Polymer Bonded LCP Device Housing Enables Selective Thermal Management for RF Device Packages.

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Abstract- **The development of broadband wireless communication systems has generated a rapid growth for RF components that need to meet the ever present need for "Smaller Faster Cheaper" electronics. Due to the high performance and increasing speed requirement of the systems, thermal management has become a key issue for these electronic components. This requirement has proved to be an obstacle for devices, inhibiting the use of lower cost plastic packaging, in favour of ceramic or metal can parts. However recent developments in polymer bonding technology have enabled novel sealing techniques that allow the use of low cost plastic housings on a variety of thermally efficient, flat plate substrates.**

RJR Polymers have developed a number of novel bonding technologies that allow the use of Liquid Crystal Polymer (LCP) housings to be attached to plated metal substrates and other materials, providing a reliable, near hermetic bond. The use of LCP molded parts as the housing significantly reduces the cost of parts compared to Ceramic or metal composites. Additionally the LCP housings can be custom designed to suit a range of applications. This paper shows a comparison of the various options and reviews the selection of the right match of CTE and thermal performance for a range of different materials.

INTRODUCTION

The development of RF components, such as LDMOS amplifiers has been a key driver in the expansion of broadband communications and wireless networks. However the need for higher power, reduced size and of course lower cost of these systems has a big impact on the component technologies being used. Due to the high performance and increasing speed requirement of RF electronics, thermal management is the key issue for the components. This requirement has proved to be an obstacle for devices, inhibiting the use of lower cost plastic packaging, in favour of ceramic and metal can parts. However recent developments in polymer bonding technology have enabled novel sealing techniques that allow the use of low cost plastic housings on a variety of thermally efficient, flat plate substrates.

The component packaging industry has developed a wide range of plastic packaging for high volume applications such as basic Integrated circuits (ICs) and as the technologies increase in speed, thermal management has also been developed. In recent times, this has generated a fast growth in leadless package technology for the Quad Flat No-lead packages (QFN) which incorporate an exposed copper die pad. However high performance, high speed electronics, especially compound semiconductors, are demanding improved Coefficient of Thermal Expansion (CTE) matching, more efficient thermal management and will utilise thicker elements with a variety of composite materials as the package base.

AIR CAVITY PACKAGES

Air cavity plastic packages (ACP's) are available in metal, ceramic or plastic molded format. Most plastic ACP's are fabricated with a thermoplastic Liquid Crystal Polymer (LCP) molded around a bare metal leadframe.

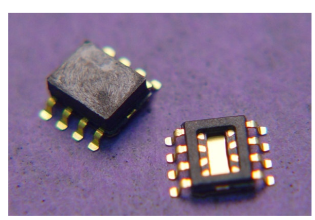

Figure 1. R-Pak pre-molded SOIC-8 lead package shown with cover (top) and without cover (bottom).
Package body is 3.9 x 4.9 mm and conforms to JEDEC MS-12-AA outline.

A semiconductor die is mounted into the package cavity, connected to the leads and finally sealed with a separate lid. A typical package is illustrated in figure 1. R-Pak is the RJR polymers trade name for the comprehensive system of materials, processes and equipment that produce these packages.

The die and wirebonds are in a cavity rather than being embedded in an epoxy. A plastic package with a cavity is commonly termed a "pre-molded" package as opposed to a "transfer molded" or "overmolded" package. Traditional transfer molded packages are made by completely filling a mold with a thermosetting epoxy which encapsulates a pre-assembled leadframe. The epoxy completely surrounds and embeds the die and wirebonds leaving no cavity.

Micro-electro-mechanical systems (MEMS) are miniaturized systems requiring packaging for environmental protection and for interconnection. While there are a wide range of MEMS devices, a common need is for packaging that allows movement of the internal device during operation, either an ACP or a cavity lid bonded over the MEMS structure.[1]. Free space optical and imaging devices cannot be surrounded with an opaque material that attenuates or diffracts light.[2]. Many sensors need to sense their environment to function as opposed to being isolated in a solid block of material.[3]. Many devices or applications are functional combinations of two or more of these technologies.

