The Packaging Revolution: BGAs, CSPs and Flip Chips (1998)

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Introduction

We are unquestionably in the midst of a powerful and profound Packaging Revolution that continues to gain momentum. The driving force is the fervent pursuit of *faster-smaller-cheaper* electronic products to satisfy an every increasing customer demand. This revolution has brought Area Array packaging concepts into center field. Ball Grid Array (BGA) packages have quickly been adopted because they take advantage of the existing Surface Mount Assembly infrastructure while providing assembly yield improvement and performance enhancement. However, the BGA and other Area Array packages have added new challenges for packaging and assembly materials suppliers and the equipment makers that serve the industry.

A second phase of this revolution involves the quest for minimal packaging. While BGAs continue to satisfy the new needs of much of the industry, some applications require the ultimate in miniaturization as more power is concentrated into portable and even wearable products. The physical limit for size, of course, is the IC itself. Although chip-size packaging may be the final destination, a plethora of micro-BGAs and Chip Scale Packages (CSPs) have arrived and many have already found some level of acceptance by our industry. The Flip Chip, a true chip-size package, is also beginning to move into high volume production in such products as pagers, cellular phones, disk drives and computers. Once again, all of these newer products require new materials, new equipment and new processes. Fortunately, the intense activity from the electronic packaging materials industry and the dispensing and assembly equipment vendors has kept up with demand. This article will highlight the latest developments in materials and machines that are helping propel and accelerate the Packaging Revolution.

Electronic Packaging Materials

The Package

Let's start with a description of the available packaging materials and then highlight some of the recent breakthroughs. We can look at a package as having four basic components, the device, a wiring structure, protection and an interface. The package is the translator that marries the solid state IC to the printed circuit board (PCB). The IC is an inorganic structure that can be made incredibly dense while the PCB is typically an organic structure with a pattern of copper conductors with much courser features. The package must therefore provide a geometric translation as well as a mechanical one.

Packageless?

Do we really need a package? What about bare die assembly like Chip-on-Board (COB) and Flip Chip (FC)? Actually, both of these die assemblies are typically packaged. The packaging is added after the assembly process - sometimes called post packaging. With COB, the wiring structure is introduced using a wire bonder and packaging material is added last in the form of encapsulant, sometimes called glob top. In the case of Flip Chip, protective packaging is added in the underfill step. Note that the chip is flipped so that the underfill ends up on the active side of the die just like the encapsulant in the COB process. Now we are ready to look at the specific materials of electronic packaging.

Die Attach Adhesives

The IC, or die, must be firmly attached to the packaging substrate, lead frame or circuit substrate with a special adhesive. The die attach adhesive mechanically bonds the chip to the platform and may also serve as a heat and electrical conduit. Many chips generate substantial heat that must be carried away to prevent damage. The chip design may also require that the back of the die be electrically connect to the platform. When both features are required, a silver-filled adhesive is used. When only thermal conductivity is needed, the adhesive filler can be a high thermal conductivity dielectric such as aluminum nitride (AlN). Adhesives are most commonly sold in paste form although films, such as Staystik from Alpha Metals, are also used. The most common method for applying die attach pastes is by needle dispensing.

Encapsulants

Chip-on-Board products, including most of the BGAs, are protected with encapsulants made of polymer composites. Epoxies are the most popular resin system because of their balanced properties and well established infrastructure. Fillers, such as silica, are added to reduce the thermal coefficient of expansion (CTE) and thereby reduce thermomechanical stress. There are three major categories of encapsulants: damming compounds, cavity fill (well fill) and free flow. Although they can have similar cured properties, their rheological characteristics are very different as are the dispensing processes. Damming compound, as the name implies, is used to form a dam around the area to be encapsulated. A dispensing machine “draws” the damming pattern with high viscosity material. The dam insures that the low viscosity cavity fill encapsulant, added next, will be contained. The dam & fill materials are used with BGAs and other products where the location of the encapsulant must be precise. Both materials are hardened simultaneously for efficiency. Success with the dam & fill process requires the right dispensing equipment and process to be covered in a later section. The free flow encapsulant is design to be used without containment and usually has a mid-range viscosity to limit flow out. Once again, the dispensing equipment and process is critical.

