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Thermoplastic Injection Molding: New Packages and 3D Circuits

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Abstract

Thermoset epoxies, discovered nearly 80 years ago, remain the workhorse materials for electronic packaging and printed circuit boards, but this may change with increasing technical, economic and regulatory demands. Modern halogen-free thermoplastics boast superior properties and automated high-efficiency high-volume processes. Injection molding can readily produce intricate 3D structures suitable for packaging and 3D molded circuits. Although there is a well-established packaging infrastructure geared to thermoset epoxies there is a much larger world-wide manufacturing base that excels in thermoplastics. Nearly 16-billion pounds of thermoplastics are molded into parts each year in the USA alone; 30 times higher than for epoxies. The time may be right for adding thermoplastic packages, interconnects and circuitry to 21st century electronics.

This paper will discuss concepts, novel designs, new processes and the advancements for injection molded packaging and highlight their impressive attributes; the lowest moisture uptake, the fastest processing and the highest stability in the world of polymers. While MEMS packaging will be a central theme, general component packaging will also be discussed including power packages and camera modules. The discussion will include the development of new BGA concepts that utilize automatic insert-molding of tiny metal balls to create the 1st and 2nd level interconnect system. Assembly topics will cover package sealing methods that include laser welding.

New Multi-Chip Package (MCP) ideas based on insert-molded flex will be described that could find use in stackable designs. Hermeticity is discussed using data to show that plastics are near-hermetic but do not yet pass MIL-STD levels. But, future work with barrier coatings may eventually lead to a low cost full hermetic plastic package. And finally we'll look at 3D molded circuits, now called MID (Molded Interconnect Devices), and search for new applications. Conductor patterning methods include molding with plating-catalyzed resin and direct laser writing. We will also consider the idea of combining molded circuitry and packaging for maximum synergy.

Introduction

Electronics can be divided into devices and interconnect structures. Electronic devices with over 100-million transistors in nanoscale dimensions are now fabricated on a single chip. More recently, MEMS and MOEMS technologies have added mechanical and optical features to chips while preserving electronic functions. MEMS chips are now used in cars, planes, rockets, military vehicles, cell phones, robots, medical devices, and many consumer products. MOEMS, now used in digital projectors, the cinema, and HDTV, can boast that a single chip contains millions of mechanical parts that are instantly moved upon command through an electronic signal making them the most complex "machine" in the world. The integration of logic, light, and mechanical action on a monolithic device, all mass produced, opens up a new epoch for technology that requires novel packaging and circuitry.

Device-level advancements are certainly inspiring and perhaps mind boggling, but these incredible devices don't amount to more than a few pennies worth of minerals and metals unless there is a suitable interface to the outside world. The component package, the printed circuit board, and the final electronic assembly, bring it all together to make the magic real. And while packaging and circuitry are mostly just conductors and insulators, selecting the right materials, conceiving the optimum design, developing the best processes and making these products by the billions, is a monumental challenge for our industry.

Packaging and Requirements

Packaging is essential technology that is evolving and unfolding at a quickening pace as the industry follows a performance-density roadmap leading to 3D stacked designs and wafer level packaging (WLP) processes. The package remains the vital

bridge between devices and printed circuit boards. But as this gap between chips and PCBs grows wider, the packaging challenge looms larger. Epoxies, discovered in 1927, have been used for nearly 50 years as encapsulants and are still the "workhorse" polymer for most packages[1]. Thermoset epoxy molding compounds (EMC) have been the easy choice since the invention of plastic non-hermetic packaging also called Plastic Encapsulated Microchips (PEM). But are epoxies still the best choice for packaging and PCBs in the 21st century?

Package Definition and Attributes

The deceptively simple package carries out a multitude of functions. Some features are essential, others are beneficial, and still others are product-specific requirements. Essential requirements include providing the electrical interconnect system between the device and PCB. Rerouting is valuable for some applications but not all; this is a geometric translation that can be used to make a high-density chip compatible with a low density PCB using a fan-out pattern. Environmental protection is almost always a requirement, but it is product-specific ranging from very low protection, for passivated chips, to high for many MEMS and MOEMS devices. The package also provides compatibility between chips with metal pads that are typically not solderable and PCBs that most commonly employ a solder joint interconnect. The package should be removable, and preferably, reworkable. Other package attributes include, testability, standardization, automatic handling, miniaturization, performance enhancement, and heat management. MEMS and MOEMS add more layers of requirements.

Package Classes

Full Hermetic

The full hermetic package, developed about 150 years ago, has admirably served the electronics and optoelectronics industries. The cathode ray tube (CRT), demonstrated by Braun in the late 1800's, used a glass enclosure to seal out the atmosphere and maintain a vacuum. Later, electronic vacuum tubes were developed as the Fleming diode and the De Forest triode amplifier tube, the first active electronic device. These early opto- and electronic devices required a vacuum to operate because the flow of electrons through free space was part of their mechanisms. But today, only a very few systems actually require a vacuum even though this century-old tradition of the full-hermetic sealed enclosure continues. The early packages evolved from glass to ceramic and metal while the principle of making a near-perfect gas-tight enclosure persisted.

Non-Hermetic Plastic Package (Plastic Encapsulated Microelectronics; PEM)

Plastic packages became mainstream products with the breakthrough introduction of the dual-in-line package (DIP). Here, the chip is typically attached to a metal lead frame (MLF) by wire bonding followed by transfer overmolded with EMC. Molding compound, a blend of solid epoxy resins, hardeners, fillers, and additives, is melted by heating, forced into a mold that holds the lead frame assembly, and heated to polymerize the material. The molding compound comes into direct contact with the die, wire bonds and lead frame. The BGA uses a similar method but an organic substrate generally replaces the MLF. Specially capped MEMS devices can be packaged by overmolding to prevent contact with mechanically-active parts, but there are some issues that will be covered later.

Near-Hermetic Package (NHP)?

