Thermoplastic Electronic Packaging: Low Cost – High Versatility

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Abstract
Thermoplastics have started to gain acceptance in some of the more challenging areas of advanced packaging, including MEMS, where lower cost, cavity style packages are required. Thermoplastics, like LCP, PPS and PEEK, can withstand exposure to over 300^{o}C thus assuring lead-free solder capability. Many polymers offer superior moisture resistance, can be formed into micro-precision packages in just seconds, and are easily recycled. Epoxies, the non-hermetic package standard for more than 50 years, can't be remelted for reuse, have unremarkable moisture properties, and typically contain elements, like bromine, that put them on the environmental target list. Some halogen compounds have already been banned. Fortunately, several modern high-performance halogen-free thermoplastics are inherently flame retardant and these nontoxic materials have an excellent record of use in telecommunications, medical, and automotive fields.

This paper will describe advances in thermoplastic packaging produced by injection molding (IM), including designs for MEMS, MOEMS, power chips, high-intensity LEDS, and photonics. The processes include shaping, formation of conductors, and enclosure by laser or dispensed adhesives for lid sealing. The newest concepts, such as the 3D stackable package, will also be discussed in terms of thermoplastics.

Introduction & Background
The package is the *bridge* linking two critical but divergent industries - semiconductors and printed circuit boards (PCBs). The chasm between chips and PCBs continues to wider and the package designers' challenge intensifies. Some package attributes are absolutely essential, others are beneficial, but many are product-specific especially for new types of devices. Essential requirements include providing the electrical interconnect structure between tiny, extremely dense semiconductors and large scale - lower density PCBs. Signal routing can be crucial for some applications like *flip chip* (FC) but not in every case. The package is the *physical scale* translator that makes the ultrafine chip features compatible with any interconnecting substrate. Environmental protection is usually a requirement, but the level is product-specific and device-dependent. Protection levels range from minimal for highly passivated chips to extreme, for certain MEMS, MOEMS, and *optoelectronic* (OE) devices that may even require a high vacuum.

The earliest electronic packages were made of glass and all were hermetic. They include the vacuum tube and the Cathode Ray Tube (CRT) that could only operate with a vacuum since these products belong to the *age of vacuum electronics*. Later, hermetic packaging technology adopted ceramics and metal that are the primary materials today. Nearly 50 years after the introduction of the glass hermetic vacuum tube, plastic packaging made the breakthrough. The introduction of the plastic component package changed our industry forever because cost was greatly reduced and automation became practical. While the semiconductor industry tends to get credit as the enabler for low cost electronic products, the plastic package also deserves tribute.

In many ways, the component packaging industry is a very dynamic business that continues to provide solutions for connecting increasingly complex devices to ever-shrinking circuit boards in package configurations with higher density form factors. But the packaging industry can also demonstrate considerable inertia when it comes to fundamental changes. Understandably, changes that would impact the long-established infrastructure are the most persistently resisted. Yet, design iterations seem to out of control resulting in too many package styles, each with countless variations. But how new are "new" designs? Many of the "new" packages can be traced back at least 40 years. New is old in many cases! Flip Chip, wire bonding, chip scale packages (CSP), surface mount, TAB (Tape Automated Bonding), and the BGA (Ball Grid Array) were all announced by the mid-1960's.

Some say that we are in the midst of a materials revolution, but is this accurate?[1] Materials, especially encapsulants, have evolved slowly without real fundamental changes. Epoxy is still the king of packaging materials with not much more than tweaking during the past 50 years. In fact, many epoxy resins and hardeners have been removed from the market due to carcinogenicity and other health-related concerns thus reducing the formulator's choices. The fundamental plastic packaging process has also undergone only modest change. The last important cost-cutting breakthrough for component packaging took place a half-century ago when the non-hermetic plastic package was successfully introduced. The DIP, or dual in-line package, became ubiquitous, and feed-through assembly eventually became the *de facto* standard that still exists, but to a diminished level.

The DIP 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 (SMA) were confirmed. However, the early SMT designs were relatively simple modifications of the DIP pack. The metal leads could simply be bent outward into a "gull wing" shape that allowed the package to be bonded to metal pads on the surface of the circuit board instead of pushing through holes in the board. Early electronic calculators from Texas Instruments used bent DIPs for surface mounting onto flexible circuits at least a decade before the SMT revolution began. Even earlier, IBM introduced the SLT (Solidstate Logic Technology) that was a surface-mounted transistor.

Plastic packaging has focused mostly on lead frame transfer molding, beginning with the highly successful dual in-line package (DIP). Flex-based packaging, invented in the 1960's as TAB (Tape Automated Bonding), is another successful form of plastic packaging. TAB has been limited to niche applications like flat panel display drivers but growth increased when micro-packages and stacked configurations gain in use with the introduction of flex-BGAs including the Tessera □BGA.

The area array packaging revolution, commencing almost two-decades ago, has played a more significant role that continues today.[2-4] The all-metal lead-frame was replaced by a chip carrier that can be a specialized printed circuit board. However, virtually all of these package designs use thermoset polymers typified by epoxies.

Thermoplastics, the other class of plastics, can be extruded, thermoformed, injection-molded and easily recycled, but they have had very limited application during the past half-century of plastic packaging.[5] But this may be changing as pre-molded package concepts solve problems and gain traction. Traditional and newer devices, like MEMS and perhaps nanotechnology structures, are opening up opportunities for new packaging. Cavity type designs, enclosures with precise microstructures, and those that can facilitate the increasing number of optical devices, are efficiently produced using thermoplastic materials and processes. While ceramic and metal packages can also provide cavities and precise features, they do so at a much higher cost than plastics. But plastics do not provide real hermeticity as defined by MIL STD 883F and that remains an issue.[6] While some claim to have achieved plastic hermetic seals, none have demonstrated a plastic hermetic package including the authors.

Types of Packages

Metal/Ceramic Hermetic

The hermetic package is typically made from metal, ceramic or a combination since these materials provide a very high barrier to gases. These designs are cavity style packages by definition - essentially a tiny box that is ultimately sealed with a lid once the component(s) is attached and interconnected. Metal packages are typically machined and represent the highest cost, but also the most reliable packages offered today. Ceramic hermetic packages are lower in cost and can provide most of the advantages of metal and some of their own unique attributes. Ceramics are excellent thermal conductors and electrical insulators. Ceramic is less costly than metal because it can be shaped by molding the "green" pliable material that is then fired to form a hard high-barrier permanent solid. In a sense, ceramics are the inorganic analogues of thermoset plastics. Ceramic and metal packages are used to provide high reliability for conventional electronics, RF products, and MEMS/MOEMS devices. They are the only proven hermetic packages besides glass.

