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Advantages of using LCP based pre-molded leadframe packages for RF & MEMS applications

By

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Abstract:

The Air Cavity Package (ACP) is a widely used option for RF products, hybrid circuit assemblies and optical/photonic devices. Typical ACP's are metal cans and ceramic leadless chip carriers (LCC). Custom ACP's are also provided by machined metal housings and LTCC options. However, over the past 10 - 15 years, the development of MEMS Sensors and LED devices has seen the use of thermoplastic pre-molded leadframe packages become the top choice for custom application specific housings. These products are now maturing and moving to "standard" package outlines where possible.

Currently, the experience gained with sensors is now being reviewed by the emerging RF application markets. Here, LDMOS power and MMIC devices are widely used in wireless network applications which require low cost, lightweight, robust packaged devices.

The electronics industry has pushed the development of thermoplastic materials to suit higher temperature applications, especially as a result of the introduction lead-free (RoHS) processing conditions. Liquid Crystal Polymers (LCP) are the choice for plastic body components and connectors, developed to suit temperatures of 300 degrees C and above. This means that packages made with such materials can withstand the typical reflow soldering processes used in high-volume system manufacturing. However, the properties of LCP present a number of manufacturing challenges for the users. Hence, Interplex has developed in-depth design, manufacturing and test skill sets that can match the needs for smaller, lower cost plastic ACP packages, such as QFN, utilizing a range of LCP materials.

This presentation will look at some of the stages of the development of MEMS packages, already engineered to suit robust, high-volume applications. It will detail some of the necessary test processes now required to qualify the technologies and show how the materials and manufacturing processes can be developed to provide enhanced reliability for non hermetic class packages. Further Interplex will propose some new development concepts that will extend the performance of these materials to meet the more stringent needs of the developing RF and power component markets for better performance packages.

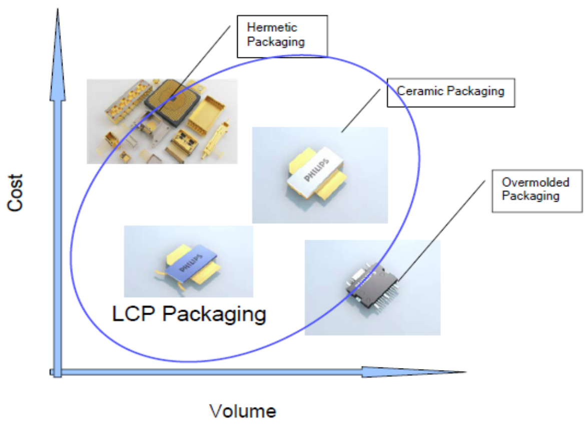
Background:

Interplex Industries, Inc. has supplied stamped, plated and molded parts to the electrical and electronics industries since 1958. The company has grown and become a leading global organization in the design and development of complex engineered plastic and metal components. In 2007, Interplex acquired Handy & Harman Electronic Components and formed the Interplex Engineered Products (IEP) division. From the outset, IEP's capabilities included precision stamping, wirebondable plating and thermoplastic injection molding, all ideally suited to a wide range of microelectronic parts, especially sensors and opto devices. Already producing parts in high-volume for automotive, medical and consumer products, IEP's skill sets matched the needs of the semiconductor markets for plated leadframes, reel-to-reel volume production and specialist thermoplastic micro-molded housings.

A number of thermoplastic materials have been developed to meet package demands generated by the emerging sensor MEMS and opto markets. Of these, Liquid Crystal Polymer (LCP) is probably the ideal engineering plastic for precision components that require high dynamic stability, good moisture resistance and resistance to deformation at the high temperatures associated with Solder reflow environments. According to one of the current main suppliers of LCP, Ticona, who produce the Vectra range, the material offers:

- high melt flow, easily fills long, thin, complicated flowpaths with minimal warpage
- heat resistant up to +340°C
- very good mechanical strength, toughness
- excellent dimensional stability
- fast cycling
- inherently flame retardant
- excellent organic solvent resistance
- wide processing window
- flash-free manufacturing

Similar parameters are also available in the Solvay Xydar brand LCP. The combination of such parameters, coupled to the fact that there is no chemical outgassing of the materials in the molded state, makes them ideal for electronic component housings. However, this material presents a number of challenges for the user. It is abrasive, and will quickly wear away an incorrectly designed mold system. It requires careful temperature and pressure control in the mold process. The mold flow design is critical and poorly balanced molds will cause 'freezing' and poor quality fill. LCP is therefore not a prime choice for most businesses having injection molding capability. Interplex has become one of the few companies able to make this material work well for them.