The packaging industry has offered only these extremes, the expensive full hermetic and the cheap non-hermetic package. We, and others, have suggested the value of an intermediate[2,3] that we refer to as the Near-Hermetic Package (NHP). While there is not yet a definition[4,5], several have sought to develop the Near-Hermetic Package - a design that is "good enough" and "cheap enough" for the packaging intermediate needs that have force the industry to use the full hermetic package with its market-limiting costs. For now, it will suffice to say that the NHP provides a sufficient barrier so that the packaged device and interconnect will meet the customer's performance criteria. The NHP will therefore have product-specific performance.

Basic Electronic Materials

Metals

Metal provides the ultimate barrier and can convey lifetimes predicted to be more than 100 years. Although raw metals can be inexpensive, the fabrication methods used for packages often adds substantial cost. So while metal is the *gold standard*, this is reflected in the price. But, metal packaging, because it is typically electroplated, can release contaminants such as hydrogen; devices that are sensitive to hydrogen may use hydrogen getters within the metal enclosure. Metal and metal composites are presently used as the device, package and PCB interconnect, but this could change in the future as nanotechnology advances.

Ceramics

Ceramic continues to be a popular material for hermetic and some non-hermetic packages that require the following attributes; good planarity and smoothness, high thermal conductivity, and excellent temperature stability. Ceramics materials and processes continue to be more expensive than organic technology although cost-reducing processes continue to evolve. Ceramic is presently the favored packaging for MEMS, MOEMS and some RF devices, but it is being replaced by plastic wherever possible for cost reduction. Ceramic and other inorganic materials can also be used for wafer-level packaging, or prepackaging, a level-0 process. Caps can be sealed over active MEMS areas to provide hermeticity and enable plastic encapsulation with non-hermetic materials.

Plastics

Plastic packaging, primarily based on thermoset polymers, accounts for about 95% of the market because of low cost, versatility, and straightforward automation. But there are issues. Thermoset materials must be mixed just prior to use or kept frozen. Once processed, they can't remelt or be reused and must be treated as scrap or even hazardous waste making disposal increasingly difficult. Most EMC's still contain halogen, bromine compounds in particular, that are destined to be regulated into extinction just like lead solders. And replacement of bromine with dubious choices like phosphorus as a flame retardant, will only add more uncertainties. Reformulating will require retesting and a reset of the learning curve. Epoxies are also relatively poor gas and moisture barrier materials, but chip passivation has allowed most devices to work well enough for it to bring success to the plastic package. What are the alternatives?

Impending regulations and the need for better performance have thrust thermoplastics into the mainstream of consideration. Thermoplastics can be cheaper, environmentally friendly, and boast near-hermetic properties far superior to non-hermetic epoxies. One of the best thermoplastic candidates only contains carbon (C), hydrogen (H) and oxygen (O), yet passes flammability specs and survives lead-free solder temperatures. Thermoplastic properties are controlled and confirmed by the resin manufacturers who complete the polymerization reactions and ship 100% polymer. Conversely, thermosets can vary from run to run since the end user is the *polymer manufacturer* who affects the final properties by carrying out *in situ* polymerization. But the increasing need for lower cost cavity packages is the catalyst for the new class of packaging based on thermoplastics. MEMS, MOEMS, some RF, and OE, have created an escalating demand for lower cost **free-space** enclosures that might be best satisfied by modern thermoplastics. Thermoplastics are also finding increasing favor as circuit dielectric materials, but mostly in the flexible circuitry domain that is also the fastest growing PCM segment. But the time also seems right for thermoplastic circuitry.

Transfer vs. Injection Molding

Polymers are long-chain molecules that occur naturally, but are now mostly synthesized. Plastics are arguably, the most important materials of today. Materials have been so important to civilization that entire eras have been named for them; the Stone Age, Bronze Age, etc. From a materials perspective, we are still in the Plastics Age and the day will come when we have plastic (organic) electronic devices in polymer enclosures on plastic circuits. Ironically, many who worked with polymers 20 or 30 years ago were told, and many believed, that the golden age of polymers had passed *because all of the basic polymers had been invented*. How wrong! But fundamentally new polymers continue to be invented, innovative processes are still being implemented and imaginative new products come to the market every month. Much of emerging Nano-electronics is based on organic, polymer-like structures that may some day replace wires and silicon transistors. Although electronics has been considered the leading edge of technology, this field is far behind in the adoption of modern polymers except for the housing, cases and enclosures that hold the electronics products.

Thermosets

Thermoset plastics, like epoxies, are produced when monomers react to form long chains that are interlinked (cross-linked) to create mega-molecules. Epoxies were the first broadly successful organic packaging materials and continue as the most widely used materials today. They are also used to make organic circuit laminates like FR4 and BT. Since epoxies are thermosets, they are "set" by polymerization when heated to about 150^{o}C or higher (ambient cure is also possible). The other major polymer class is thermoplastics, polymers that can be melted by heating since there are no confining cross-links. The key distinction between thermosets and thermoplastics is the cross-link. A cured epoxy part is more or less one giant molecule that can't melt and it was the non-melting characteristic that made them a good choice for packages and circuit boards that needed to withstand the high temperatures of soldering. Early thermoplastics would soften and deform at solder temperatures, but there is no problem for today's materials.

Many now feel that the thermoset class of polymers, especially epoxies, has reached a plateau and will continue to fall short as packaging and PCB requirements increase. Relatively high moisture absorption is an increasing concern and so is the need to add flame retardants. But epoxies are still the dominant polymer for electronics and are used in plastic packages, encapsulants, underfills and circuit boards. While epoxies are notable for their balance of properties, they don't really excel in any particular area. In fact, without a significant level of fillers and modifiers, epoxies can't be used in electronics. Substantial amounts of organic bromine compounds must also be added to pass flammability standards. Encapsulants and underfills typically contain more filler than epoxy resin to tame the high CTE (Coefficient of Thermal Expansion) that ranges around 8 – 90 ppm/^{o}C. And when it comes to water absorption, they are a "sponge" compared to many other commercial polymers. Epoxy-based circuitry laminates require a substantial level of glass reinforcement to control their dimensional-instability as well as bromine for flame retardancy.