Plastic Non-Hermetic Post Molded

The standard plastic package is typified by the epoxy post-molded package that ranges from the original DIP to a myriad of peripheral lead and area array styles. The key feature of post-molded packages is that the chip(s) is already in place before the package body is formed by any of several methods, but most commonly, by transfer molding. The plastic package class has a much greater number of sub-types and products due to the popularity and versatility of polymers. Packages may be classified by "footprint" that has been standardized by JEDEC (once known as the **J**oint **E**lectron **D**evice **E**ngineering **C**ouncil) and other standards organizations. A ceramic package is shown in Figure 6.

Pre-Molded Plastic

The pre-molded package has a body that is formed before the chip is added. The package is typically a cavity style although it can also be a simple platform such as the type used for flip chip CPUs (Central Processing Unit). The package must be open to accommodate die attach and interconnect, but it may be sealed in a final step. A lid may be bonded, the package cavity can be filled with encapsulant, or a flip chip may be assembled without covering the device.

Plastic Packaging Manufacturing

Selecting Polymer Materials

A rather obvious vital criterion for plastic packaging materials is that the finished product must withstand the abuse of lead-free soldering. The harshest environment experienced by most packages is assembly. Accepted alloys like SAC [Tin (Sn), Silver (Ag), Copper (Cu)]; 95.1-96.5%Sn/3-4%Ag/0.5-0.9%Cu melt at 217^{o}C to 220^{o}C but are processed at up to 260^{o}C. There has been a tendency to increase the oven temperature to get better wetting of lead-free alloys. While 240^{o}C may suffice for lead-free soldering, we have used 260^{o}C in testing. Once the high temperature criterion is met, there are other requirements that are important and many are listed in Table 1 while Table 2 shows high-temperature plastic resins that can be considered for packaging. LCP remains the first choice for most developers.

Table 1

Property	Criterion
Melting point	>300^{o}C
Moisture absorption	<0.5%
Processing	Injection molding
Halogen content	~ 0
Safety	Non-toxic, no toxic by-products
Coeff. Thermal Expansion	0 – 25 ppm/oC
Flammability	V-O
Color	Variable
Cost	Low to moderate
Mechanical	Robust
Chemical Resistance	No swelling in common solvents
Electrical	Good insulator
Compatibility	Enable conductor processes; plating, etc.
Availability	Commercial; multiple source

Table 2 – Thermoplastics for Packaging

Plastic	water abs. %	MP	UL94*	CTE/30% glass
LCP	**0.02 - 0.10 %**	**280 - 352°C**	**V-0**	**0 - 20 ppm**
PEEK	0.15%	340°C	V-0	16 ppm
PPA	0.15 - 0.29 %	310 - 332°C	H-B V-0	22- 40 ppm
PPS	0.01 - 0.04 %	280°C	V-0	19 – 27 ppm

LCP = Liquid Crystal Polymer; PEEK = Polyetheretherketone
PPA = Polyphthalamide; PPS = Polyphenylene Sulfide
* May vary with filler level and type.

Environmental Factors

RoHS (Reduction of Hazardous Substances) has renewed attention to toxicity of materials. All new packages should be designed without mercury (Hg), cadmium (Cd), lead (Pb), chromium VI (Cr^{+6}), but also with the ability to tolerate the rather harsh conditions of lead-free soldering. Flame retardants, especially bromine, are under attack even with the lack of solid scientific evidence of real hazards. Some bromine compounds that have been problematic are already being restricted, but the element itself is being targeted. Bromine is accused of forming physiologically-harmful dioxins similar to materials used as Agent Orange defoliants in Vietnam. These dangerous compounds are said to form when incineration temperatures are too low. This does not seem to be an issue in the USA where EPA rules requires minimum incineration temperatures that destroy organics. But elsewhere, the solution may be to ban elements rather than correct the process. Unsurprisingly, the identified dioxins are mostly chlorine-containing, probably from ever-present PVC (Poly-Vinyl Chloride) known as “vinyl”. Since bromine does not transmute to chlorine, chlorinated dioxins CANNOT be derived from the bromine flame retardants. Alleged increases in chloro-dioxins when circuit boards are incinerated may be due to the copper that can catalyze their formation. Since halogens, the *elements of life* are under attack, prudent material selection suggests that halogens be avoided altogether. Other “legal” flame retardants, like phosphorus, may also be a poor choice because they can form toxic and physiological agents during combustion. The safest (from regulators) materials will contain only carbon (C), hydrogen (H), and oxygen (O), although nitrogen (N) and sulfur (S) should continue to be acceptable. The last two elements, N and S, generally reduce flammability. LCPs contain only C, H, and O but are inherently flame retardant because of their high packaging density and resistance to oxidation. Since filler, such as silica, is generally added to LCP and other thermoplastics, flammability is further reduced.

Thermoplastics, unlike thermosets, can be easily reused since they melt and remelt.[7] There is no net waste during manufacturing since scrap, in the form of mold runners, can be reground and added back into the molding machine. Waste epoxy is becoming a serious disposal problem so this is a good time to consider thermoplastics. While some may claimed that epoxies can be recycled, this usually means paying someone to add them to asphalt. In the future, and even under some of today's "take back" laws, discarded electronics will need to be recycled since incineration and land filling are not the best solutions. The thermoplastic package can become the easiest type to recycle since the metal, plastic components are readily separated, and the thermoplastic can be used as molding regrind just as is the case with beverage containers and similar discarded items.