Air Cavity Packages:

Packaging electronic components in cavity housings has long been the primary option for prototyping, multichip assemblies (hybrids), optical devices and RF devices. The plastic package has really been for single Semiconductor devices that are typically for high volume applications. The plastic technology was originally a pre-mold thermoplastic around a leadframe but moved quickly to over-mold, the transfer mold technology with thermoset plastics as this solution provides good protection against moisture ingress (MSL 3 typically) and is low cost.

Accelerated by the development of sensors and medical MEMs devices as well as the need to get cost out RF type devices for use in wireless and broadband applications, low cost and cavity packaging are now the targets of both the RF applications and the MEMS sensor communities. The package element is often up to 80% of the device cost, so the need for cavity, low cost, plastic options is continuing to drive innovation. Miniaturisation and development of automated high volume assembly are a necessary step to achieve ultra low cost. Low cost micro-sensor parts like MEMs microphones, gyros and accelerometers are now used in phones, laptops and tablet computers as well as computer games and toys for the consumer markets. These and many other sensor elements need some form of Air Cavity Package (ACP) that needs to be small, lightweight and readily available in significantly high volumes to be cost effective. Such ACP's are available in metal, ceramic or plastic molded format and most plastic ACP's are fabricated as a pre-molded housing around a plated metal leadframe.

The explosion of MEMS onto the market happened about 10 years ago when, low cost package solutions were (and still are) becoming the drivers for new technologies such as 'last-mile' fibre optic Telecom systems, mobile phones, Bluetooth and wireless networking. Premolded frame technology was then the only solution that could create a viable housing yet meet the performance demands of these technologies. It still continues to be the main solution to match development needs for future applications despite the introduction of 3D and wafer level packaging options becoming a key option for the high volume markets.

The developments of the plastics, has seen LCP become the front runner for virtually all plastic ACP solutions that require other than standard housings and due to its excellent performance it is becoming material of choice for use with a growing market of Cavity type QFN package options. With a temperature performance of 300 degrees C and above it is a workable option for use in solder reflows and with Eutectic die attach processes.

Leadframes:

A leadframe, which provides a copper pad for die attach and thermal/electrical conduction is now a key necessity for RF devices as well as many MEMS devices. For RF there are 3 key aspects: Die CTE mismatch, thermal management and grounding. To work with these aspects a number of leadframe materials can be utilized. Copper (CTE 9.7) is a preferred choice due to thermal conductivity (see table 1), cost, available plating finishes and manufacturing (etch or stamp) options. However if CTE is the issue then Kovar (CTE 4.1) is a possible option. Other alloy material such as Copper Tungsten (CuW), Copper Moly (CuMo) and Diamond provide a range of selectable parameters but will be a significant cost adder. For smaller packages such as the emerging options of Air Cavity QFN parts copper is possibly the only solution for volume applications as many features can be incorporated due to the etching process capability for manufacture. Multiple sources of etched or stamped leadframe parts are available and offer either closed or open tool options. However, many of these will only offer a copper frame. There are few alternative materials now used for leadframes, typically CDA 102 or Olin/CDA 194 are the preferred copper alloys but some Nickel iron alloys (alloy 42) are still required for certain applications. The advantage here is that LCP is not affected by the different thermal conductivities of these materials during the molding, provided the process windows are carefully set up.