Most RF amplifier devices utilise 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. In other cases, hermeticity is primarily important to reliability of the devices, similarly to the typical Silicon integrated circuits.

RJR Polymers have developed their R-Pak process to produce near hermetic ACPs by injection molding of low moisture diffusivity LCP coupled with a patented sealing methodology. The term "near hermetic" refers to packages that are capable of passing fine leak testing but are not exclusively made of metal and glass or ceramic [4]. Testing and qualification procedures such as leak test, moisture diffusivity and JEDEC moisture sensitivity qualification data are regularly utilised to support that definition.

The assembly process for air cavity and transfer molded packaging is essentially the same, differing only in how the packages are "sealed". A transfer molded package is molded around an assembled leadframe that creates the package with no internal cavity. An ACP is sealed with a cover after component assembly into a premolded cavity in the package. The R-Pak injection molded packages use a modified LCP compound for the dielectric molded around metal leadframes. A typical package construction is shown in figure 2.

The very low moisture diffusivity of R-Pak packages provides excellent environmental protection for MEMS, photonic devices and sensors.

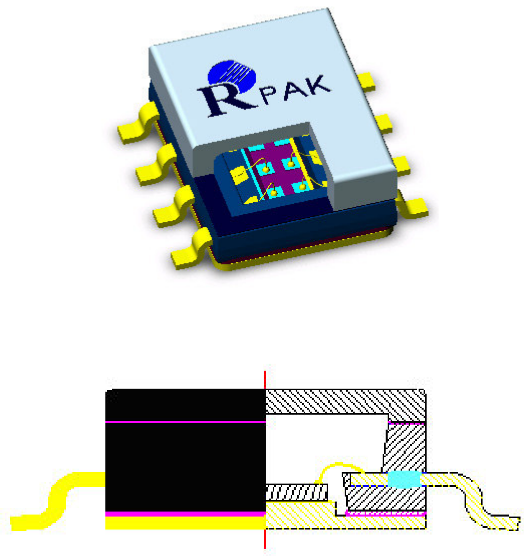

Figure 2. Representative R-Pak package. Top; cutaway of cover illustrating the internal cavity with a die on metal package base. Bottom; end view of package with cutaway on right showing cross section of package.

PACKAGE DEVELOPMENTS

Because ACP's are applicable to a variety of applications, the full potential of the materials and processes can be realized by application optimized package design. The insert injection molding process allows for flexibility in placement and shaping of the package leads. R-Pak packages can be manufactured as cavity packages with plastic sidewalls and base as shown in figure 3, or as a 3 piece package as shown in figures 1, 8 & 9.

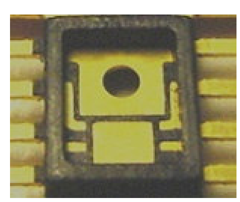

Figure 3. An 8 Lead MEMs Sensor package with molded cavity sidewalls ...

The patented 3 piece construction incorporates a metal base for high power dissipation and optimum electrical grounding.[5]. The metal based package also presents the option of high temperature die attach in a plastic package.[6]. High power semiconductors may be die attached first with gold/silicon or gold/tin eutectic to the metal base and then the premolded plastic package body assembled to the base. The die is then wirebonded and cover sealed to complete the assembly. Typically an Iso Thermal Sealer (ITS) equipment, as produced by RJR Polymers, is used for cover (lid) sealing and for the package body to metal base assembly for these metal based packages.

The materials used to make these ACPs are fundamental to the electrical and environmental performance advantages of R-Pak. The 4 key components for such a package as detailed in figure 2 are:

- The package body Lid and base utilising LCP. Here, RJR have developed HTP 1280, a custom designed LCP thermoplastic molding material.
- Sealing epoxies such as those developed by RJR formulated for optimum adhesive and moisture barrier properties.
- Interconnection leadframes of various alloys that have specific advantages for different applications.
- Substrates to support die, add thermal management and provide any necessary electrical interface.