Processes

Numerous plastic shaping processes are available since plastic manufacturing is ubiquitous. More industries use plastic processes than any other method category. Shaping methods include thermoforming, casting, dispensing, jetting, printing, stenciling, vacuum forming, blow molding, injection molding, transfer molding, extrusion, embossing, and a several specialty methods. Although several of these methods could be used to form plastic packages, molding dominates. Transfer molding is used for thermoset polymers while injection molding is used for thermoplastics. Both processes employ a cavity mold to create the shape. Both molding methods generally place inserts into the molds to provide the electrical interconnect; the method is known as insert molding. This topic is covered in more detail in the next section. Figure 1 compares the two molding processes; transfer vs. injection. The most important difference is that transfer molding is designed to handle thermoset prepolymers and the starting material is not polymerized although it may be B-staged, or partially polymerized. This means that transfer molding requires polymerization inside of the mold although complete polymerization may occur in an oven after the material has been hardened to a level where the package can be transferred out of the mold. While nearly any shape can be transfer-molded, including cavities, the packaging industry has focused on over-molding where the chip(s) and its carrier are placed in the mold and a molten mixture of resin, hardener, filler and other additives, typified by epoxy molding compound (EMC) is applied over the structure but contained by the mold to produce the desired package body shape. The plastic may surround the chip and interconnect or may only cover the top as with many of the BGA designs.

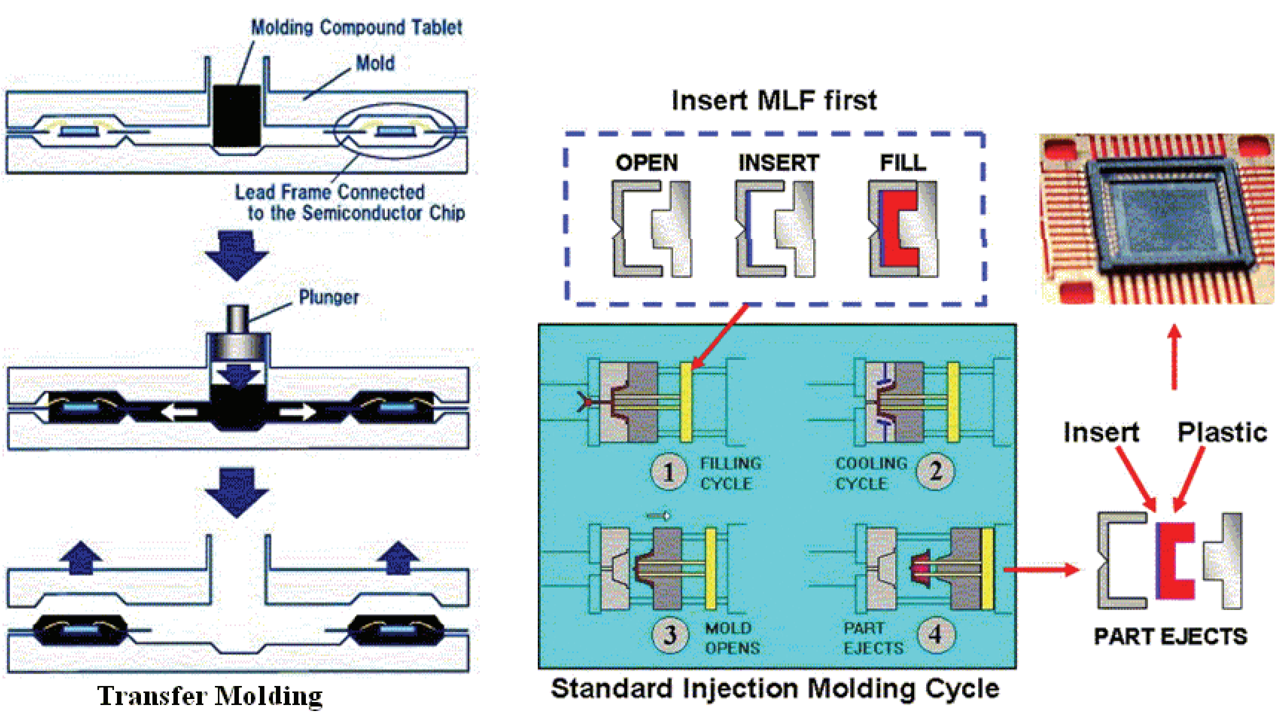

Figure 1 – Comparison of Plastic Molding Processes

Injection molding uses fully polymerized resin as the feed material. Since the resin is already polymerized to a high-temperature plastic, much of the process and equipment deals with liquefying the resin pellets. Considerable mechanical action is applied along with heat to convert the resin to the right viscosity for injection into the mold. A heated barrel with a mechanical screw is the primary means of converting the solid polymer to the liquid phase as shown in Figure 1B. Considerable pressure is applied to the molten resin making it necessary to keep mold sections tightly closed with considerable clamping force. The mold is also kept at a temperature that provides the best filling, plastic properties and cycle time by means of a heat exchanger. Since that plastic melt can be near 400°C, cooling is necessary even though the mold is generally held well above ambient temperatures.

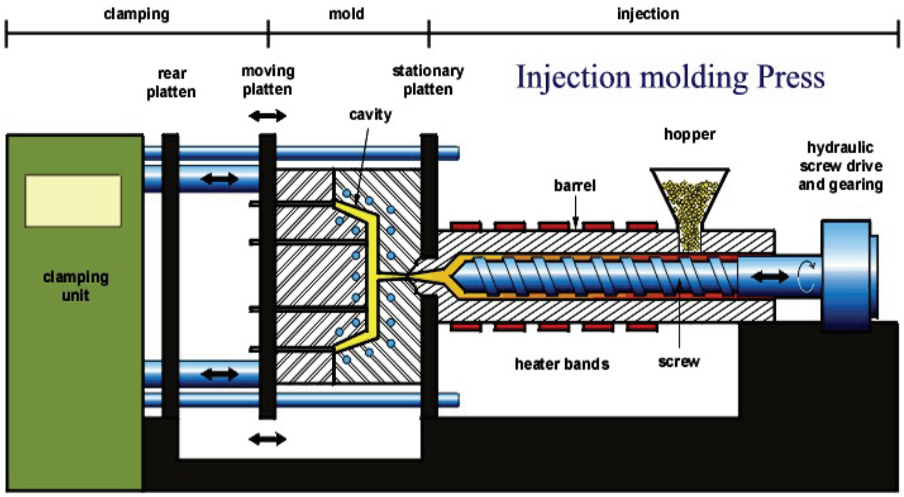

Figure 1B - Injection Molding

Conductor Technology

The easiest way to add conductors to plastic is by insert-molding a patterned metal lead frame (MLF) that will ultimately become the package terminations. The MLF is commonly used for both transfer and injection molding. While low expansion alloys were initially popular, plated copper is now common for MLFs. Since wire bonding is the most common 1st level chip connection method, the MLF finish must support wire bonding. Finishes include gold, silver and palladium that may be selectively applied. Nickel is a common base plating since the resulting package terminations must be solderable. While the MLF is a low cost, easily automated means of adding conductors it can be too limiting for several types of packages and alternate methods are available.

