LOW COST AIR CAVITY LCP
(LIQUID CRYSTAL POLYMER) PACKAGING

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ABSTRACT

Quantum Leap Packaging has developed low cost Air Cavity LCP (**Liquid Crystal Polymer**) packaging for high frequency, power, MEMs and other applications. This unique packaging technology allows for the combination of improved electrical and thermal performance over conventional ceramic packages at much lower costs. Using QLPs proprietary LCP technology, copper flanges and lead frames can be incorporated into the package(along with other metal systems) which can provide for twice the thermal conductivity and a higher electrical conductivity than conventional lead frame and flange materials used in ceramic packaging. In addition, the packages can meet the same reliability requirements as standard ceramic packages, including passing gross leak and fine leak tests (1 X 10-9 cc/sec). Two lid solutions are also available which include B-stage epoxy, and a unique ultrasonic welding process. In addition, the packages can be provided in strip format, so as to be compatible with conventional automatic assembly operations.

INTRODUCTION

Materials technology for packaging throughout the years has been divided into two classes with three distinct material sets. Classifications have included hermetic and nonhermetic packages. In the former category, low temperature co-fired ceramic (LTCC) and metal materials have dominated.

In the nonhermetic packaging domain, overmolding technologies have dominated, with materials based on epoxy formulations, including cresol novalac, biphenyl and multifunctional formulations. Ceramic and metal packages have been used for high reliability and high performance applications, particularly, where a cavity in the package is needed so as to not require contact of an encapsulant or other material with the device. In addition, these material sets and manufacturing methods result in traditional hermetic barriers, where moisture and gasses are kept from penetrating the packages. Epoxies in overmolding technologies are used for high volume and lower reliability applications because the epoxies have much higher permeabilites with respect to moisture and gasses.

For many years packaging for new high performance devices, which required cavities, relied on these age-old ceramic and metal package technologies. These technologies were developed more than twenty years ago, and were based on low temperature co-fired ceramic materials, or machined metal housings, with ceramic feed-throughs. These packages have always been deemed to be initial product packages, with the hopes of cost reducing the packages by using overmolding technology.

As there are extreme cost pressures on semiconductor and optical products, packaging is becoming a high percentage of the cost of these products, particularly when the packages are manufactured using metal and ceramic materials.

Because of these cost pressures, there has been a need to develop a new class of packages, which can be manufactured much more cost-effectively, and has the ability to provide comparable reliability as the traditional materials. Quantum Leap has developed a series of package families that are footprint compatible to ceramic packages, and offer similar performance at much lower cost. These packages are based upon proprietary LCP formulations, and are manufactured with micro-injection molding technologies which are automated to provide for lowest possible costs.

MATERIALS

Liquid crystal polymers (LCPs) are a class of materials that have been used in industrial applications for over 20 years. The initial target market for LCPs were in the area of “nonstick” cookware products, developed by a Tupperware division (1).

The LCP materials are based on wholly aromatic chemical structures that have the unique properties of possessing polymer chains, which exhibit crystallinity in the liquid form, and subsequently solidify into an ordered crystalline structure in the solid form.

The predominant molecule in the LCP formulations is 4-hydrobenzoic acid (HBA), which in turn has an extremely high heat resistance temperature. LCPs are co-polymerized with other monomers which provide for a balance of properties. Because of this chemistry and crystal packing structures, these materials have very interesting properties with respect to applications in the electronics domains.

The general properties of LCPs include:
Advantages:

- High strength and rigidity.
- Low viscosity, high moldability.
- Low shrinkage, low coefficient of linear expansion (flow direction.
- Low heat of fusion therefore, fast cycle times.
- Very good dimensional stability.

Disadvantages:

- Anisotropy (strength, shrinkage.
- Low weld lines strength.
- Poor adhesion to metals.
- Assembly problems—ultrasonic welding, adhesion of adhesives.
- Limited high temperature capabilities (cannot meet eutectic solder temperatures)

Because of the advantages, these materials have proliferated in many electronic applications including surface mount connectors, bobbins, and have been used as replacements of many thermoset materials, mostly in low reliability applications. Therefore, it can be said that these materials while expanding into new product applications, still only enjoy niche markets.