Transfer Molding

The transfer molding process has been used for about 50 years to encapsulate electronics. The steps are straightforward: a chip is attached to a lead frame that is normally a strip or an array of chip bonding sites. Polymer adhesive is the usual die attach material and it can be dispensed at the wire bond station. Once the adhesive is quickly hardened by heating, wire bonds are made between the chip pads and the corresponding lead frame bond sites. The “loaded” array (or strip) is now placed into the molding tool. The transfer mold consists of a heated chamber that is separated from the cavities but connected to each other through a system of runners and gates. The process begins by closing the loaded mold. Simultaneously, EMC in the form of solid pre-heated preform (called a puck), is moved into the chamber and heated to melting. An auxiliary ram then pushes the liquefied material through the runner and gates into the cavities, completing the transfer process and encapsulating the chip and lead frame. Post heating may be required to fully-polymerize the epoxy.

The transfer-molding process has many advantages: loading a preform into the pot takes less time than loading preforms into each mold cavity, tool maintenance is generally low although gates and runners are susceptible to normal wear, longer core pins can be used and can be supported on both ends allowing smaller diameters, because the mold is closed before the process begins, delicate inserts and sections can be molded, and tight dimensional tolerances perpendicular to the parting line are possible. If the mold is properly designed and operated, flash is extremely thin and easy to remove, higher tensile and flexural strengths are easier to obtain with transfer molding, and automatic de-gating of the mold's tunnel gates provides cosmetic advantages. Figure 1 shows a lead frame before die bonding, Figure 2 shows EMC ready to be automatically placed into the heating chamber or pot, and Figure 3 depicts the transfer molding process.

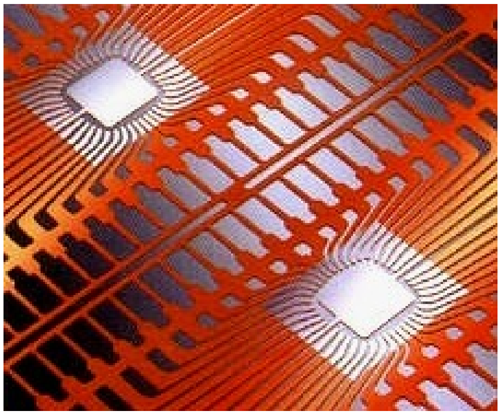


Figure 1 - Metal Leaf Frame (MLF)

Figure 2 - EMC Preform; Pucks

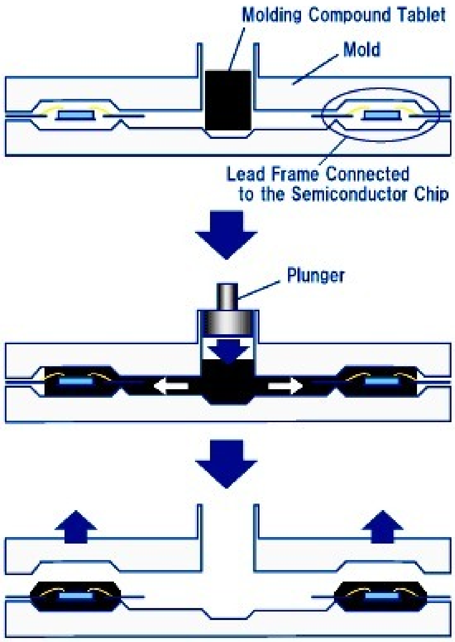


Figure 3 - Transfer Molding

Thermoplastics and Thermoforming
Thermoplastics also have long chains but they are <u>independent</u> (not cross-linked) so that thermal energy will cause a transition from solid to liquid state, while cooling returns the material to the original solid with virtually no property changes. Thermoplastics can therefore be reshaped because of this reversible phase change and this is the basis for injection molding and other thermoforming processes. Plastic thermoforming is a very large world-wide industry that is highly diversified. Today's thermoplastics are superior to EMCs in critical categories and can take the abuse of lead-free soldering, have an order of magnitude better moisture resistance, are rapidly shaped into precise 3D structures, and many pass flammability standards without adding halogens, phosphorus, nitrogen compounds, or hydrates.

Injection Molding
The Injection molding (IM) process first liquefies the plastic resin, injects it into a metal mold that can have 100 or more package-shaped cavities, and then finally ejects finished parts. The cycle is repeated. A complete IM cycle for a package array takes about 10 seconds. The hot molten plastic is quickly cooled by the mold to form a tough solid part that will not melt during soldering. IM, one of the most ubiquitous manufacturing processes, is used around the world to produce large and small parts for every industry, including automotive and electronics. One drawback is that large, multi-cavity molds can be expensive. Plastic injection molding is well-suited for electronics and several companies now offer molded cavity style packages made from high-temperature plastics such as LCP (Liquid Crystal Polymer) or PPS (Polyphenylene Sulfide). The thermoplastic shaping processes have also kept pace. Injection molding can produce tens of thousands of packages in an hour – all automatically. Micro-molding has advanced to a level where precision parts can only be identified under a microscope (see Figure 4). One of the most valuable features of IM is that it can readily produce complex 3D cavity style package structures. Injection molding can form a strip or array of cavity BGA packages at high-volume and low cost using economical engineering plastics like LCP. This polymer class is not new but has been recently popularized as a new flexible circuitry substrate.

