can effectively fill these spaces to enhance mechanical stability.
In AI-driven server and data center applications, where large high-power chips are common, capillary flow underfills help manage thermal expansion and improve the reliability of solder joints in these systems.

Underfill Material Properties

Several key properties should be considered when choosing a capillary flow or no-flow underfill. One of the most important properties of an underfill is its viscosity, as it is essential for ensuring the material spreads uniformly and fills the gaps between components and the substrate. The curing mechanism is equally important; for instance, no-flow underfills must cure during the reflow soldering process, meaning the material must withstand soldering temperatures without degrading. Good thermal conductivity of the underfill helps dissipate heat generated by the electronic components, which is critical for maintaining performance and reliability. Ideally, its CTE should match that of the components and the substrate to minimize thermal stress and prevent delamination or cracking during thermal cycling. Adequate adhesion to the component and the substrate ensures the assembly's integrity, especially under mechanical and thermal stress. The underfill should also be capable of absorbing mechanical stress without causing damage to the components.

Underfill Material Types

Epoxy-based resins are most commonly used for both capillary flow and no-flow underfills. They offer strong adhesion to various substrates, a high Young's modulus, good thermal conductivity, and material stability.

Acrylate-based resins also provide good adhesion; these underfills can be formulated to have low viscosity and they cure fast.
Silicone-based underfills typically have a low Young's modulus, excellent thermal stability, and good resistance against moisture and chemicals.
Hybrid underfills combine properties of different resin systems, such as epoxies, acrylates, and/or silicones, to achieve a balance of desirable

characteristics, including enhanced thermal conductivity, improved flexibility, and faster curing times.

Thermoplastic materials are also used in some no-flow underfill formulations. They are reworkable but usually have a lower modulus compared to thermoset resins such as epoxy.

Considerations for Electronics Manufacturing: Optimizing Dispensing Techniques for Underfill Materials

Underfill materials are applied either with traditional nozzle dispensers or through jetting, a process similar to inkjet printing that offers precise control over shot size. Although jetting can be somewhat more complex to set up and requires slightly higher initial costs, it is more precise, reduces material waste, and is significantly faster than traditional dispensing. This makes it the preferred method for high-volume production, especially for smaller, fine-pitch components or complex geometries found in mobile devices, wearable electronics, and advanced packaging. Additionally, in applications where the close proximity of the nozzle to the component risks direct contact and potential component damage between the part and the dispensing system, jetting serves as a viable alternative to traditional nozzle dispensers.

Dispensing underfill materials in electronics manufacturing presents several challenges. Achieving uniform coverage without voids or gaps demands precise control over the dispensing process. Advanced dispensing equipment with accurate flow control ensures consistent application by managing the viscosity of the underfill material to match specific dispensing conditions, thereby improving flow and reducing the risk of void formation. Highly accurate integrated weight scales are used for mass flow calibration through precise software control, automatically adjusting the dispense timing and flow rate with high-resolution pump controllers to compensate for any variations in flow rate due to viscosity changes over time or from slight differences from batch to batch to prevent voiding.

Another challenge is the potential for underfill material to cure prematurely during the dispensing process, which can lead to clogging and inconsistent flow. This issue can be mitigated by carefully managing temperature and humidity conditions in the manufacturing environment. Using materials with tailored curing profiles that provide sufficient working time before curing can also help. Underfills are applied more quickly and accurately in a heated environment compared to room temperature, which is why advanced dispensing systems incorporate in-line preheating stages. These stages bring the substrate and components to the desired temperature before starting the underfill application, thereby improving throughput. Continuous temperature monitoring, such as with IR cameras, ensures that the underfill is applied within the appropriate process window.

Ensuring proper adhesion between the underfill material, the component, and the substrate is critical. Inadequate adhesion can lead to delamination and mechanical failure. Surface preparation techniques to enhance bonding can include plasma cleaning or applying adhesion promoters. Selecting underfill materials with good inherent adhesion properties tailored to the specific substrate material is also important to improve reliability. A key concern for high-volume production is maintaining throughput while ensuring quality. Automated dispensing systems with real-time monitoring and feedback controls can help maintain high production rates without compromising quality. Implementing inline post-process inspection techniques such as automated optical inspection (AOI) or X-ray inspection can quickly identify and address any defects, ensuring consistent product quality.

Conclusion – Underfill Dispsensing in Electronics Manufacturing

Underfill materials are essential in modern electronics manufacturing for their ability to enhance mechanical strength, thermal management, and environmental protection of electronic assemblies. Each type of material serves specific purposes such as bonding, protecting, insulating, and conducting, and therefore should be selected based on the requirements of the application. They play a crucial role in ensuring the reliability and performance of high-density and high-performance electronic packages, making them essential in the production of advanced electronic devices. Understanding and overcoming the challenges in dispensing underfill materials through precise and intelligent process control, environmental management, and surface preparation is crucial to enhance their effectiveness and reliability.

Read More About Underfill Materials Dispensing in Electronics:

Underfill Dispensing for Medical

Capillary Underfill Dispensing / Progressive Cavity Displacement Dispensing

Underfill Software