The predominant features of the materials that have made them suitable for thermoset material replacements in the electronics domain, include the following:

- Resistance to lead-free soldering temperatures.
- Flame resistance.
- Low moisture absorption.

Because of several disadvantages, these materials have not been used in the semiconductor or optical packaging space. The major reasons include: adhesion problems with metals (leadframes, etc), anisotropy, differential shrinkages along different axes and unfamiliar package manufacturing techniques (injection molding—most package foundries are most familiar with transfer molding).

QLP's work has focused on developing LCP compounds and packages which overcome the previous material and manufacturing deficiencies. The purpose of this effort has been to develop a class of packages that can replace the older ceramic and metal technologies, while providing for comparable reliability performance, at a much lower cost.

Specifically we have focused on:

- LCP compounds with tailored mechanical properties (CTEs, shrinkage, etc)-- Matching copper, silicon, and ceramic.
- Isotropic compound formulations.
- Adhesion of LCPs to leadframes and metal inserts.
- High temperature materials that can resist eutectic soldering (AuSn—330C and AuSi-430C).
- Hermetic material and package designs: passing gross and fine leak testing.
- Package, material and sealing techniques which provide for low moisture ingress.
- Lid sealing technology: ultrasonic welding technology and B-stage epoxy solutions.
- Micro-molding for high volume manufacture.
- Development of LCP films for interconnect and wafer-scale packaging.

The material sets that QLP has developed include a family of thermotropic liquid crystal polymers developed specifically for air cavity applications. Since this is a family of materials, several LCPs are available which can be tailored for specific applications. Table 2 summarizes several critical properties of the QLP formulations for cavity package applications.

The significance of this table is that several properties of the materials can be tailored for specific applications. This includes coefficient of expansion which can be matched to either copper, silicon, gallium arsenide, glass, or ceramic, dielectric constants, which can vary from 2.9-3.9 and melt temperatures which can vary from 330^{o}C – 450^{o}C

Material	**CTE** ppm/ C	**Dielectric Constant**	**Loss Tangent**	**Heat Deflection Temp (^{o}C)**	**Melting Point (^{o}C)**
QLP-1	17	2.9-3.2	.002	440^{o}C 280^{o}C	470^{o}C 330^{o}C
QLP-2	6	2.9-3.9	.002	360^{o}C	390^{o}C
QLP-3	3	2.9-3.9	.002	360^{o}C	390^{o}C

Table 1 Material Properties

PACKAGE DESIGNS

Design for MEMs and High Frequency RF Devices

There are two configurations of packages that have been developed for cavity packages by Quantum Leap. These include the Quad Flat No-Lead (QFN) packages which are cavity versions of the over-molded QFN packages which has been standardized by the JEDEC committee (2). This style of packages is appropriate for packaging MEMs, high frequency RF, such as VSAT (up to 30GHz and beyond), optical, image sensors and other high volume devices that are cost sensitive.

The other family of packages is a configuration of packages with flanges, which is used to dissipate significant power (up to 500 watts) and has relied on ceramic package technology for the necessary reliability. Applications include silicon LDMOS, Gallium Nitride (GaN), Gallium Arsenide and other high power devices.

AIR CAVITY QFN DESIGN

Figure 1 shows the construction of the QFN package family.

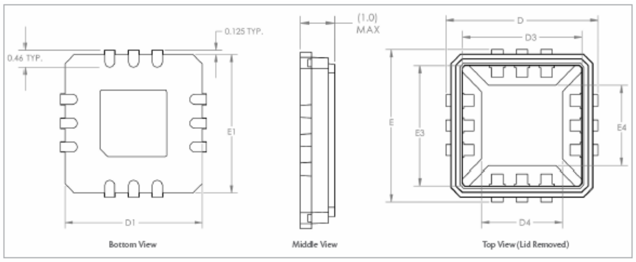

Figure 1 QFN Cavity Packages

Table 1 shows different package styles that are available with the QFN standard.