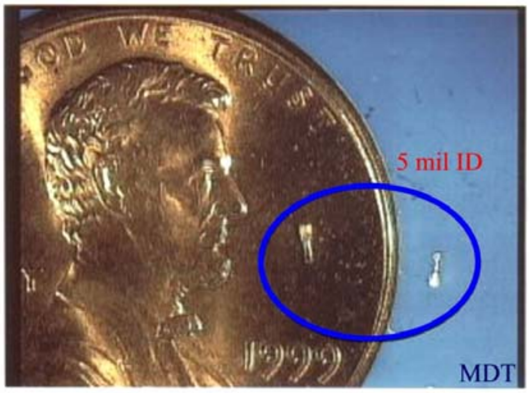


Figure 4 – Tiny Micro-molded Part

Designing New Thermoplastic Packages

MEMS Special Requirements

Microelectromechanical devices can have exceptional requirements depending on their mechanical motion classification. MEMS devices move, or cause motion in materials. The obvious requirement for MEMS devices with motion is “free-space”, or “head room”. When free space is required, thermosets become less practical since a cavity is more difficult to produce using transfer molding. However, plastic injection molding is an ideal method for producing cavities, ports, or various 3-dimensional precision structures. MEMS may have one additional requirement and that is a controlled atmosphere. Many of these devices are affected by the relative humidity; stiction, wear, and corrosion rates are strongly influenced by relative humidity. Therefore, the package may need to contain a specific internal atmosphere that is modified by getters, anti-stiction agents and even vapor phase lubricants. Optical MEMS, or MOEMS, has the extra requisite of a light path; window or fiber port.

Thermoplastic Concepts for Cavity Packages

The simplest molded packages use a metal lead frame that is stamped, or etched out; the form factor is a strip or an array or chip sites for increased productivity. The MLF strip or array is positioned into the injection mold cavity similar to the method used for transfer molding. But the MLF is not loaded with chips and the mold is designed to create cavity shapes instead of flooding the plastic over the surface of the frame. The mold closes under high clamping pressure measured in tons; press ratings are often in clamping force. Next, the injector ram forces melted plastic into the mold cavities under fairly high pressure. The mold is usually cooled (but held above ambient) using a jacket connected to a chiller to maintain temperature by recalculating water or a heat transfer fluid. The cooling plastic solidifies in seconds, the mold opens and ejector pins push out (eject) parts from the mold. The process is repeated and is usually automated. Figure 5 shows the insert molding process that can be used to make packages and hundreds of other products.

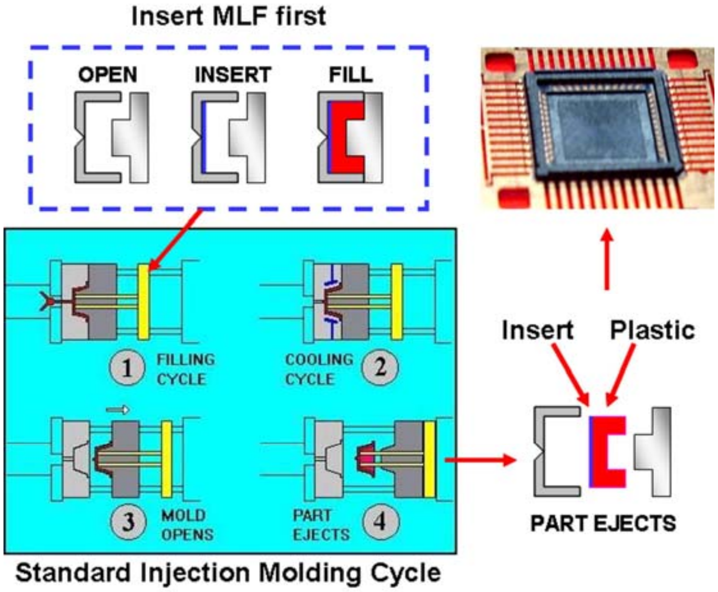


Figure 5 – Insert Molding Process

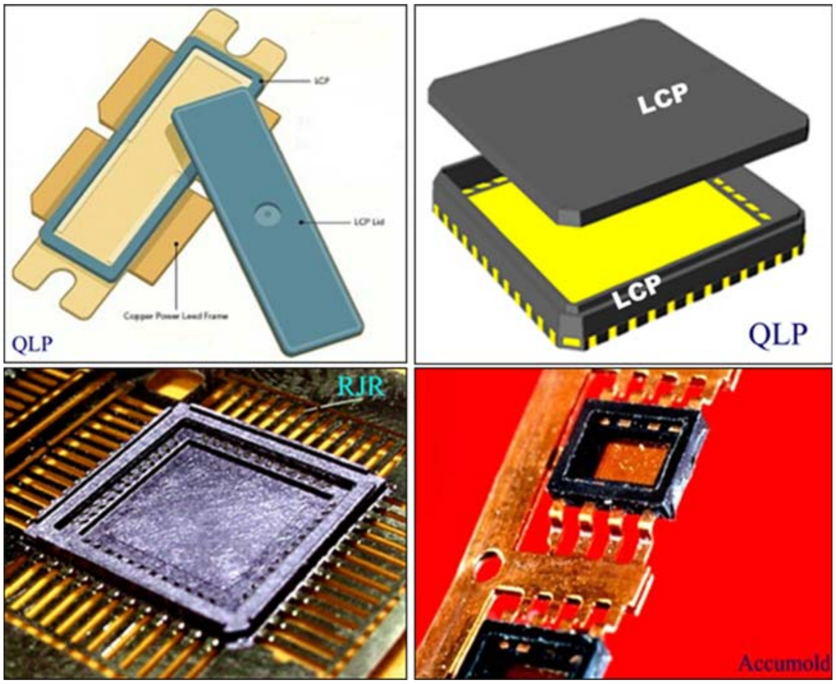


Figure 6 – Plastic Cavity Packages

There are several injection-molded packages that are being sampled today and a few are in low-volume production, and they are based on insert-molded lead frames and are shown in Figure 6. We sought the simplest cavity package design and heeded Einstein's axiom, "Everything should be made as simple as possible but not simpler"[6]. Most electronics is not much more than electrical conductors and insulators, but in the optimum configuration. The package, except for metal types, is an insulated platform and enclosure with electrical conductors. As discussed earlier, the MLF can be transfer overmolded with thermosets, or injection insert-molded with thermoplastics. But the contiguous lead frame is not the most straightforward pass-through interconnect scheme for a package. A simpler way is to insert-mold discrete metal connectors.