Area array packaging, which became popular in the 1990's typically employs a circuit type chip carrier made of rigid or flexible circuit substrate. The loaded carrier is over-molded with EMC or encapsulated with liquid epoxy by needle dispensing to produce ball grid array (BGA) type packaging. Thermoplastic can also be used with area array packaging but an over-molding equivalent is not used since the very hot and viscose resin could damage the chip, interconnect structure and substrate. Instead, the chip carrier can be insert-molded with thermoplastic and the chip added later. Flexible circuitry makes an ideal material for insert-molding and it can be manufactured and used in strip format. TAB (Tape Automated Bonding), also called TCP (Tape Carrier Package) is a type of package that is often encapsulated by dispensing or transfer molding and the product can remain in strip or reel form until the package is bonded to a PCB.

Conductors can also be applied after the package is formed but this approach is only used for thermoplastics since the package is pre-molded. Various selective plating methods been introduced over the years and several newer processes have been described. Several "direct-write" methods are available that were developed in the 1980's for 3D molded circuits although new ones have been introduced in the last few years including methods where a laser defines the conductor pattern.

Package Sealing

Pre-molded cavity packages, once loaded with devices, are generally sealed by bonding a lid although they can also be filled with encapsulant. In some cases, an encapsulant that can be a fluid or gel, is added to exclude moisture and gases prior to adding the lid. This method can only be used with MEMS if the chip is first capped. Addition of hydrophobic gel to thermoplastic cavity packages is being used for some capped MEMS inertial sensors to insure that there is no moisture-induced corrosion occurring at the interconnections.

There are several ways to bond lids to cavity packages and the process may depend on the type of lid material. Lids are typically made from metal, ceramic, glass, and plastic. Sealing methods can be divided into adhesive bonding and melting of the package, lid material, or both. In a sense, both methods can be viewed as adhesive sealing. The adhesive is either added or the package/lid material becomes the adhesive (self-bonding). Each method is now described in terms of the equipment and process.

Photonic sealing typically employs an infrared (IR) or near-infrared laser (NIR) with at least 10 watts of power. The same lasers that are used for solder reflow may work for plastic sealing. Laser sealing of plastics was one of the first laser processes disclosed soon after the invention of the laser many decades ago. The material requirements for effective laser "transmission bonding" are:

1. The lid must permit sufficient transmission of energy to interact with the package substrate (or applied adhesive),
2. The plastic must absorb enough photonic energy to melt/soften,
3. The melted plastic must bond to the lid when cooled.

The lid must be sufficiently transparent to the wavelength so that the enough energy reaches the plastic package to cause melting, but the transmission value can be less than 50%. In fact, partial absorption by the lid can enable better bonding since both materials are heated. Glass, many ceramics, and most plastics meet this criterion. While transmission bonding is an attractive method, direct heating of the lid by laser can also be effective. Metal lids will typically absorb enough energy to melt the plastic package at the interface and thus affect bonding.

Lasers can also be used to activate adhesives. Thermally-activated adhesive can be applied to the lid or package and the IR or NIR laser can selectively heat the adhesive. One laser-activated adhesive system is described in USP 6,936,644 where microcapsules of catalyst are heated and ruptured by the heat laser. But UV curable adhesives can also be used and the energy source can be a UV laser (new diode UV lasers have become available) or more traditional UV lamps. Glass lids are especially applicable because they can transmit sufficient energy to enable rapid adhesive hardening. Figure 2 shows the Speedline R&D laser used to seal both plastic and glass lids to molded thermoplastic package bodies. Most package assembly lines have dispensers.

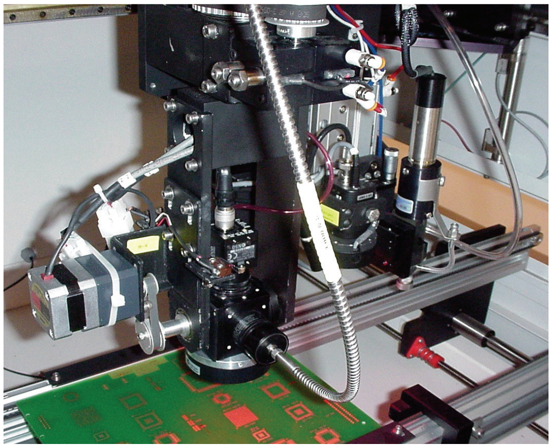

Figure 2 – Speedline R&D Laser (~800 nm)

The lid can be also be bonded by other heat-generating methods. A hot platen can be used on metal, ceramic or glass. Thermosonic bonding, long used in general plastic assembly, can also be used for lids, but we have not explored the method.

Adhesives can be applied to lids or package bodies by needle dispensing or screen printing. We have found that needle dispensing offers the most advantages that include essentially no waste, no tooling (programmed), ability to deal with different heights, high selectivity, and capability to use a wide range of materials. A modern dispenser, like the Speedline XyFlex, can also provide quality control using advanced vision systems. Figure 3 shows the basic equipment and Figure 4 is a close up. A multi-dispenser can be used to apply die attach adhesive and lid adhesive.

Figure 3 – XyflexPro Dual Line Dispenser

Figure 4 – Dispenser Close-up

Thermoplastic Package Designs

The simplest and most common design is insert molding of Metal Lead Frames (MLF) using a high- temperature thermoplastic resin listed in Table 1. The MLF is typically presented as a strip into a multi-cavity mold for better throughput, handling, and economics. The process is somewhat comparable to transfer molding using MLFs but there is a major difference. Transfer molding starts with a “loaded” lead frame; chips are already attached and bonded in a post-molded process. While thermoplastics might be used in a similar manner, this has not been desirable because of the high resin temperature to achieve a liquid state and a possible high melt viscosity that is apt to cause wire sweep, or bending of the wire bonds. Instead, bare lead frames are molded with thermoplastic using a pre-molding process. The chip can be added after the package body has been formed and is still in strip format. Figure 5 shows a strip of pre-molded thermoplastic packages before the exterior metal frame is excised and formed.