It should be noted that some packages can use a leadframe with an integrated metal base, and some sensor packages may only require a pre-molded plastic base as the substrate.

One particular package style that can really offer cost effective performance benefits is the QFN. This type is now widely used by the Semiconductor Industry. A QFN typically incorporates a coplanar exposed die pad as part of the leadframe and is then overmolded to fully encapsulate the die. However with the introduction of LCP as a thermoplastic material that can withstand high temperature environments, RJR have developed a process for molding the leadframe only. This enables the mounting of dies, MEMS, and / or circuit assemblies directly to the substrate.

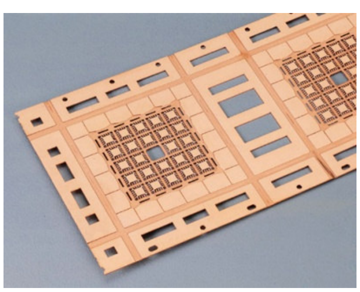

Figure 4. Custom ACP QFN leadframe

The leadframe/substrates for these package types, see figure 4, are designed and molded on a range of frame matrices which can be utilised in standard die attach, wirebond and capping assembly equipment. Alternatively custom substrate designs can also be built, such as the rectangular 72 i/o substrate shown in figure 5.

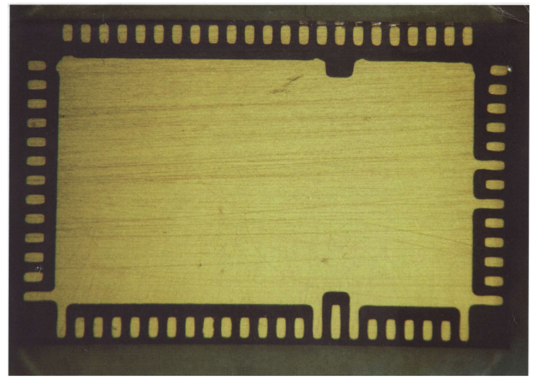

Figure 5. Rectangular QFN substrate for hybrid assembly or MMIC subsystem application

For these QFN package options, the ‘Air Cavity’ is typically facilitated by the use of a simple molded Cavity lid as in figure 6 or perhaps a metal cavity lid as used by some specific MEMs sensor devices. The flat base of this type of QFN does offer additional possibilities for lidding. For example, a 2 part lid assembly is possible by using a molded ring frame and flat lid, such as a glass lid for optical devices. Further, again depending upon the application, even just a polymer, glob top coating could be sufficient encapsulation.

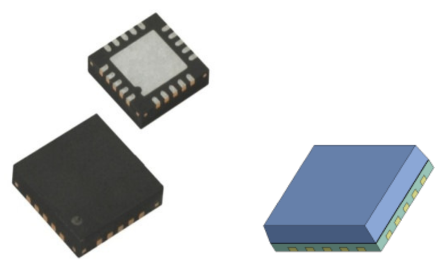

Figure 6. QFN assembled with a one piece cavity Lid (3D drawing version on right)

LCP MATERIALS

Liquid Crystal Polymer materials are becoming a key part of the emerging Electronics Industry. Suppliers Ticona (Vectra materials) and Solvay (Xydar materials) are developing these plastics for use at high temperatures (above 300° C) which is enabling use of these materials in a host of applications from basic circuit board substrates through complex injection molded piece parts.

The LCP materials used for ACPs and pre-molded packages have been developed to work with the complex assembly processes, die attach and wirebond, as well as allow for multiple excursions through the temperature gradients of a variety of solder reflow processes. The RJR HTP 1280 LCP is one of these a high performance thermoplastic molding materials that has many intrinsic advantages. The properties of HTP 1280 are summarized in Table 1.