We first selected the thermoplastic, a commercial resin in the Liquid Crystal Polymer (LCP) class, so named because the polymer chains orient into orderly crystalline structures even in the liquid state. These C-H-O based molecules are superb environmental materials that pass the V-O flammability rating without additives because of their efficient molecular alignment. The efficient molecular packing also results in a high melting point and good barrier properties. LCPs have been used for some time to make precision, moisture-resistant, dimensionally-stable parts like optical connectors and there is a wealth of knowledge available. Commercial LCPs have about 10 times better gas barrier performance than epoxies and behave more like glass when it comes to moisture. This appears to be the right moment in time and technology, and higher environmental attentiveness, to adopt thermoplastics into packaging and circuitry. These resins are reasonably priced and widely available. Table 1 compares some of the best thermoplastics from the view of a packaging material. The infrastructure is also in place and there are more injection molding machines than transfer molding presses. Although the packaging industry has mostly disregarded "thermoplastics thinking", MEMS need for cavity packages could become the entry point. Injection molding is ideal for making cavities and this is done everyday for billions of plastic parts, so why not packaging? Now, back to the pass-through interconnect selection.

Table 1 – Thermoplastics for Packaging

PLASTIC	water abs. %	MP	UL94	CTE/30% glass
LCP	**0.02 - 0.10 %**	**280 - 352°C**	**V-0**	**0 - 12 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

The sphere is the most natural and universal shape and therefore one of the easiest and cheapest forms to manufacture. Attractive forces at both atomic- and macro-levels readily form spheres. Industry produces hundreds of spherical products ranging from BGA solder balls to silica filler. Spheres are easy to handle since they are perfectly symmetrical. Billions of metal spheres are used in ballpoint pens, for example, making them a low cost commodity. All of this leads to the choice of metal spheres for conductors. But since solder would melt at the molding temperature of more than 300°C, the candidates must be non-fusible metals. Copper and nickel are reasonable choices, but copper has more advantages. Copper balls were first plated with Ni followed by palladium for solderability and wire bonding compatibility. Palladium over nickel has been used on lead frames for decades by Motorola and others. The palladium is very suitable for wire bonding and does not degrade solder; gold could cause solder contamination problems. The Ni/Pd finish is lead-free and compatible with L-F solders. Pd tends to be readily wet by polymers and could improve adhesion. We can select a size, such as 30 mils for the spheres and a package thickness of 10 mils (1/3) to permit the ball to protrude through the package bottom and into the cavity. The metal ball is really the equivalent of the pin for a PGA, but we have selected an optimum shape.

The electrical interconnect structure can be thought of as a lead frame that is not held in a pattern. This “lead frame” pattern is determined by the mold tool that has tiny curved depressions, or dimples, to accommodate and hold the metal balls. So our lead frame inventory is a container of metal balls in standard sizes. We can even use mold inserts to "program” and change the I/O pattern. The metal balls are automatically placed into mold cavities using a vacuum pick-up similar in concept to the BGA solder ball placers. The entire package can be manufactured automatically in a molding machine with a “ball placer”. The packages can be molded in a multiple array of several dozen or even a hundred parts for efficient handling and throughput. Small plastic connecting tabs can be used to hold parts together for chip loading and testing. The packages can then be singulated by punching, cutting, lasing, or snapping the tabs. Testing can be carried out while packages are still in array since the ball conductors are isolated. Conventional lead frames must be excised or singulated. We added one more step, although it could be accomplished by modifying the mold. The balls protruding inside the package were coined flat to aid wire bonding and to insure a tight seal and this is shown in Figure 7. The copper is easily shaped and there was no damage to the plating.

The next step is chip attachment and wire bonding that can be done on a conventional line if the array of packages is laid out to a standard configuration to accommodate chip assembly lines. Once chips are assembled, the lids can be bonded to seal the package. This can be done with individual lids, or as a sheet of plastic material. Glass lids can be used for optical devices but plastic is preferred for MEMS. LCP can be used, as well as other plastics including optically clear materials. The lid sealing can be accomplished with any of several bonding methods including adhesives, thermosonic and laser welding[7]. The sealed packages can be tested and singulated. If lids are a sheet, this can serve as a carrier for test and burn-in. Since the balls are made of Cu or Ni, they can be socketed for test/burn-in without deformation that can occur with solder balls. The singulated Near-Hermetic Package (NHP) is ready for standard SMT assembly. Solder paste is applied to the PCB by stenciling, without any additional steps since paste is needed for the other SMDs anyway. This package is still in development, but prototypes have already passed the helium fine leak test and JEDEC Level-1.

Figure 7 – Coined Balls

Injection-Molded Package Tests

The mold was designed as a 2-up (2 identical cavities) and each had an array of 16 concave depressions in the base and top sections to accommodate the 16 metal balls. The .030” balls were placed with a manual vacuum pick-up array from a vibratory bowl. A magnetic pick-up might be feasible for nickel balls. Once loaded with balls, the mold halves were closed and LCP resin was injected at about 340°C. The mold was opened and parts ejected. Figure 8 shows molded prototype parts as a connected pair. Figure 9 shows the design with coined balls. High volume production would utilize a tool with multiple cavities and the packages would be connected together in a standard assembly array by small tabs.