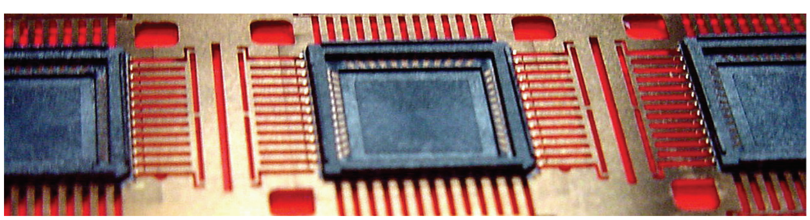

Figure 5 – Pre-molded Thermoplastic Packages (courtesy RJR Polymers)

Other thermoplastic package designs include Quad Fine Pitch No Lead (QFN) constructions shown in Figure 6. The QFN design is similar to the Ceramic Leadless Chip Carrier (CLLC) that became popular many decades ago. Figure 6 compares the Ceramic LCC to the modern plastic QFN.

CLCC (National Semiconductor) PQFN (QLP)

Figure 6 – Leadless Packages

Our own work has explored the use of metal balls, or spheres, as an alternative to a patterned leadframe. The idea was to use discreet individual pass-through interconnects instead of a traditional MLF that adds cost and waste. The Pin Grid Array (PGA) also uses discrete connectors in the form of pins, but we sought a simpler idea, and one that would allow the package to be assembled by SMT. The metal sphere is the ideal conductor shape for several reasons. First, it is completely symmetrical so that there is no orientation requirement. But equally important, the sphere is an easy shape to manufacture and metal spheres are widely available in suitable sizes. Spheres are used in everything from ball bearings to ballpoint pens. Since the sphere is a natural shape that is formed by surface tension, this form of metal is produced at low cost, Solder spheres for BGAs have been available for a long time and methods for production and inspection have evolved to a very advanced level. However, solder is unsuitable for injection molding since melting would occur in the mold. A high-melting metal, or other conductor, is required since it must serve as a “lead frame” rather than a joining material. Preferred metals include copper, copper alloys, and nickel. Copper was selected because of low cost, availability and ductility. Nickel has the advantage of being paramagnetic that could allow novel assembly and recycle separation processes to be used.

While the starting point can be a sphere, this is not the ideal shape for the finished package as will be discussed later. Figure 7 shows the insert-molding process developed by Matrix, Inc. (Providence, RI). Copper spheres, plated with gold over nickel, are placed in depressions in the mold base. We have also used copper with palladium over nickel. A simple vacuum pick & place process analogous to BGA sphere placement can be used. The mold is then closed and corresponding depressions in the top-half capture and seal off the part of the spheres to prevent resin from covering the intended connection areas. Molten resin is injected to instantly fill the mold cavity. LCP has a very low viscosity under molding conditions and extremely fine detail can be produced. The mold temperature is controlled by running water, or other fluid, through channels in the mold designed for this purpose. We have found that a mold temperature of 100°C to 150°C provides good filling. Thermal energy is actually removed from the mold since the injected plastic temperature can be nearly 400°C.

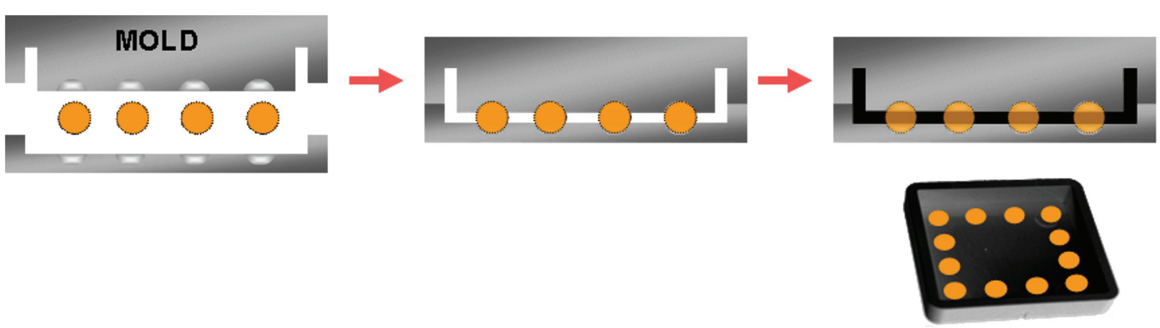

Figure 7 – Insert Molding of Metal Spheres

The resulting plastic package has approximately 1/3 of the conductor sphere protruding through the bottom and 1/3 into the interior package “floor”. Each sphere becomes the pass through electrical conduit with the top connected to the chip and the bottom soldered (or plugged into) a PCB. Although a spherical shape is well-suited for the 2nd level solder connection to the PCB, a curved surface is more difficult for wire bonding, yet possible, as shown in Figure 8. But it is a simple matter to coin and shape the copper sphere so that a flat surface is presented to the wire bonder. The mold can be fabricated with a shallow recess, or none at all, so that flattening occurs during injection molding. However, we are presently coining (flanging) the spheres as a post-operation to allow variations for experimentation. Figure 9 shows possible coining profiles as well as the present coining shape. Since the copper balls are relatively hard, the package can also be clamped into a socket for test and burn-in. In fact, the package can be plugged in to a socket in a PCB so that field repair or upgrade is possible.

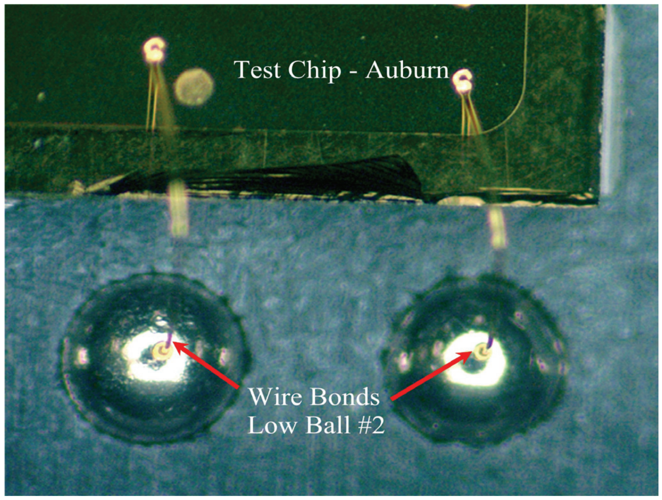

Figure 8 – WB to Sphere (Courtesy of Auburn University)

