step 10

Encapsulation:

Materials, Processes and Equipment

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The electronic package might appear to be just a tiny black container for holding the chip, but it really is a sophisticated system when we consider the tasks to be accomplished, and under extreme conditions. The package continues to be the bridge between the disparate industries of semiconductors and PCBs. But as the chasm between chips and PCBs grows wider, the packaging challenge grows larger. Some package attributes are crucial, others are valuable, and still others are product specific. While the electrical interconnect structure is obviously vital, it's much less complicated than the dielectric materials, especially the encapsulant. The conductor may be a metallic element or simple alloy, but the encapsulant is a complex composite with as many as a dozen ingredients.

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The enclosure, whether it's a plastic encapsulant, ceramic or metal, determines the package type, or class. Glass (the original hermetic package; the vacuum tube), ceramic and metal enclosures meet the highest level of requirements — full hermetic. All commercial plastic packages fall below this level and are classified as non-hermetic. But newer polymers and processes may add a third class, the near-hermetic package (NHP). In this article, we examine the common plastic encapsulated package system that is also known as polymer encapsulated microelectronics (PEM). The standard materials are thermoset epoxies that are applied over the chip by transfer molding. Later, a disruptive approach to encapsulation that uses thermoplastics, the other broad class of polymers, and injection molding is discussed.

Figure 1. Encapsulated plastic packages. Courtesy of Motorola.

Plastic Packages

The introduction of the plastic non-hermetic package 50 years ago was a major step along the road to low-cost electronics. Just consider the ramifications of moving back down the technology curve to a time when each active device was packaged in a rather large glass enclosure. Now, think about the 125 million active devices in a modern computer chip. Electronics and life as we know it would be impossible without solid-state electronics and modern packaging.

While discrete devices were the first to use plastic encapsulation, the dual in-line package (DIP) was an important breakthrough in packaging because it used low-cost plastic and manufacturing automation. The DIP became ubiquitous and feed-through automated assembly eventually became a reality. But the DIP (shown in Figure 1 with SMDs) and other feed-through packages eventually lost favor when a multitude of surface mount technology (SMT) packages were commercialized throughout the 1980s and the merits of surface mount assembly were recognized. The 1990s continued to advance SMT, as the need to miniaturize and boost lead count became important drivers for continuing development. The area array packaging revolution gained momentum as the preferred solution for size reduction and superior performance and this

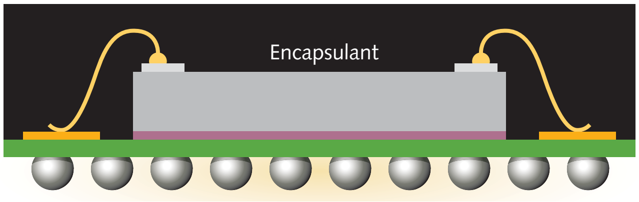

Figure 2. BGA die up.

trend continues today.[1] Figure 2 shows a common BGA package design that uses epoxy encapsulation.

Encapsulants come in two physical forms, solids and liquids, but their compositions are similar. The solids types are epoxy molding compounds (EMC) are a blend of solid epoxy resin, hardener, flame retardant, filler, and several additives. The EMC preforms, or "hockey pucks" shown in Figure 3, are used in transfer-molding machines. We'll cover encapsulation processes shortly. Liquid encapsulants have similar compositions, but the resin and hardener are liquids to allow the material to be directly applied onto the chip and interconnect (typically by wire bonding) using dispensed instead of molding.

Almost all of these encapsulants use epoxies that are not all that different from the original ones developed all the way back in 1927.[2] The epoxies react with many kinds of molecules, and those that are useful for producing products are called hardeners. Anhydrides are one of the most important reactants, or hardeners, and are used in many encapsulants and underfills. Epoxies are noted for versatility and balanced properties but are rather average in general characteristics. Additives are required to bring their properties to a level were they can function as encapsulants. Flame retardants, especially bromine-containing epoxies, are added to reduce flammability and meet specifications. The average epoxy coefficient of thermal expansion (CTE) is several times too high for encapsulation, but adding low CTE filler, like silica, brings it to an acceptable level. The typical black color comes from adding colorant.

