Underfill Update

MATERIALS AND PROCESSES

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Underfill is a special encapsulant that protects the chip, enhances the thermomechanical performance and makes the entire structure more robust. The most common encapsulation is epoxy overmolding where melted resin-hardner-filler is injected around and over the device and chip carrier assembly, followed by thermally hardening into the familiar plastic package.

Flip chips of the early 1960s used low-expansion ceramic substrates that more closely matched the thermomechanical properties of the chips. Modern flip chip technology uses lower cost, but higher expansion materials, particularly organic substrates. But the excessive thermal mismatch between the chip and organic substrate produces stress and strain on the tiny interconnect structure that typically is a solder joint. Each thermal cycle causes solder joints to elongate and then compress until they fatigue and eventually crack (Figure 1). The simplest solution is to add underfill between the chip and substrate. Underfill locks the chip and substrate together so they move in “lock step” with little differential movement. Simply put, underfill mechanically links the low-expansion chip to the substrate and constrains its higher expansion so that the interconnect joints are preserved and high reliability is restored. Figure 2 shows the underfill protection mechanism.

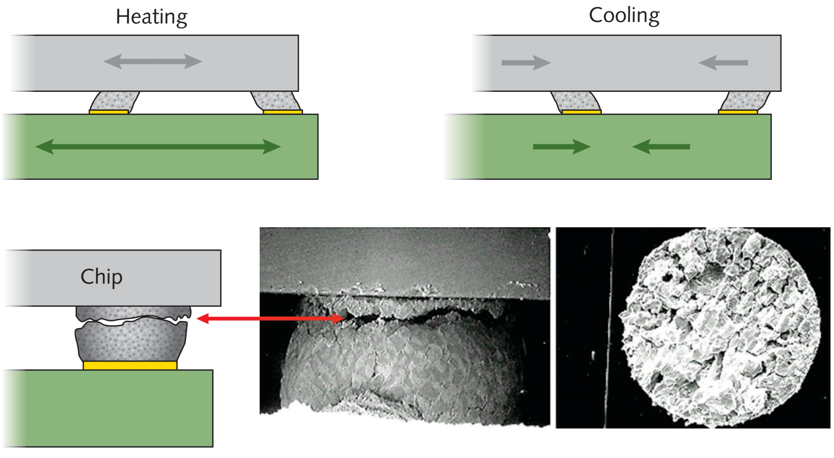

Figure 1. Stress and strain.

Ideal Underfill

Underfill should be easy to apply, process rapidly, bond tightly to the chip and substrate, and have the proper modulus and coefficient of thermal expansion (CTE) for reliability under harsh conditions. Reworkability is a valuable feature. The CTE should be close to the value of the joint. Only the X-Y plane expansion of the chip-substrate is mechanically coupled, making the underfill CTE less critical for this plane. However, the underfill vertical plane is only restrained by the tiny interconnect joints and excessive expansion reduces reliability. Matching the CTE of the underfill with that of the joints eliminates vertical strain. Since most polymers have a CTE that is three or four times higher than the target value, addition of lower expansion filler is the popular solution. But while filler provides the desired final properties, it also causes most of the problems for the underfill before cure. While liquid, post-applied or capillary underfill is still the de facto standard, it may not be the right system for the ideal underfill.

Classes of Underfill

Capillary Flow Underfill. The fill process requires that the underfill reach a fluid state. While gravity, pressure or a vacuum can be used to move the underfill into the chip-substrate gap, surface ten-

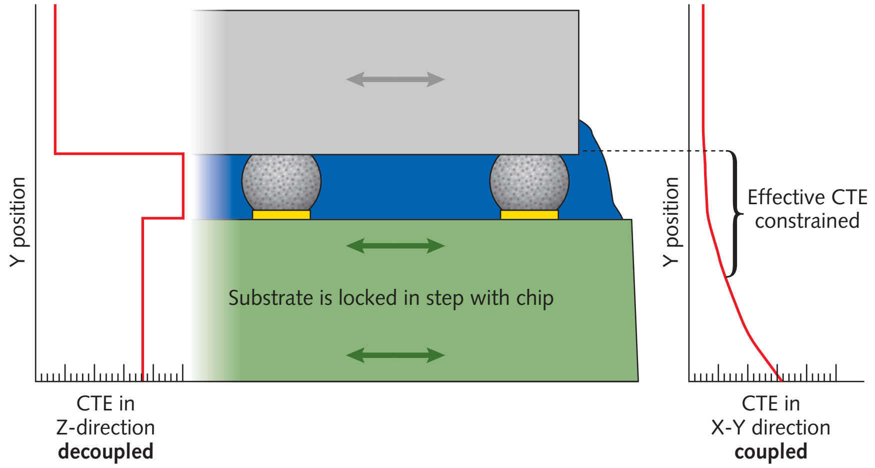

Figure 2. Underfill mechanism.

sion called capillary flow, is used. Vacuum has been used for underfill-like materials (VUF), but the process is used primarily for encapsulating micro-ball grid arrays. Capillary flow exploits the basic wetting principle of surface chemistry: intramolecular attraction exceeds intermolecular forces. The underfill resin molecules must be more strongly attracted to the chip and surface substrates than to each other so that an "advancing contact angle" is created and rapid wetting occurs. The surface tension of the underfill must be lower than the surface energy of the solid surfaces and surfactants typically are used to reduce surface tension. The energy of wetting is the engine that pulls the underfill along the gap, while the resistance of viscosity acts to retard the flow.