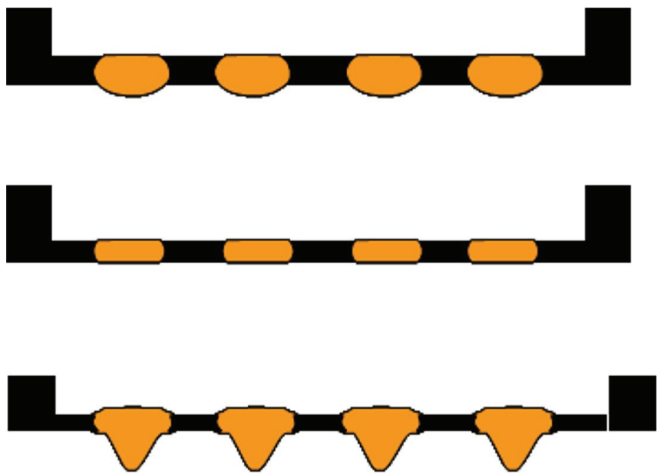

Figure 9 – Coined Bumps

Issues

Initially, we did not attempt to exactly match the TCE of the plastic body to that of copper since LCP has a low value compared to most other polymers. The gross leak testing was easy to pass, as was the JEDEC moisture test, even at level 1. However, when the new higher temperature lead-free soldering exposure conditions were used, sporadic leaking around spheres was identified and attributed to thermal mismatch stress. We are presently molding parts with new LCP resins that have a higher level of mineral filler that is expected to provide a TCE of about 18 ppm/^{o}C. But LCP properties make the challenge more complex. Crystallization during molding occurs with LCP and this changes the TCE values. LCP will actually crystallize in the liquid state and hence the name, “liquid crystal”. The result can be different levels of crystallinity throughout the part with different TCE values. Figure 10 shows properly molded and coined spheres while Figure 11 shows cracking that can occur during molding if the resin/filler is not optimized. Cracking occurred probably induced by resin nit, or confluence lines, before coining.

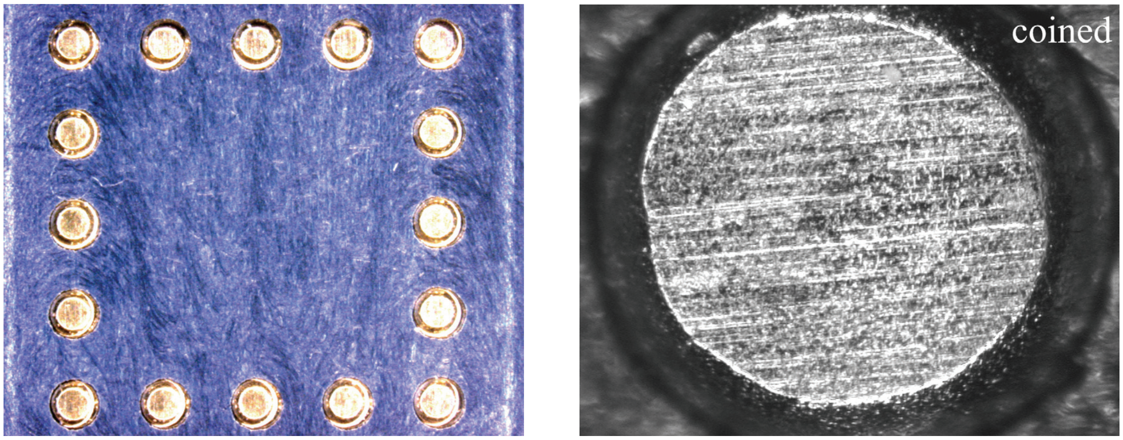

Figure 10 - LCP Packages with Coined Spheres of Copper (Au/Ni Finish)

Figure 11 – Stress Cracks in LCP around Spheres

Heat Management

Many semiconductor devices release considerable thermal energy and heat removal by the package is a requirement. The need for thermal management continues to increase as power and density factors rise. Thermoplastic packages can be ideal for adding thermal platforms. The MLF can be designed with a heat transfer platform and this is being done for thermoplastic QFNs. Our ball array design can just add spheres under the die as heat conduits. The coined spheres present significant area to the chip that can be bonded with thermally-conductive adhesive. However, a metal heat slug can also be insert-molded. The heat-transfer platform can be placed into the mold as a discrete metal pad or as a strip. In either case, the spheres remain electrically isolated so that testing can be performed without singulating. A strip of packages could be formed and die would be loaded and tested while still in strip form. Figure 12 shows one possible design. This type of package could be used for high-intensity LEDs, power devices, or anything that needs effective heat removal. The lid can also have thermal dissipation properties as shown in Figure 13. This type of package is most suitable for low I/O chips but both LEDs and power chips have very low lead counts.