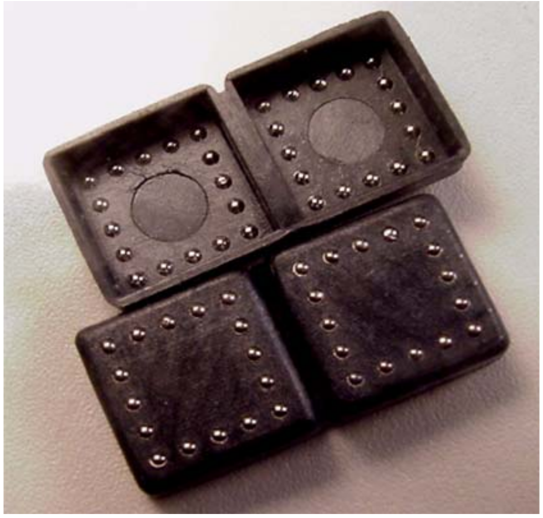


Figure 8 - Prototypes

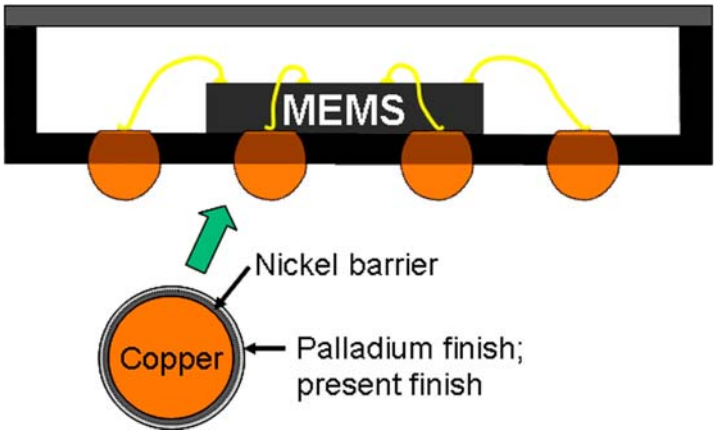


Figure 9 – Diagram: Low Ball Assembled

The mold could be designed so that the ball capture dimples were made shallow or even eliminated on the inner package side for coining. We decided to coin, or flange, the balls after molding since this would produce a compression fit as the ball profile became more elliptical and did not require mold modification.

Lids and Sealing

Once a die is attached and wire bonded, the package can be sealed. For non-mechanical chips, the cavity could be filled with encapsulant. The lid can be made from almost any conductor or non-conductor; metal, ceramic, glass, or plastic. Lid sealing to plastic is thoroughly described in the literature and our efforts were confined to laser sealing that is described but not well documented. We used a Speedline prototype soldering laser, model DLS, with adjustable power of 30 watt in the near infrared wavelength. The light source is a diode laser bare and the complete laser assembly was provided by Coherent. A search of the literature showed that the idea of using lasers for sealing plastic-to-plastic goes back to the 1960's when lasers were first being explored for industrial use. More recent literature indicates that the concept of using a laser to seal glass lids to LCP molded packages is a known art and apparently in the public domain; free of patent encumberment. A recent Kodak patent describes a molded LCP package for CCDs where the glass lid can be bonded using any of numerous conventional means including adhesive, heat sealing, ultrasonic welding, or laser welding"[7]. Note that the patent does not claim laser sealing, but only disclosed it as being known. Figure 10 shows the DLS system.

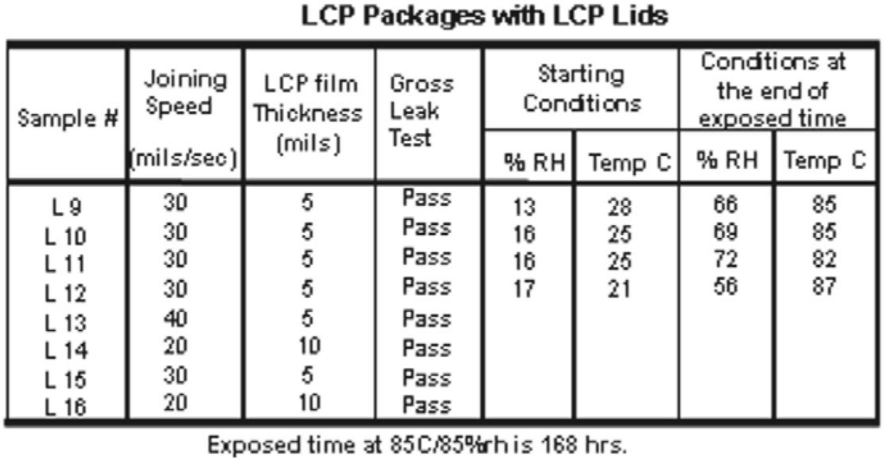
Figure 10 – Speedline Prototype Laser

We found that glass and plastics sealed well to the packages. LCP and other plastic are typically compounded with carbon black that readily absorbs infrared energy. We were able to seal glass to our packages and test caps with high adhesion. The glass seals passed both the gross leak test and helium fine leak test. The fine leak test was performed by an outside lab that reported no detectable leaks for 25 samples within the limit of their test sensitivity of 1 x 10^{-9} cc He / Sec.Atm. We caution that passing the helium fine leak test is NOT proof of hermeticity or ability to pass MIL STD testing. Our results suggest that a near infrared laser is a practical means of sealing glass lids to molded LCP. Tests were also run on LCP film and sheet material used as a lid seal. The lid material should have no IR absorber since heating should occur at the interface. Lid thickness ranged from 2 mils to 25 mils. While a 2 mil thick film is readily bonded to our LCP package, the material is so thin that it can fail during JEDEC testing. The heating to simulate soldering conditions can generate enough internal pressure to delaminate the thin material by allowing peeling to occur. But materials of 4-mils and greater do not show this failure although bulging was observed during heating at 4-mil thick. The maximum thickness limit, at least for our laser, is about 25-mils. Absorption and scattering appear to reduce the beam energy to a level where sealing is inadequate.

Hermeticity Testing

Although passing the relatively easy helium leak test is desirable, it should not be touted as proof of hermeticity. All plastics allow moisture to pass through and LCP is no exception. We feel that water vapor transmission is the most important criterion since water serves as a catalyst and medium for numerous undesirable reactions within a package. We therefore decided to measure the internal relative humidity using a T&H sensor from Sensirion. Table 2 also shows results of exposing sealed LCP caps to 85%rh/85°C. Figure 11 shows the sensor connected through the LCP test cap before lid sealing. Figure 12 shows the T&H curve measured inside the package while exposing to 85%rh/85°C.