Although early capillary underfills had slow flow rates because of higher viscosity resins and fillers with poor morphology, today's materials flow rapidly — especially when the substrate is heated to reduce viscosity. This appears to be the practical limit of increasing flow rate. So while capillary flow underfill (CFU) is the most popular class, other types hold out the promise of greater productivity.

Molded Underfill. Plaskon and others have demonstrated that assembled flip chips can be simultaneously overmolded and underfilled using transfer molding machines. The process is suited to BGAs, and has had some commercial success.

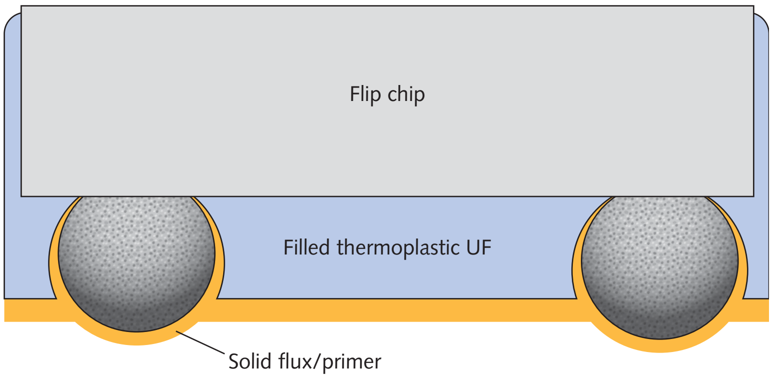

Figure 3. WUF.

Pre-dispense/'No Flow' Underfills. Considerable research and development has been directed toward underfills that can be applied to substrate before the flip chip is assembled. The pre-applied type of underfill must also provide the flux activity for the solder bumps to form joints with the substrate pads. Most underfills today are based on hardeners that provide some level of flux action, but more aggressive flux agents can be added.

The pre-applied underfill chemistry must be slowed down, since standard products are designed to cure quickly at 150° to 165°C. A boost to 215°C, up to 240°C, experienced during soldering greatly accelerates polymerization. The rate doubles for every 10°C. A rate above 200°C can result cause a standard underfill to harden well before solder has melted and formed joints. Pre-applied underfills require a total reformulation. Some products designed for Sn-Pb will not work at temperatures for lead-free solders.

Several companies offer pre-applied underfills, but NUF has been slow to be adopted. One issue is that filler in the underfill can interfere with solder joint formation. Leaving out filler solves the soldering problem, but produces strain on the chip interface. However, nanoparticle filler may solve the problem. The NUF process begins with dispensing underfill onto the assembly site. This process must be carefully controlled for acceptable results. The underfill must be symmetrically dispensed, or the chip will tend to skew or move off center. Ideally, the solder reflow profile provides sufficient curing.

Solid Underfills Applied to Substrate. Conventional wisdom suggests that underfills must be liquid, but solid "underfills" have been in use for decades. Anisotropic conductive adhesives (ACA) can be viewed as a solid underfill, although some might argue that this is a stretch because they contain a small percentage of conductive particles. However, flip chips bonded to glass are assembled with adhesive containing no conductive filler. Gold bump to gold pad pressure connections have been used for LDC drivers for about 20 years. The adhesive shrinks upon curing by UV through the glass panel to create a connection "tension spring."

One company offers a solid film or "resin sheet" underfill. The sheet is first laminated to the substrate with a custom machine. The flip chip assembly step, just like ACA bonding, requires force to be applied so that the chip bumps displace resin and make contact with the circuit pads. Once again, a special flip chip bonder must be used. While the resin film underfill demonstrates that solid underfill is possible, the benefits provided appear to be somewhat offset by requiring a laminator and a customer bonder.

Solid Wafer-level Underfills. The best site for solid underfill is the bottom of the flip chip. A flip chip with built-in underfill and flux assumes characteristics of a chip scale package. The solid underfill must also provide flux properties. A readily reworkable underfill could transform the flip chip into a true package (a package is removable), and this is easier with WUF.

There are at least two approaches to construct a ready-to-assemble flip chip "package." A single material with combined flux and underfill can be used. But a two-layer system has important advantages.[1-4] Layer 1 can be the underfill that contains filler and is preferably made with thermoplastic resin. Thermoplastic films and pastes are presently used for reworkable die attach applications and some are applied as pastes to the back of wafers, followed by drying. These systems can be modified with appropriate fillers to become underfills applied to the active side of the die. Layer 2 contains a solid flux without filler, and is applied only to bumps. Figure 3 shows the optimized WUF concept. Note that a fillet is possible, using a patented process where the chips are singulated, expanded on Nitto Tape and then coated.

The ultimate underfill process is transparent to the assembler. Wafer-level flux/underfill should require no force during assembly, although a product that requires a flip chip bonder will still have high value. Solid film that melts at 80° to 120°C can quickly wet the substrate. Polymerization follows gelling, after solder joint formation.

Conclusion

CUF underfills flow rapidly and cure in less than 5 minutes. However, the time and equipment burden required for underfilling limits flip chip advancement. Pre-applied systems improve productivity. But, solid flux/underfill, as an integral part of the flip chip, is the logical path for optimizing and fully enabling this technology. True reworkability would transform the flip chip into a real chip scale package to take advantage of the SMD infrastructure. Reports suggest that WUF is feasible and a product is likely. This will have major ramifications for the packaging industry. **AP**

References:

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