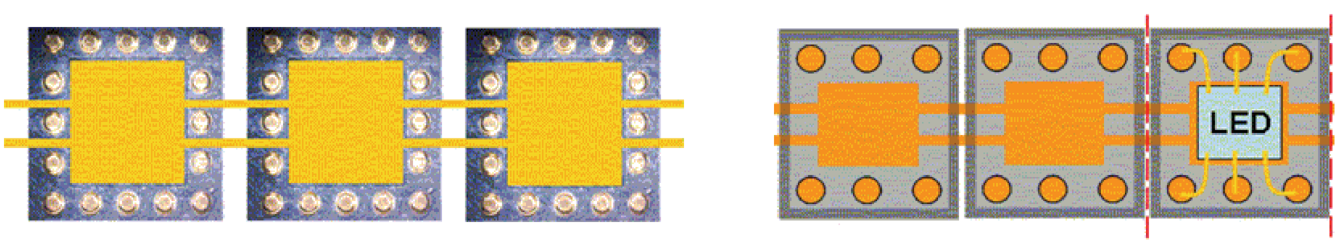

Figure 12 – Insert-Molded Heat Strip

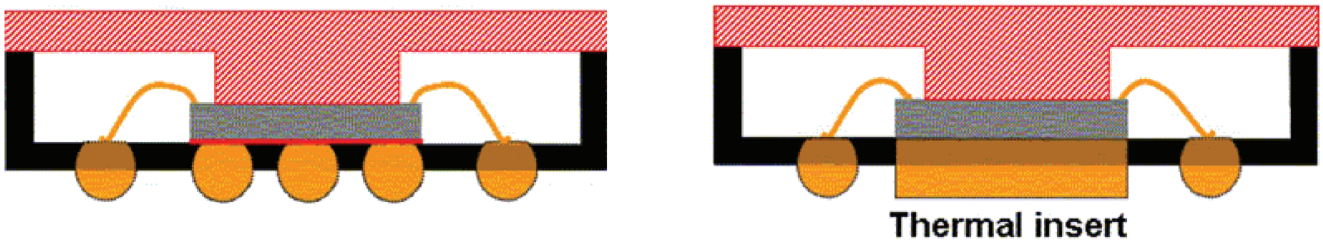

Figure 13 – Heat Management Package Designs

Stacked Plastic Packages
We may be in the finally densification phase of packaging. We have moved from packages that occupied many times more area than the die to chip scale and even chip-size configurations. The obvious next step has been to stack one chip on top of another just as has been done with dwellings for millennia by stacking floors. But we can also stack packages that contain one or more chips and there are certain advantages for both stacking methods. Plastic packages can also be configured for stacking. In fact, memory DIP packages were stacked by experimenters in the early pre-IBM-PC days of personal computers. Some may be old enough to remember when Radio Shack computer enthusiasts "piggy backed" DIP packs on top of existing arrays to double memory; this may be the first example of plastic package stacking.

The thermoplastic package also lends itself to configurations where packages can be stacked. We are considering several designs although no prototypes have yet been built. The ball array package is well-suited to stacking. The simplest approach is to leave enough sidewall clearance so that a package can be placed on top of another with balls from each making contact to enable joining. The simplest design is to wire bond chips and then connect balls by thermocompression as shown in Figure 14. The issue is with wire bonding since it is more difficult on a curve surface as mentioned earlier. There could also be a problem with compression bonding the gold-plated balls that have wire bonds attached. Alternatively, routing could be added by selective plating (shown in Figure 15) or by insert-molding a flex circuit. While a package body with walls can afford protection, a version without walls could also be viable and simpler to make. An area array molding approach, where many package platforms are molded in a single cavity, is also worth considering. The array could be singulated before or after die bonding. Since thermoplastics can be cleanly cut with a laser or by a simple hot wire, singulation would not require sawing, as is the case with area molding of thermoset packaging. Figure 16 shows the array-molding concept for stacking.

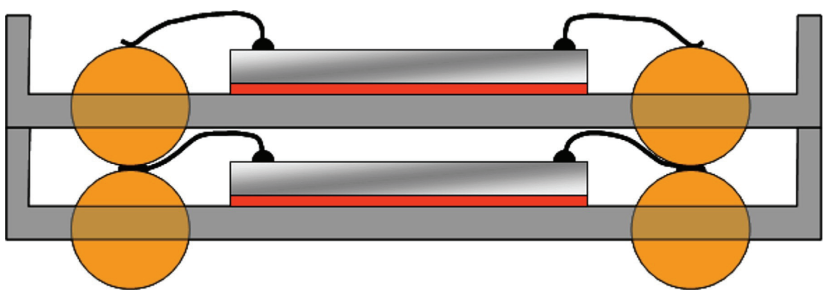

Figure 14 – Stacked Using WB and TC

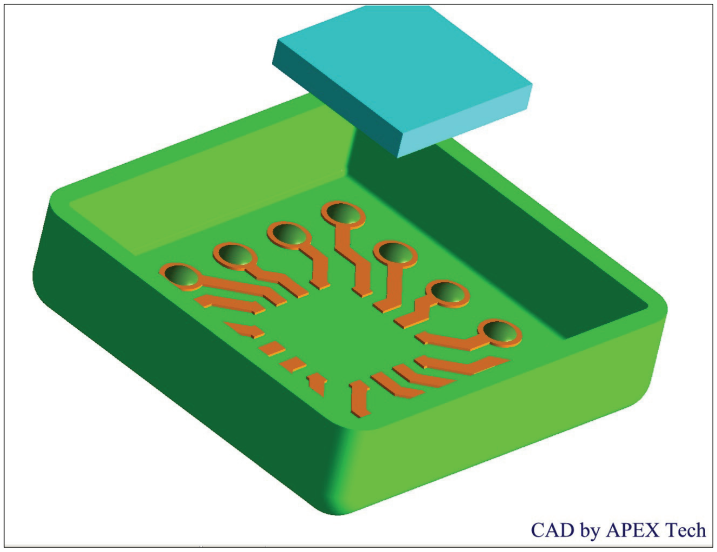

Figure 15 – Stacked Routed FC (reduce wall height for ball connection)

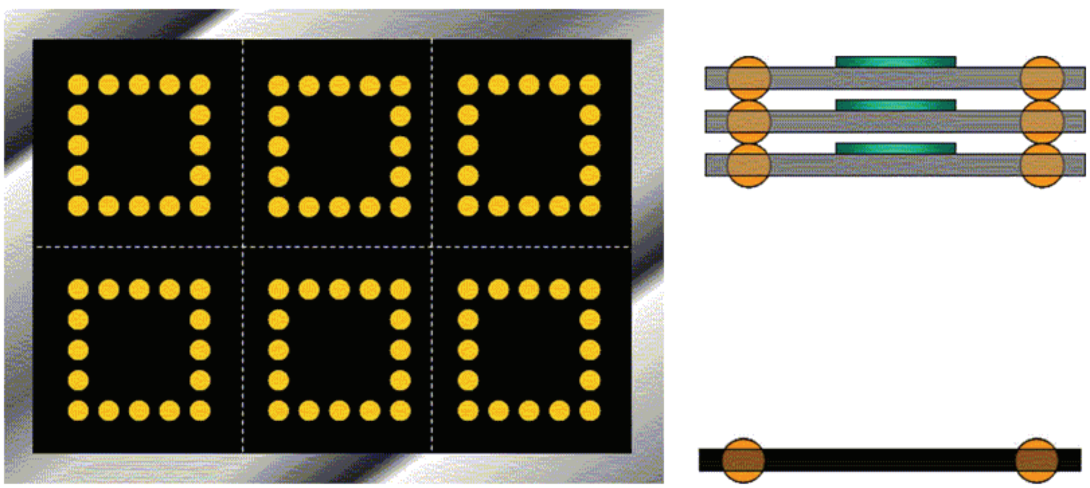

Figure 16 – Array Molding

Applications

Thermoplastic cavity packages can be used for many, but not all types of MEMS devices. Pre-molded LCP packages have already been used for gyroscopes. The MEMS chips are typically capped at wafer-level before packaging at this stage. While transfer molding can be, and is used for capped MEMS sensors, chip contact with a high-modulus polymer that undergoes shrinkage on polymerization, adds stress that reduces device performance. Cavity applications therefore include such devices that will not tolerate desensitization. And as MEMS devices become more complex, thermoplastic packaging will offer more advantages over other types since injection molding can provide very intricate and precise features at the same cost as today's simpler designs. However, more intricate package designs will boost mold tool cost.