Table 2 – In-Package Humidity Testing



LCP Packages with LCP Lids

Sample #	Joining Speed (mils/sec)	LCP film Thickness (mils)	Gross Leak Test	Starting Conditions		Conditions at the end of exposed time	
				% RH	Temp C	% RH	Temp C
L 9	30	5	Pass	13	28	66	85
L 10	30	5	Pass	16	25	69	85
L 11	30	5	Pass	16	25	72	82
L 12	30	5	Pass	17	21	56	87
L 13	40	5	Pass				
L 14	20	10	Pass				
L 15	30	5	Pass				
L 16	20	10	Pass				

Exposed time at 85C/85%rh is 168 hrs.

Figure 11 – Sensirion T&H Sensor

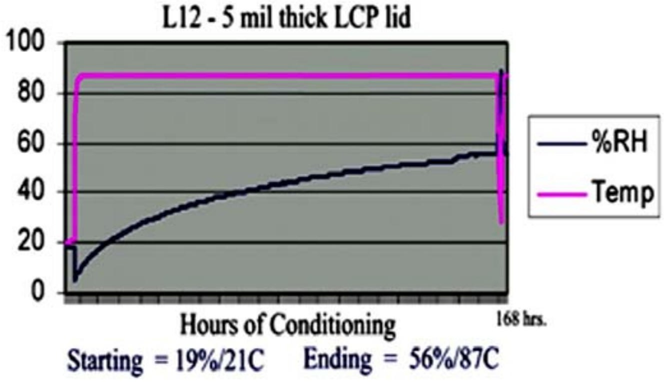


Figure 12 – T&H Curve for Sealed Packages at 85%rh/85°C

Applications

A thermoplastic injection-molded package is being used for capped MEMS today. Probably some MEMS bare die devices will also use similar packages in the future. But the ability to insert metal into the plastic should lead to valuable designs for other areas such as power devices that need extra heat dissipation. Another potentially viable area is for chips that require substantial heat dissipation such as power controllers. Figure 13 shows possible designs where heat could be transferred from the chip to the circuit board and to a heat sink. The area under the die could be populated with metal balls for heat removal. Since they are coined flat, there would be a good interface with the die. But if a higher heat transfer was needed, a metal slug could be insert-molded as shown. If even more heat removal was needed, a heat sink lid could be added and a thermal fluid or gel could be introduced into the cavity as shown.

The optical area also appears to be a good target for thermoplastic parts. Figure 14 shows how the same insert-molded ball package could be used for a cell phone camera by designing the lens housing as a sealable lid. The lid can be design for laser sealing to avoid organics that could outgas from an adhesive.

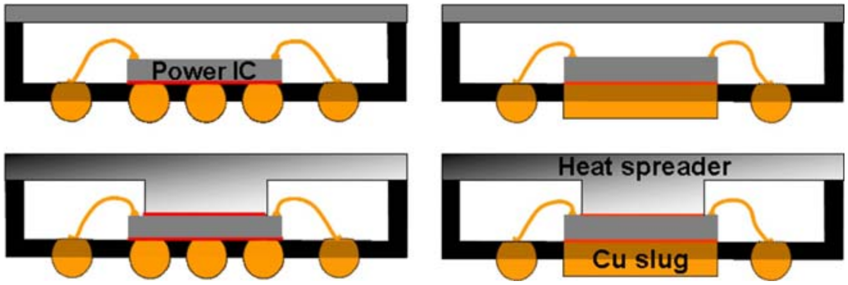


Figure 13 – Power Packages

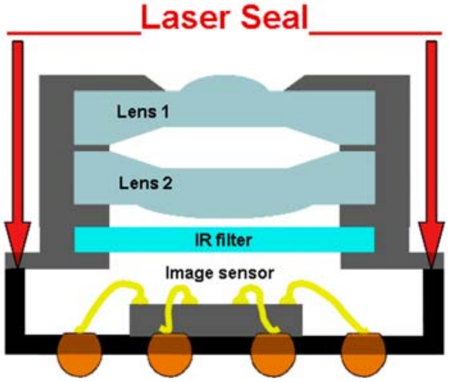


Figure 14 – Camera Module

Multichip molded packages are also possible and Figure 15 shows one approach using in-molded flexible circuitry. The flex becomes the 1st level interconnect and parts of the "hinge" so that the molded lid also becomes a chip carrier platform. Plastic hinges have been molded for decades but the idea has not been applied to electronic packaging. Since the flex brings circuitry to the lid, it is now possible to design interconnect pads into the lid to permit package stacking. While this package concept may fit memory, it could also be used for custom analytical packages. For example, a spectral source could be assembled to the top side of the package and a photodetector to the lower. A plastic or glass tube (could be a flat ribbon shape) could be interposed for introducing test samples into the beam. The result is a tiny spectrophotometer head.

No commercial polymers totally exclude oxygen and moisture that can degrade a device, but a full hermetic plastic package should be possible if a barrier coating is added to the plastic after molding. There are several viable strategies and we can expect to see progress in this area of packaging within the next year or two. While non-conductive barrier coatings are in development, the simplest from a materials perspective is to use metal coating. One concept is to plate the exterior of a plastic cap with metal and heat seal it to a BGA platform or other chip carrier. Or the entire plastic part could be plated and soldered to a carrier made of ceramic with metal conductors and perimeter metallization for soldering. One more approach is to selectively plate a plastic cap on the interior walls and floor for hermeticity. A connection buss would also be plated on the outside and onto the upper edge or all four edges. A ceramic module could be sealed to the cap with components facing inward so that the module became the lid. This same type concept could also be used for small flat panel displays (FPD) especially new OLED types. The display becomes the lid. The bonding would need to create a hermetic seal and the electrical connections concurrently. Possibly, solder coated terminations on the module would work. An alternative to plated metal would be to insert-mold a flexible circuit. The flex could be bumped to form a BGA by well-known methods now used to make flex-BGAs. Figure 16 shows a ceramic chip carrier with a plated metal cap.