The construction of the package involves injection molding a ring of liquid crystal polymer over a copper alloy leadframe. Critical to this is providing the necessary locking features in the leadframe so as to anchor the plastic properly to the metal features. In addition, the packages are molded on a leadframe substrate which is in an array format. This is the desired format such that assembly of devices into the leadframe is done in an automated fashion utilizing standard high-speed wirebonding and die attach equipment. The concept is to use same assembly equipment as is used for the overmolded QFN assembly. Figure 2 shows the format of the substrate which is molded using a 20 x 6 format.

DIMENSIONS									
D	E	MAX. LEADS	D1	E1	D3 Cavity	E3 Cavity	D4 Die Pad	E4 Die Pad	MAX. DIE SIZE (Theoretical)
3.0	3.0	8	2.75	2.75	2.43	2.43	1.11	1.11	0.86
4.0	4.0	16	3.75	3.75	3.43	3.43	2.11	2.11	1.86
5.0	5.0	24	4.75	4.75	4.43	4.43	3.11	3.11	2.86
6.0	6.0	32	5.75	5.75	5.43	5.43	4.11	4.11	3.86
7.0	7.0	40	6.75	6.75	6.43	6.43	5.11	5.11	4.86
8.0	8.0	48	7.75	7.75	7.33	7.33	5.91	5.91	5.66
9.0	9.0	56	8.75	8.75	8.33	8.33	6.91	6.91	6.66
10.0	10.0	60	9.75	9.75	9.23	9.23	7.71	7.71	7.46
11.0	11.0	68	10.75	10.75	10.23	10.23	8.71	8.71	8.46

Table 2
QFN Formats

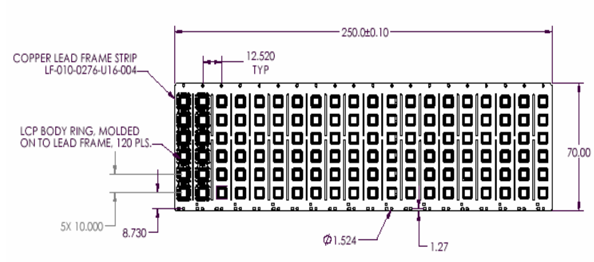

Figure 2 Array Format

This format allows for the following process flow for manufacture:

A) Manufacture leadframe in strip or reel-to-reel format.
B) Plate the leadframe prior to molding.
C) Injection mold package bodies onto leadframe substrate
D) Die attach devices onto leadframe.
E) Wirebond devices.
F) Attach lid to package.
G) Excise package from leadframe strip (punch or saw)

The leadframe material is manufactured using a high thermal conductivity and high hardness copper alloy such as CDA 194 Extra spring hard material. The coefficient of expansion (CTE) of this material is 17 X 10^{-6} in/in/^{o}C which is similar to the effective CTE of multilayer printed circuit boards (PCBs) minimizing the stresses on the solder joints due to mismatches of CTE. The leadframes are pre-plated with nickel (Ni) and palladium (Pd) (flash of gold) prior to molding. This plating system is compatible with lead-free soldering systems, and passes standard ageing tests. The leadframes are injection molded in reel-reel format and are then excised to necessary strip length. There are several features in the molded structure that injection molding with LCPs allows for. They include:

- Thin-walled construction (.010")
- Flow into half-etched sections (.004")
- Epoxy dam construction.
- Lead-in for lid assembly.

The LCP materials can flow into very thin sections which allows for molding of features into "retention" sections of the leadframe. In addition, since the LCPs are extremely tough materials, wall sections can be extremely thin, which allows for maximum size of devices in the cavity.