The crystalline domains in the LCP material result in a polymer with very low water vapour transmission and moisture absorption characteristics.

TABLE 1

HTP 1280 LIQUID CRYSTAL POLYMER MOLDING COMPOUND

HTP 1280 – PLASTIC BODY COMPOUND		
Physical		
Density	1.67 gm/cc	ASTM D792
Water Absorption	0.02%	ASTM D570
Mechanical @ 23° C		
Tensile Strength	21,000 PSI	ASTM D638
Tensile Modulus	2.5×10^6 PSI	ASTM D638
Elongation @ Break	1.2%	ASTM D638
Flexural Strength	31,000 PSI	ASTM D790
Flexural Modulus	2.4×10^6 PSI	ASTM D790
IZOD Impact Strength Notched	1.6 ftlb/in	ASTM D256
Thermal		
Melting Point	280°C (536°F)	ASTM D3418
DTUL @ 1.8 Mpa (264 PSI)	270°C (518°F)	ASTM D648
Electrical		
Volume Resistivity	10^{12} ohm-cm	ASTM D257
Surface Resistivity	10^{17} ohm	IEC 93
Dielectric Strength	766 V/mil	ASTM D149
Dielectric Constant	3.7 @ 10 MHz	ASTM D150
Dissipation Factor	0.003 @ 10 MHz	ASTM D150
Arc Resistance	165 Sec.	ASTM D495

The low moisture transmission rate means that packages made with LCP are more nearly hermetic than any other type of plastic package. This is shown in the comparison to other polymers in figure 7. This water vapour permeability rate of LCP shows that it is similar to glass. Further, the associated very low water absorption percentage means that LCP packages do not create problems during soldering from the sudden vaporization of absorbed moisture that can cause package failures.

The mechanical properties of HTP 1280 are a nearly ideal balance for electronic packages. This strong and tough, but not brittle, thermoplastic is inert and resistant to corrosives and solvents, non-flammable, and contains no halogens. Since LCP is a thermoplastic it can be recycled and reused by regrinding and remolding unlike thermoset epoxy transfer molding compounds.

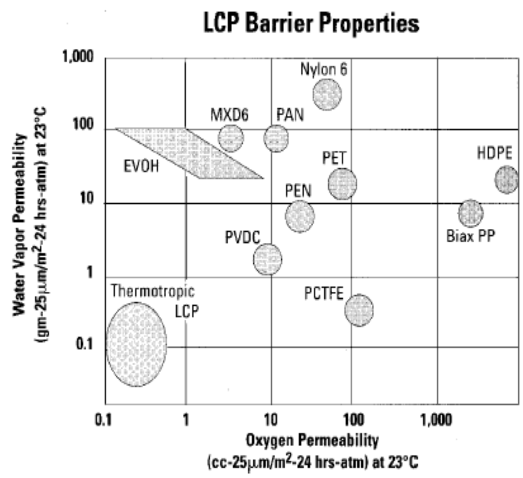

Figure 7. Water vapor and oxygen permeability of plastics. [7].

POLYMER BONDING

When considering package design there are actually more elements than the 4 key components listed above. Referring back to the R-Pak device shown in figure 2, there are seven aspects to be considered:

1. Cover Material
2. Lid Seal
3. Sidewall Material
4. Lead seal
5. Lead Material and finish
6. Base seal
7. Base Material and finish.

Whilst this signals a high number of process steps, to achieve the desired level of hermeticity, the sealing is the important part. Provision of the polymer epoxy to suit the material interfaces is the key issue. There are plastic ACP options which can reduce the number of steps and there are versions available that will not provide any sealing. These are acceptable for many applications however more and more RF devices, Photonics, Optics and MEMS devices require a minimum hermeticity for long term reliability. On the plus side of this is the ability to vary the materials for Lids, leadframes and substrates to meet the needs of the devices to be packaged. A unique flexibility of package options is provided by the R-Pak process as a result of the capability of RJR to be able to select the optimum polymer seal as an interposer between different materials.