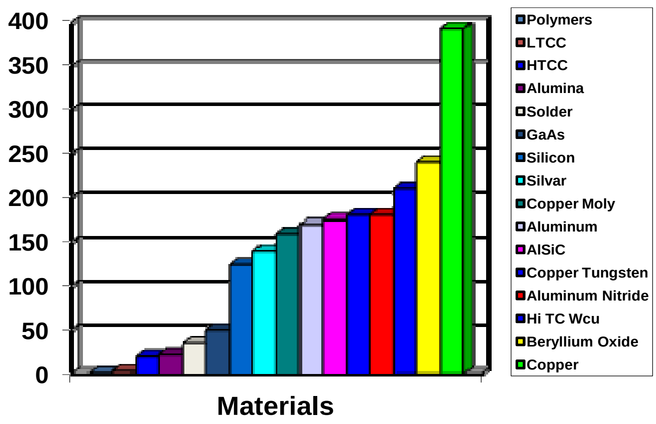


Table 1 – Thermal Conductivity (W/mK) of a range of substrate materials

For plastic ACP a pre-plated leadframe is the ideal choice, but the temperature performance of LCP is now such that post plating can be considered as a viable option. This has advantages of allowing copper wirebonding to be used and for treated copper interconnection leads to have an improved adhesion to the LCP materials thereby giving a better seal. The downside to this approach is both the limitation to the plating options and the additional after assembly provision of a plating process. Reel-to-reel high speed plating lines ensure minimised cost and can offer tight tolerance selective plating of stripe, spot or depth controlled with selective systems. Finishes available are ductile Nickel, hard Gold/soft Gold, Silver, Palladium, Palladium/Nickel, Tin Alloys and reflowed Tin. LCP processing temperatures are relatively low compared to the plating processes and a plated frame will provide a clean flat surface finish for the mold materials to adhere to. It should be noted that a careful leadframe design will incorporate a number of "key in" features, that can be stamped or etched and provide both mold lock and moisture ingress barriers for the LCP to metal interfaces.

MEMS

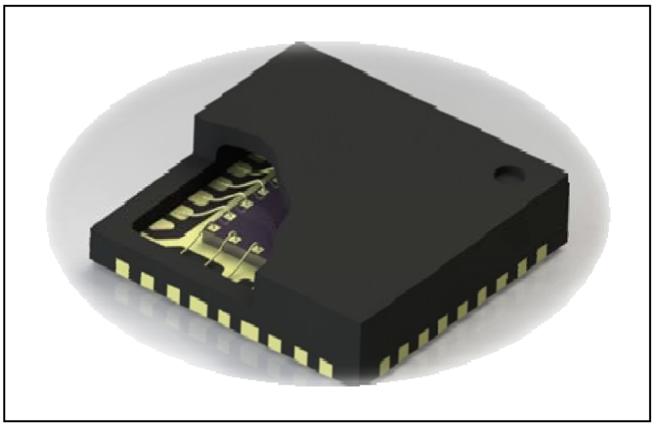
Sensor developments are one of the successes of MEMS devices and there are many applications now on the market. In terms of packaging, these products have really been a follow on from the opto LED emitter-detector products and photodiode sensing applications that are now in high volumes for applications such as paper detectors in printers, optical encoders, position sensors and of course rain/light sensors for the automotive market. The MEMs applications are now not just opto sensors, but are gyros, accelerometers, and microphones, as well as fluid and gas sensors, proximity sensors, motion detectors, IR movement and heat sensing. New applications are rapidly emerging for radiation detectors (micro-bolometers), fluid and drug dispensers, micro-projectors and other medical applications. However all of these have issues with packaging. Many will adopt the new wafer level package processes but others will remain as ACP because of the needs to be open to media such as air, liquid, gas or light, or a combination of these. Because LCP is resistant to most chemicals it becomes the ideal material for the package housings. The design of the package is now a top level issue as it is the most expensive part of the sensor.

The MEMS pressure sensors were some of the driver components requiring ACP and utilizing pre-molded leadframes. These are still pushing the market and the engineering capabilities to incorporate a sensor with control and monitoring components into the same package as the connectors. It is typically no longer a box, but is application dependent and, because it is an injection molded part, it can have added features such as manifolds, attachment points, bolt holes and mounting features, as well as a built-in connector. The Automotive types in particular are becoming sophisticated packaged plug and play modules. LCP is very important here as it has high withstand temperatures enabling mounting of sensors on engine manifolds and in exhaust systems where operating temperatures above 200 degrees C are endured.