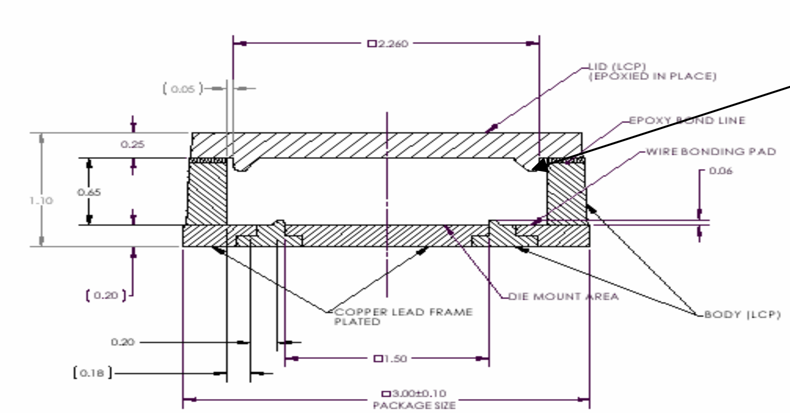

Figure 3
Cross section of Cavity
Package

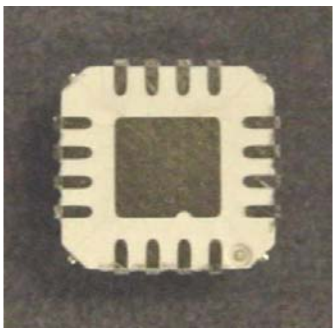

Figure 4A
Bottom View
OF Package

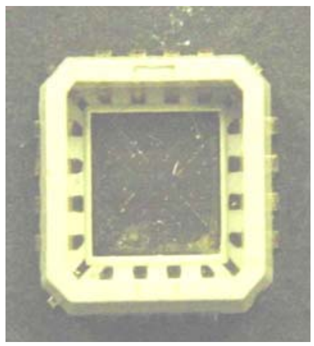

Figure 4B
Top view of the
package

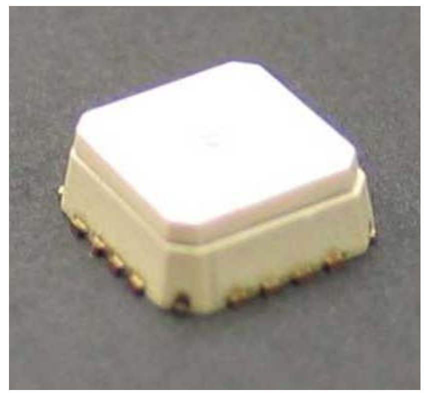

Figure 5
Assembled View of
Package

Figure 4C
Top View of the
Lid

Figure 4D
Bottom View of
the Lid

LID SEAL

Two techniques have been developed for sealing lids to packages. Figure 6Aand 6B shows a lid which has been developed using a pre-applied "B-stage epoxy". This material has excellent adhesion to LCPs and can be provided with the adhesive already dispensed and slightly cross-linked to the lid. The customer then attaches the lid and cures the epoxy using temperatures in the range of 165^{o}C-175^{o}C

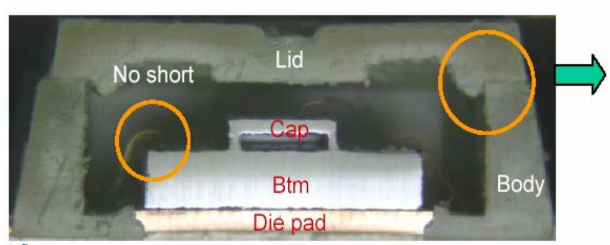

Figure 6A—Cross
Section of Air Cavity

Figure 6B
Close-up of lid seal

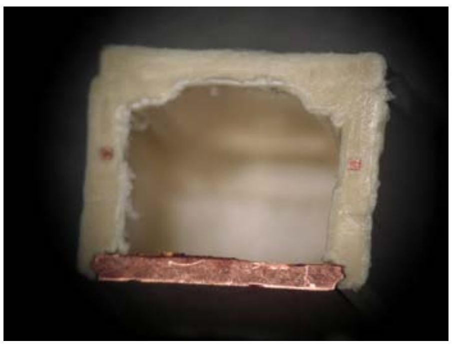

Figure 7
Close-up of US joint

Figure 7 shows a package, which is sealed using an ultrasonic welding process. This process involves welding a lid using ultrasonic vibration/motion at a specific frequency. This process has been developed so that the lid vibrates, causing friction to be applied to a "weld projection", which in turn causes the weld projection to melt.