Both liquid and solid epoxies must be thoroughly polymerized to be useful as the package enclosure. EMCs are actually low melting mixtures of resins and other constituents that must be polymerized into non-melting structures that have good mechanical strength and enough thermal stability to survive the solder assembly process. The same is true for liquid encapsulants. Polymerization, the formation of high molecular weight structures by chemical reactions, occurs when heat is applied to a system that contains epoxy resin, hardener, and usually an accelerator to increase the reaction rate. The resulting thermoset structure is highly cross-link in 3-D and cannot melt. Excessive heating, however, can cause the polymer to degrade by thermal decomposition, a present concern with the increasing temperatures required for many lead-free solders. Epoxies also absorb significant amounts of moisture, and the explosive release as steam, called popcorning, is exacerbated by higher soldering temperatures.

Encapsulation Processes and Equipment

The most common process is transfer molding. Loaded packages (connected chip) are fed into the molding machine and into a mold cavity. The package substrate can be a metal lead frame (MLF) or a higher density platform like a BGA assembly. The EMC puck is preheated in the molding machine and then melted to a liquid state so that it can be injected into the mold cavity to surround the chip and wire bond structure. The mold is designed so that the metal leads or a BGA bottom circuit is not encapsulated. But everything else, including the IC, is covered with the liquefied mix. Heat causes the encapsulant to polymerize, the mold is then opened, and the part removed. A post bake may be required to achieve full properties and some post processing may be used. For example, when an array of packages is overmolded (area or flood molding) as if it were a single unit, the individual packages must be singulated by sawing, or some other cutting method. The molded packages can now be tested and packaged in tape and reel, or some other suitable format for pick-and-place equipment.

Figure 3. EMC performs.

Figure 4. Cavity-down package.

Liquid encapsulants typically are applied using automated needle dispensing equipment by one of two basic methods. A cavity-down (die down) package, shown in Figure 4, is filled with a low viscosity liquid encapsulant after the die is attached and bonded. The encapsulant must be hardened by heating, or baking the assembly for up to 30 min. The process is more complicated for a die-up BGA. A retaining dam must be formed, and this can be done by using a needle dispenser to "draw or write" a border around the perimeter of the BGA substrate. The damming compound typically is a liquid epoxy with a thixotropic agent, like fumed silica, but otherwise is similar to the epoxy "fill" that is next dispensed inside the dam. The two epoxy encapsulants are cured together by heating. A two-stage cure, the first at mid-range temperature followed by a higher full-cure, may be used to minimize shrinkage and warp. Liquid encapsulation is more often used for prototyping and shorter production runs.

Other Encapsulation Processes

The main encapsulation methods have already been discussed, but others are noteworthy. Encapsulants can be printed using a thick stencil or be "flowed in" with a stepped stencil, a process developed several years ago by one company*.[3] While stencil printing is highly productive since it is a parallel process, the method has been used in few applications, primarily due to poor cosmetics. By the time the encapsulant paste is thick enough to prevent slump during curing, the material tends to cling to stencil walls and produce raised edges, or "dog ears".

The molded underfill (MUF) process, uses a modified EMC (finer filler) and a standard transfer molding machine, but the mold is designed to force underfill under a flip chip while simultaneously overmolding the package.[4] While MUF still appears to be a good approach to increased productivity, the process has had only limited acceptance. One issue has been the need to either add a vent hole in the package or to use a vacuum system to remove the air that is displaced from the mold cavity.

Near-hermetic Packages

Those who have worked in the plastics industry realize that most of the products we call "plastics" are made from thermoplastics, not thermosets. Computer cases, nearly all electronic product housings, interior automotive components, Scotch tape, food packaging, carpets, CDs, recording tape, credit cards, clothing, trash bags, beverage containers, and hundreds of thousands of other products, are made from ubiquitous low-cost thermoplastics.