RF Applications

LCP materials are now widely used for RF circuit substrates. As LCP film is a thermally stable thermoplastic material with a low dielectric constant of 2.9 at 10 GHz with negligible moisture effects, it is used as flexible-circuit-board materials for applications from audio frequencies to well past 40 GHz. The Glass filled LCP materials used for injection molding exhibit a number of similar properties and ACP QFN package housings using copper leadframes and a pre-mold LCP base and wall have been proven to give excellent performance in applications at frequencies > 20GHz. The QFN type LCP packages offer good thermal expansion match to laminate circuit boards and by employing gold plated copper lead frames, high thermal dissipation can be achieved. The material stability allows circuit matching to be designed that will, in many cases of RF component products, enhance the performance of the devices.

Most RF amplifier devices utilize compound semiconductor (III-V) materials, typically Gallium Arsenide (GaAs) compounds. These devices benefit from being packaged in a cavity housing to prevent undue stress on the materials and in many cases, hermeticity is not critical to the device’s functionality. The RF MMIC market is fast growing and is pushing the package providers to support them with ACPs that have a high number of i/o, very short interconnect paths, low height and no stress. QFN outlines are ideal for this and use of LCP with these package outlines provides an ideal solution, offering short lead lengths and a solid metal die pad for improved thermal management. However the QFN package style does not allow for much variation in the type of materials usable for the substrates and the thickness of such materials.



For RF power amplifiers, LDMOS and other power devices, LCP materials can provide a solution that competes well with the industry standard Ceramic packages. LCP offers a lighter weight, potentially lower cost option.

Bonding of LCP to different substrates is feasible with Polymer epoxy adhesives, or some novel custom mold designs. In a similar manner to packages used for Power semiconductor devices, an LCP wall is designed and molded with interconnects and it is then bonded to a suitable base. In power devices, sealing is done with silicones after chip assembly to provide the hermeticity level and protection for the wirebonds etc. and for added protection an LCP lid is bonded or welded to the housing.

Performance testing

Qualification of LCP packages often falls between two camps, as in one case it is treated as a plastic package and therefore subjected to a set of typical test processes and in the other case, RF especially, it has to match the performance of ceramic full hermetic packages. Further as the aspects of application performance increase, additional tests, MIL STD or Jedec need to apply. However as most of the parts are ACP, many of the tests applied for a “standard” overmolded plastic devices are not valid. Likewise many of the tests for a sealed ceramic package, such as fine leak for example, cannot be applied to plastic packages with lids sealed by epoxy materials.

It is well understood that most LCP pre-molded packages have issues with sealing around the metal leads, but the demand is that a production / market ready organic package should be capable of passing a Gross Leak test. In order to meet future demands the interface between the LCP and plated copper leadframes will have to be capable of passing gross leak after the following consecutive tests:

- MSL-3 followed by die attach
- Wire bonding
- Epoxy lid seal
- MSL-3 followed by JEDEC reflow
- 1000 Air to Air cycles @ -65C / 150C

Most LCP package producers, including IEP, have the capability to perform all of the listed tests. However IEP have developed a stringent temperature test for LCP packages which is more severe than the typical lead free solder JEDEC reflow test. Most reflow processes have a ramp time to temperature and a cool down time. Most reflow processes subject devices to a maximum temperature of 260 degree C although choice of reflow oven may dictate the process. Vapour phase ovens have a rapid and focused heating process which is a different profile to the typical Infra-red and convection ovens that may have excursions up to 280 degree C to ensure reflow of the typical SAC solder alloys. Further a typical reflow process is in a belt type furnace/oven which is a time determined process. In order to ensure that the device performance is not marginal, IEP have developed a rapid thermal test method that subjects the parts instantaneously to 260 degree C in a batch oven. The full IEP test methods are shown in Table 2.

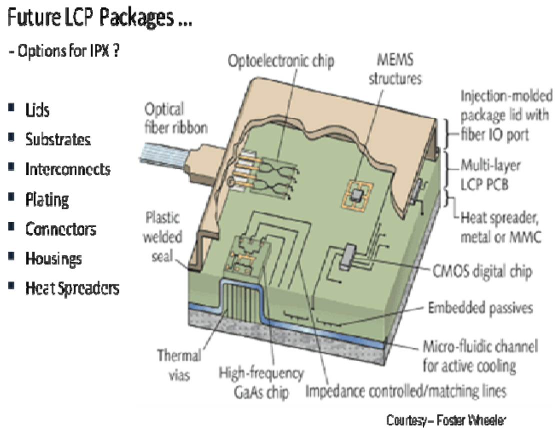
IEP - Test Conditions for simulating Semiconductor Package assembly and test processes.