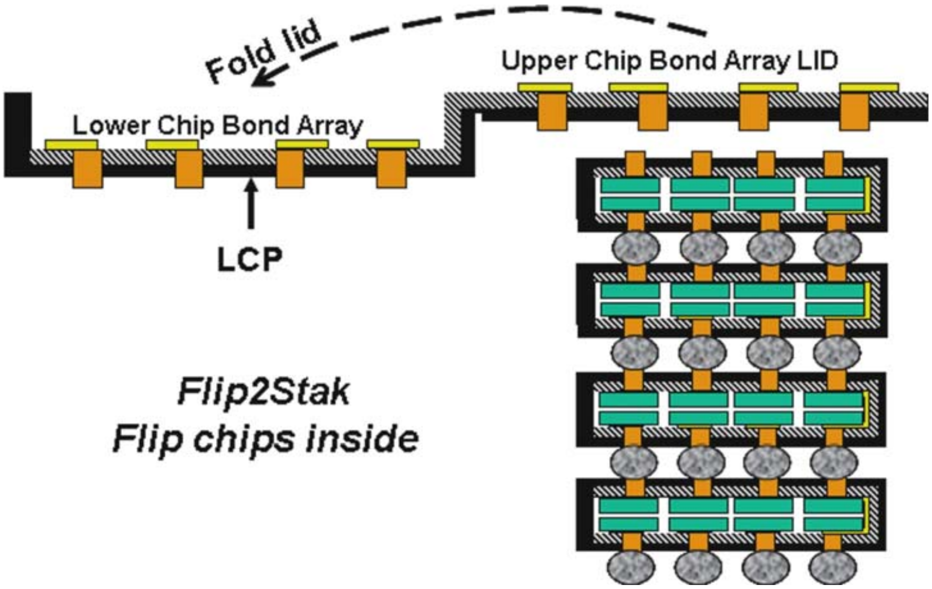


Figure 15 – Flip2Stak Design

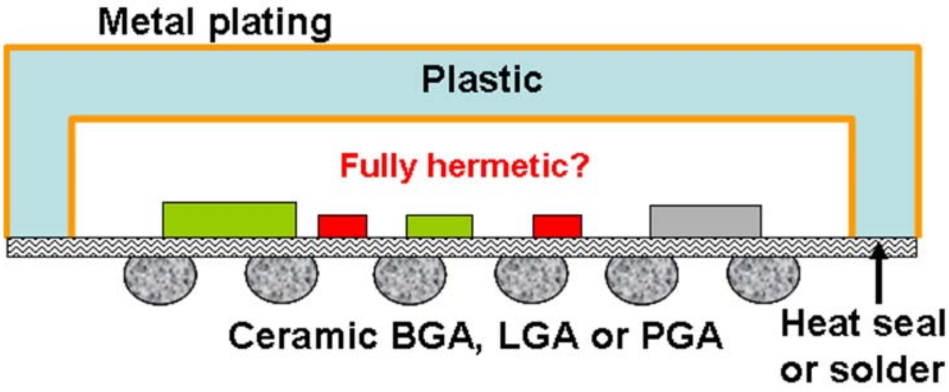


Figure 16 – Hermetic Plastic Package

3d Molded Circuits

During the 1980's 3D molded circuits attempted to make inroads, but failed to capture any significant share. There were ample reasons why the molded circuit idea never caught on, but most had to do with inappropriate strategies not technology. The suppliers viewed the problem as need to sell higher-priced resin and not about the customer and unsolved needs. Today, there are many processes for forming conductors in molded plastic circuits but we are investigating laser-activated plating and 2-shot molding/plating. Both methods produce a selectively-platable pattern that becomes the circuit. Two-shot molding involves using a mold with a catalyzed plastic in one mold, placing the resulting part in a second mold and covering all but the area that will have circuit traces. Now the finished part can be placed in an electroless plating bath and metallization will occur where catalyst is exposed. There are several modifications of the process, including double-mold presses, but the basic idea is the use of a platable and non-platable resin. The antenna in Figure 17 that was done as a two-shot process by Nokia and Hitachi Cable Ltd. looks like a good application for this technology. So it should be possible to design a complete system or subassembly that can be molded effectively and even incorporating the package. Perhaps a modified antenna with an RF-MEMS switch, or MEMS filter would make sense. A package cavity would be added and a MEMS chip could be wire bonded followed by lid sealing. One issue for MID is high tooling cost. But almost any cell phone component would have the high volume required.

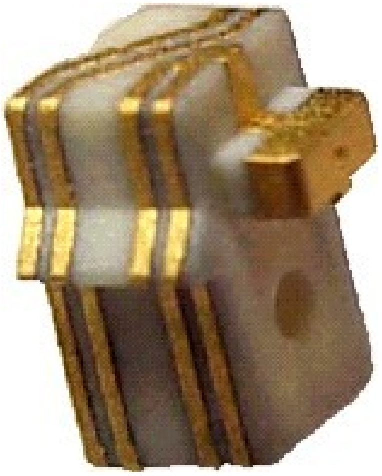


Figure 17 – 3D Molded Antenna

Conclusion and the Future

Thermoplastics, like LCP, have the right properties for component packaging including high temperature tolerance, low moisture absorption, low flammability, and trouble-free precision molding. Cavity packages can be readily molded from LCP using metal lead frame insert molding. We developed a simpler and potentially lower cost concept where metal balls are insert-molded into the package to protrude into the package base and exterior bottom to accommodate wire bonding and SMT assembly. Preliminary data indicates the in-molded ball package could be useful for MEMS and other devices such as power and optical. Injection molding is a highly versatile plastic shaping process that could also be used to make more complex packages including multi-chip and stackable types. Injection molding can also be used to produce 3D circuits. Future designs could combine molded circuits and packages into single units such as RF antenna modules, filters, or oscillators.

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