Fluidic MEMS devices, which are now coming to market, will need packages that can "pipe" fluids to the chip. R&D versions employ hand-assembled micro-plumbing that is impractical for commercial applications. Our industry has been so accustomed to keeping materials out of packages that it may seem heretical to design packages with plumbing. But advanced MEMS devices will interact with matter that includes gases, liquids, and solids. Even today, there are MEMS sensors that require access to external samples. Drug delivery systems based on MEMS pumps and valves will certainly require access to materials, and the injection-molded package is the right choice. The ease of adding lids or other structures to the package body is another plus for thermoplastics. Today, hundreds of thermoplastic products are shaped and connected using thermal processes and we can take advantage of this long history by moving to thermoplastic packaging.

Certain optical devices are also candidates for thermoplastics but we should not expect a hermetic enclosure with any plastics unless a secondary barrier is added and this may be feasible. Imaging chips, like CCDs, are being packaged in thermoplastic packages with glass lids. Many infrared sensors can also utilize plastic enclosures. However, complex, chips like Texas Instruments' DLP^{TM} optical MEMS device apparently require a higher level of hermeticity and/or mechanical stability than plastic packaging can provide. The DLP (Digital Light Processing) chip, with over 1-million electromechanical mirrors, is still packaged in ceramic even though TI has experimented with polymer materials.

High-powered LEDs are well-suited for thermoplastic packages since hermeticity is not require in many cases and plastic has been the most common LED package for decades. Early LEDs used clear epoxy resin as a glob top material that also formed the lens. High-intensity LEDS can be aided in heat removal by thermal inserts as was show earlier Figure 12. The same is true for power chips where it may be necessary to sink heat to a metal heat slug that is soldered to a heat spreader on the PCB.

While waiting for promised the Nanoelectronics Revolution, we can speculate on the packages that will be required. The carbon nanotube (CNT) may become the basis for the new age of non-silicon electronics, but there are many other possibilities. We do not even know if hermeticity will be required. Since organic materials, including the CNT, can display high electrical conductivity, the package of the future may not even use metal. But we can be assured that insulative materials will be required in any future electronic package. Thermoplastics seem to offer many advantages for Nanoelectronics including the ability to micro-mold and emboss very fine features. Since plastics can faithfully replicate extremely small features, they may actually become part of the new electronics serving as the dielectric base for Nanoelectronic devices.[8] Figure 17 shows possible devices of the future from National Materials Research Institute.

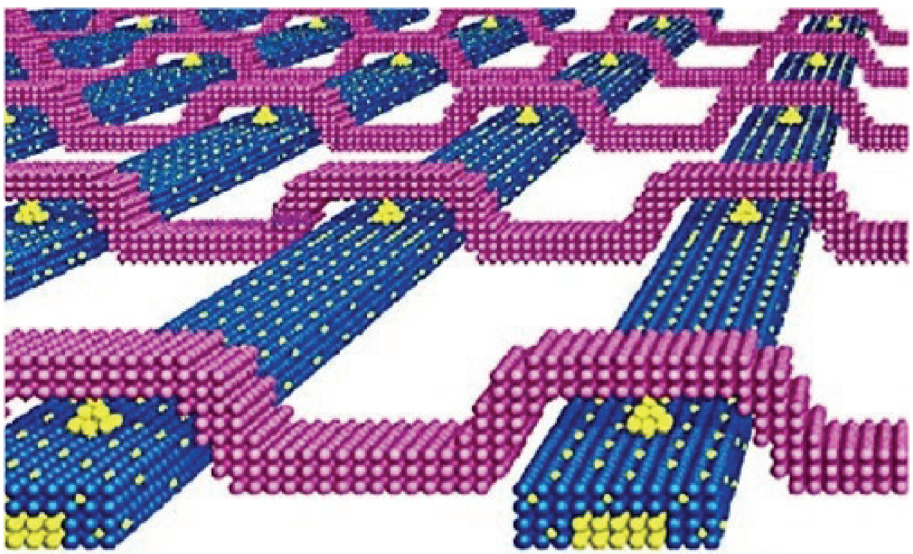

Figure 17 - Nanoelectronics

Conclusion

Polymers provide the lowest cost and most versatile materials that are suitable for packaging. Most packages, perhaps 95%, are made with plastics to the extent that the plastic package is ubiquitous. But thermoset epoxies have been the *de facto* standard even though they are a relatively poor performer compared to modern thermoplastics. Thermosets have dominated because they can be applied directly at a relatively low temperature, and then polymerized in place to high-temperature, non-melting structures. Thermoplastics are remeltable and those that can withstand solder processing temperatures must be processed at very high temperatures that can be detrimental to may semiconductors. The practical use of thermoplastics thus seems to require that the package be pre-molded, or formed, before the semiconductor devices are added.

Pre-molded packaging has become more popular in the last few years because the injection molding process easily produces cavity style packages that are increasingly useful for newer optical and electromechanical chips (MEMS). The injection molding process allows precision cavity packages to be manufactured with extreme detail and automatically. Conductors can be introduced by insert-molding patterned lead frames, discrete conductors such as spheres, or flexible circuitry. Conductors can also be added by selective deposition especially plating using newer direct write technology.

The use of thermoplastic packages will grow in the future as the best solution for specialized devices that cannot be overmolded. The excellent environmental properties of thermoplastics may also boost use as traditional flame retardants are restricted and recycling becomes mandatory. However, the low cost and established infrastructure for thermoset packaging make it unlikely that thermoplastics will move beyond niche applications in the near future. However, increasing popularity of MEMS and the road-mapped transition to Nanoelectronics in the next 10 - 15 years could make thermoplastics the standard package or even the base structure for devices.

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