Underfill

The Flip Chip is bonded directly to a carrier or circuit without wires using a Direct Chip Attach (DCA) process. The junction is formed by a conductive joint such as solder although conductive adhesives are also being used today. Solder-bumped FCs are attached to the circuit by solder reflow. A small gap results between the substrate and chip that should be accurately controlled. Typical gaps range from about 15 microns to more that 100 microns. The very small Flip Chip joints are placed under mechanical strain during thermal cycling unless the chip and substrate have nearly the same CTE values. Since the most popular substrate for Flip Chip is cost-effective organic, there is a significant thermomechanical mismatch between the silicon chip (CTE = 2.3 ppm/C) and the PCB (CTE = 15 - 25 ppm/C). Under such circumstances, the FC assembly would be expected to fail in a relatively short time during thermal cycling as the joints fatigued and fractured. Fortunately, the materials suppliers have supplied a practical and cost-effective solution in the form of underfill.

Underfill is a liquid polymer-based composite that is designed to flow under the Flip Chip in a predictable manner. The resin system is highly filled with special silica to match the CTE to that of the joining material, about 25 ppm/C for eutectic solder. The underfill is then hardened by thermal polymerization so that it “locks” the chip/substrate structure together and moves stress away from the joints. The result is a substantial increase in joint reliability. Once the FC is properly underfilled, the assembly will normally pass well over 1000 thermal cycles (-55^{o}C to 125^{o}C). The underfill process requires precise dispensing of material at a specific temperature. The dispensing equipment should be capable of applying heat to the substrate to increase the flow rate. The challenge of rapidly flowing a highly filled material between a narrow gap requires ingenuity from both the materials supplier and equipment builder.

Some exciting developments have occurred during the past year for underfills. Most are aimed at boosting productivity on the assembly line. Very fast flow underfills are a reality. Rates of more that 2.5 cm/minute are available. Fast flow requires careful dispensing, however, since air can be trapped with an incorrect application program. Cure speed is now down to only 5 minutes without sacrificing reliability. These so called, snap flow/snap cure underfills are already in use on cellular products and pagers. We are also beginning to see added features like *Color Change on Cure*. Alpha Metals recently introduced the color change option. The underfill starts off as a brilliant red, but converts to an amber color during the final stage of polymerization. If you’re seeing *red* at the end of your oven, the process is out of control.

CSP Materials

The Chip Scale Package (CSP) is a bridge between the larger BGAs and Direct Chip Attach. The CSP can bring some of the best features from each technology. CSPs, such as the Tessera μBGA, can be tested, easily handled by SMT lines and reworked as required. The μBGA and other CSPs often require special encapsulating materials and equipment. The μBGA uses an elastomeric polymer that is dispensed inside of the package in their manufacture. Early on, the filling process was plagued with problems that suggested specialized equipment. Camalot has since designed a dispenser that applies material under a vacuum thus solving problems with air entrapment. Once again, the machine-materials interface is key to success.

Other Packaging Materials

We have covered the common polymer-based adhesives and encapsulants, but BGAs, μBGA and FCs require a system for joining them to the PCB. Solder is the universal interconnect "glue" of electronics. Nearly all BGAs and most FCs use some form of solder that is formed into a sphere or nearly spherical shape. The solder balls, called solder spheres by producers like Alpha Metals, are attached to the bottom of the BGA. Alpha Metals, the world leader in sphere production and technology, makes products in several alloys and a variety of sizes. The attachment process and sphere specifications are described in detail in a later section.

What about Flip Chip bumps, how are they generated? While there are over a dozen processes in use or on the horizon, most commercial methods involve solder or conductive adhesives. Solder can be applied by vacuum, plating or printing. However, one of the most exciting new processes involves fluid jetting of solder that will be covered in a later section.

Conductive SMT adhesives, long used by the hybrid circuit industry, are becoming popular for some Flip Chip assembly. The adhesives are typically made by adding silver flake and powder to liquid epoxy resins. These adhesives, although related to die attach products, are formulated to print or stencil in fine pitch format. The adhesives offer product-specific advantages over solder. They are processed at low temperatures (120^o to 150^oC) that make them compatible with temperature-limited substrates like polyester flexible circuits. While lead, found in most solders, contains trace amounts of thorium and other elements that emit α-particles, the adhesives have none. This makes them well-suited for memory Flip Chips which are very sensitive to α-particles.