- Die attach @ 410°C +/-5°C x 3.0 minutes
- Wire bonding @ 150°C x 3.0 minutes
- Epoxy Lid Seal @ 180°C x 10 minutes
- Gross leak test @ 125°C x 1.0 minute
- Reverse 30 degree lead bend
- Gross leak test @ 125°C x 1.0 minute
- MSL-3 – 10 days @30°C 60%RH
- JEDEC Pb Free solder reflow profile 260°C x 3 times
- Gross leak test @ 125°C x 1.0 minute
- 500 Liquid to Liquid cycles @ - 65°C / +150 °C
- Gross leak test @ 125°C x 1.0 minute
- Continue to 1000 Liquid to Liquid cycles @ - 65°C / + 150 °C
- Gross leak test @ 125°C x 1.0 minute

Table 2 – IEP performance test criteria

Future developments

The boundaries are continually being pushed in order to achieve smaller, faster, cheaper electronic devices. Higher operating temperatures, improved thermal management, hermetic sealing and reducing sizes are the challenges for future package technologies. New applications also need to be supported by developments of the base materials used in these packages and these must also take into consideration the limitations of the available LCP materials, leadframe dimensions and mold design capabilities.



At one end of the scale, new epoxy materials are being formulated that use carbon nanotubes to provide strength and conductivity for micro-molded parts. Use of Silicone based resins is being developed to seal and protect sensitive devices and combinations of material developments with base LCP formulas will extend performances of these plastics. However changes to materials inevitably involve a process change and it is often this area that is the most difficult to develop. Equipment modifications and upgrades may be necessary or more likely some novel equipment may be required to enable a process to be utilized. The designs of the mold tooling, for example gating, may need to be adapted or completely revised to ensure that the materials work as designed and that the product produced maintains a high quality yield.

Substrates materials are developing to enhance thermal management requirements of high speed, high frequency and power devices. New sealing processes, such as laser welding are also providing solutions for use of plastics in harsher environments, and new metal processing techniques offer more accurate dimensions, better interconnections and unique design features to suit emerging applications.

As the demand for improved package performance is a continual need, IEP is constantly looking at ways to develop new technologies for metal processing, plating and molding. This includes development of the LCP materials and processes to improve the adhesion between the plastic and the metal leadframe during molding. It also includes use of ductile layer technology to provide solutions to CTE mismatch issues that are significant for RF and other devices. The key driver is to establish a process to produce packages that will perform in harsh environments with elevated operating temperatures and will have a moisture resistance to at least MSL3. To do this IEP have developed proprietary, unique processing capabilities at the manufacturing stages and will incorporate a number of high level test procedures to ensure reliable performance. In the longer term, applications for such packages will demand a low cost, plastic housing that will withstand die attach temperatures of up to 400 deg C and capabilities to meet MSL1 levels.

Summary:

LCP premolded leadframe packages offer a good number of advantages to the RF device designer as well as for the MEMS sensor markets. The correct design will offer all the key elements, functionality, device/circuit connectivity, interconnection to next level, device protection – mechanically and environmentally, a means for handling, an application fit and all at the lowest possible cost. The use of LCP for the molded package body provides a robust, protective housing for RF, MEMS and optical components. It enables the use of leadframe options to provide enhanced thermal connectivity both for small high frequency MMICs but also for large power devices. The low dielectric constant also helps provide a reduced parasitic interference for high frequency applications.

The combination of the technologies is the ideal solution for packages with either standard outlines such as a QFN or for custom designed housing features. These can be done as low cost developments matched to low cost production techniques and suited to niche as well as mass market applications. The future is already seeing the development of new LCP formulas to provide improved plastic to leadframe interface adhesion as well as increased thermal performances making ACP with a pre-molded LCP leadframe a prime choice for emerging technology applications.

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