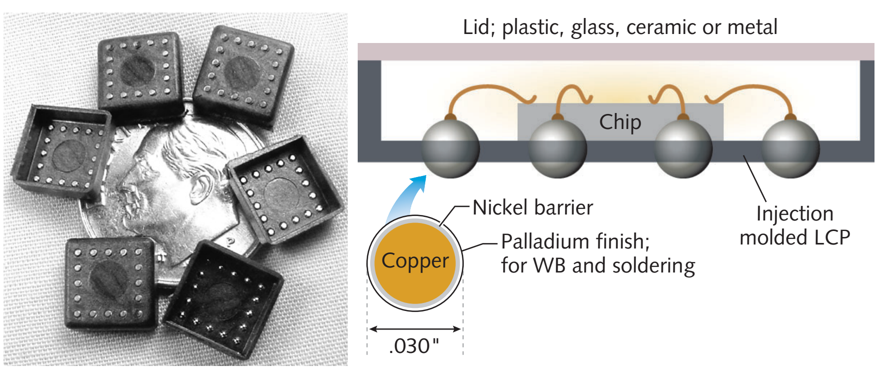

Figure 5. A low ball prototype (left) and diagram (right) are shown here.

Remeltable thermoplastics are easily formed into complex shapes or into thin films by thermo-shaping processes like injection molding and extrusion. So why aren't thermoplastics used for electronic packages? The answer 50 years ago, was that this class of plastics could not take the heat of soldering. But that's no longer true.

In fact, our favorite plastic, liquid crystal polymer (LCP) melts at more than 300°C. Commercial LCP resin is inexpensive, passes V-O without halogens and generally beats EMCs in every category. For example, moisture absorption is 10× lower for LCPs. That makes popcorning nearly impossible, unless that substrate is a "sponge."

Recently, several developers worked with LCPs for electronic packaging using injection molding (IM). There are many more injection molding machines in the world than transfer molders, but not in the packaging area. There is no waste with thermoplastics, since any scrap can be reground and reused. In the not-so-distant future where recycling of electronics will be required, thermoplastics will be the obvious solution. Hardened epoxies cannot be reused and often are classified as hazardous waste. Matters may be made worse when popular bromine flame-retardants are banned in the future. It's time to look at the new packaging class, NHP.

So, how do you make NHPs? The simplest way is to insert-mold a conductor array with plastic, place the array in the mold, and shoot. The conductor set can be a metal lead frame, a flexible circuit, or a handful of tiny balls. Our approach is to insert molding of balls to make a low ball BGA shown in Figure 5. The plated copper balls are placed in the dimpled mold cavity, shot with resin, and the finished cavity BGA is ejected. This is a 9-second process that can produce thousands of packages per hour by adding more cavities per mold. The metal balls replace the metal lead frame, since they protrude into the package for wire bonding, and outside through the base for SMT assembly. Once the die is attached and connected to the package, a plastic or glass lid can be sealed using near-IR (Figure 6). This is a fast, clean, volatile-free lid-seal process, and the package appears well suited for MEMS that often require a cavity. Finally, MEMS can have a low-cost package. Since transparent lids can be used, there may be a fit with MOEMS and optoelectronic applications. Where is the encapsulant? It is the molded plastic that encloses the chip and interconnect assembly, although the chip is actually surrounded by air. Time will tell if electronics is ready for modern thermoplastics, or another 50 years of epoxies. AP

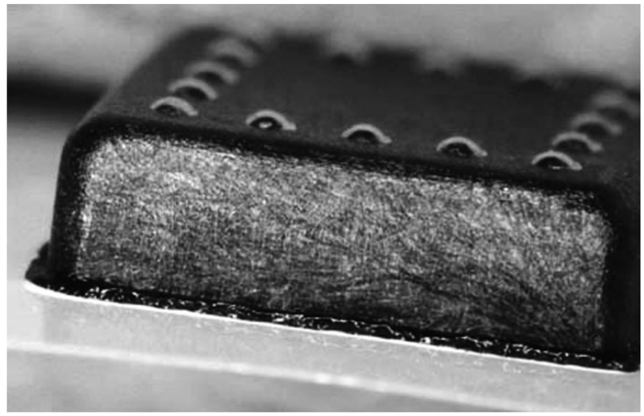

Figure 6. Laser-sealed plastic led sheet.

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