Material parameters are therefore the key to optimising package performance for the devices. One of the desirable LCP characteristics for injection molding is the lack of adhesion to metals. While this results in clean release from the mold without using contaminating mold release agents, this same property means that LCP does not naturally bond to an insert molded leadframe. The RJR process uses a moisture barrier epoxy to seal the leadframes penetrating through the package body. This process seals the frames and makes packages near hermetic. [8][9][10]. To seal the interconnection, the RJR moisture barrier epoxy is applied to the leadframe before injection (insert) molding of the package body by the patented "inverted stamping" process.[11]. This epoxy is formulated to adhesively bond to the LCP mold compound and the leadframe metal, forming a leak tight seal where the leads pass through the package body.

Sealing the package base is the second process requiring the selection of the right application specific epoxy. The "3 piece" construction generally incorporates a metal base for high power dissipation and optimum electrical grounding. These metal based packages also offer the option of high temperature die attach in a plastic package.[12]. High power semiconductors may be die attached first with gold/silicon or gold/tin eutectic to the metal base and then the premolded plastic package body assembled to the base. The die is then wirebonded prior to lidding. The package body to metal base assembly requires a selected epoxy to meet the needs of bonding the LCP to whatever substrate is to be used. As stated previously, this substrate can be chosen to suit a number of parameters determined by the application, not specifically but usually for thermal compatibility with the devices to be packaged.

For the third assembly level, that of lidding or sealing the package, an epoxy with similar moisture barrier properties is required to final seal packages after the die is assembled. This is typically a 'B' stage epoxy that is applied to the package lids. It should be noted here that the epoxy type selected depends upon the lid material. Lids can be Thermoplastic, LCP, Metal, Ceramic or Glass. The materials parameters such as Thermal expansion (CTE), flexibility and surface finish that each exhibit differentiates the type of epoxy required.

The sealing process at this stage is crucial and use of automated sealing equipment is necessary if the Humidity sealing is critical. Recognizing that process control and consistency is key to high yield, RJR manufactures equipment to support package assembly by the customer. Their IsoThermal Sealer (ITS) is an elegant solution to the challenge of keeping package assembly consistent, controlled, simple and high yielding.[13]. While cover sealing with pre-applied B-staged epoxy can be done by a clip and bake method, optimum results are obtained with an ITS.

The variety of package options that are now possible will require careful selection of the sealing materials. For example, a QFN cavity lid, as shown in figure 6, is typically LCP and will be required to bond to both metal and LCP plastic. A RF amplifier package as shown in figure 8 will be assembled as per the R-Pak process requiring both leaded ringframe LCP to metal seal and LCP to LCP lid seal.

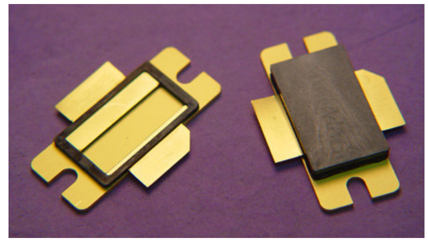

Figure 8. A 30W LDMOS amplifier package, designed with thick metal substrate for CTE match and thermal enhancement.

THERMAL MANAGEMENT

The full potential of the materials and processes can be realized by application optimized package design. The insert injection molding process allows for flexibility in placement and shaping of the package leads. Packages can also be manufactured as cavity packages with both plastic base and sidewalls for some applications. But if any level of thermal or conductive enhancement is required a metal base, usually isolated from the interconnection leads is a must as in figure 9.

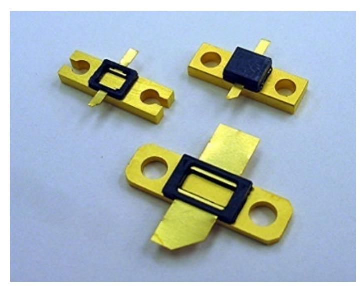

Figure 9 RF component package options.

The metal leadframe, which forms the conductive interconnection elements of a package are usually a Copper alloy. This is the most commonly used leadframe material and the HTP 1280 LCP molding compound is formulated to be a close CTE match. Copper is a very versatile choice for leadframes with excellent electrical and thermal conductivity at low cost. Copper can be readily plated with a wide variety of finishes to suit the application. While copper is most common, nickel-iron (A42) leadframe alloys can also be used where very stiff or very thin leads are desired. The R-Pak construction process is versatile enough to work effectively with any leadframe metal.

One of the most attractive properties of LCP is that the CTE is low and can be tailored. HTP-1280 is manufactured to be a close CTE match to copper, the most commonly used leadframe material for all types of packages. This CTE compatibility results in a highly reliable, matched system that minimizes differential thermal stresses.

However the RF and power markets are in need of more closely matched materials. Although they would prefer to use a package with a copper base, as this is generally suitable for a reasonable level of power dissipation and good electrical grounding, the development of different device materials is now pushing the demand for use of a range of different materials in order to provide better device CTE matching. Table 2 illustrates the range of materials now being considered.

TABLE 2

THERMAL PERFORMANCE OF SUBSTRATE MATERIALS

Material	Thermal Conductivity - W/mK	Avg CTE	Plating types
HTCC Al@O3	10	8	All
BeO	285	9	All
OFHC Cu	394	17	All
AlSiC MCX-703	185	7	All
AlSiC MCT-587	235	5.8	All
AlSiC MCT-487	255	4.8	All
Wcu 90/10	190	7	All
Moly Cu	160	7	All
CMC	185	6	All
CPC 1:4:1	235	9	All
RPak350	350	10	All
RPak330	330	8	All
RPak260	260	6.5	All
Aluminum Diamond	500	7.1	All
Diamond	1000	1	CVD

The list of materials is by no means exhaustive. RJR have formulated their own specifications for Copper alloys that meet most applications requiring good thermal management (High thermal conductivity) however the CTE mismatch to Silicon, Glass and Compound Semiconductors utilised in some devices is perceived the more critical factor. Here the average CTE is from 3 for Silicon to just below 6 for Gallium Arsenide devices. This factor in mind, choice of AlSiC for the substrate is now becoming popular especially for Power devices. [14].

Where ceramic packages are constrained to use a metal base CTE matched to the Ceramic, injection molded plastic packages can use inexpensive copper as an alternative to more expensive CTE matched metals or composites. Alternatively, the R-Pak type of design can combine the best of all. The capability to change the substrate to match different materials, without having to change the footprint of the device, the size or the position of the interconnection leads offers a new dimension for the system designer. This approach can provide an ideal solution for the device yet keep costs down particularly in the development and pre-production cycles.

CONCLUSION

The continual need for "Smaller, Faster, Cheaper" electronic systems affects all applications and routinely pushes the boundaries for component packaging. Further, the high performance and increasing speed requirement of RF electronics, is necessitating the need for enhanced thermal management and is a key issue for the components. This requirement has proved to be an obstacle for devices, inhibiting the use of lower cost plastic packaging, in favour of metal can parts or ceramic packaged parts.

The use of LCP and selective polymer bonding in the R-Pak process provides a package technology with the widest range of product flexibility. The technology allows the use of a range of high performance base materials not possible with any other competitive package technology. These can be applied to industry standard package outlines/ geometries or in custom designed devices. With the advent of QFN there are options of multiple leadframe configurations in standard package outlines which can significantly reduce costs to tool up new designs.

The polymers and processes developed for this package technology allows use of the lowest cost thermal base options or specialised high performance material options with low cost manufacturing processes. These processes are utilised in production with high volume manufacturing practices. Injection molding and high speed epoxy application processes have been developed to ensure cost effective packages.
The unique developments of the right polymer bonding epoxy materials and related processes, has enabled a package technology that is flexible, producible and cost effective for the RF, Power and other advanced device technologies.

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