The process is instantaneous, such that melting and freezing occurs in the matter of microseconds. This process lends itself to high volume automation. Figure 8 shows the ultrasonic welding equipment.

Figure 8 Ultrasonic Welder

WAFER SCALE PACKAGING OPPORTUNITIES

With QLP's materials and process technology, it is possible to develop wafer scale packaging.

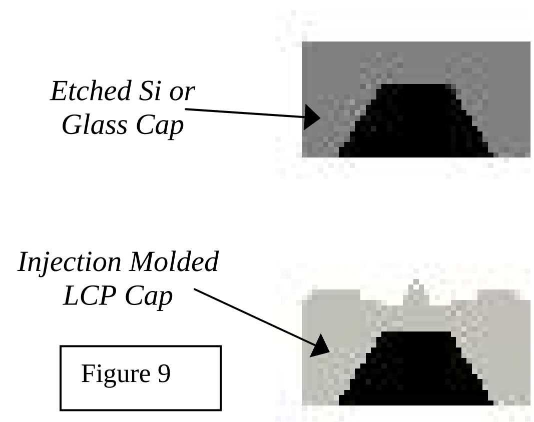

Figure 9

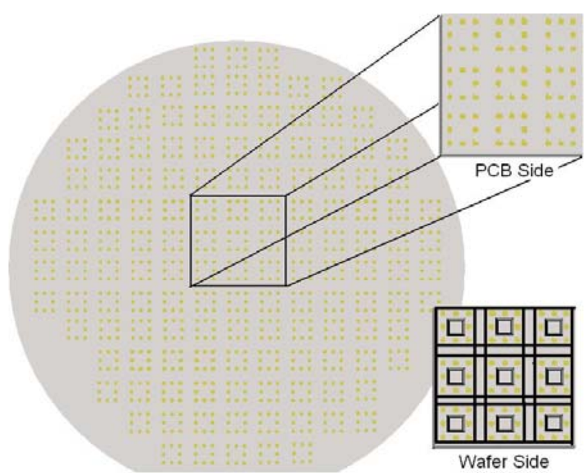

Figure 10

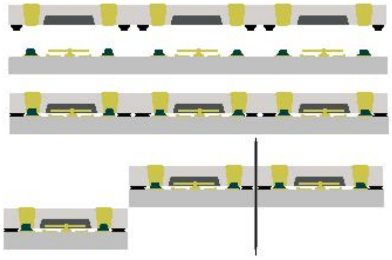

Figure 11

Figure 9 shows wafer caps which are manufactured using liquid crystal polymers with CTEs near 3 ppm/^{o}C. The wafer caps are bonded to the wafers using three potential techniques: organic seal, metallic seal or, true melt sealing.

Figures 10 and 11 show a cavity wafer scale package that includes true metallization. The metallization can be applied using several techniques, including lamination/pattering, sputtering and electroless plating. Because permeability of the LCP is extremely low, this wafer level packaging approach provides for near hermetic solutions.

SUMMARY

Cavity packaging of devices has been dominated by metal and ceramic materials for over 20 years. New innovation is required to drive cost effective successful products into mass production. QLP is developing materials and process technologies so as provide for new ways of packaging MEMs, RF, optical and stress sensitive devices.

REFERENCES

1.Chemical Market Reporter, July 5, 1999, Alex Tullo.

2. JEDEC standard Document, Thermally Enhanced Plastic Very Thin and Very Very Thin Fine Pitch Quad Flat No Lead Package. HVF-PQFN, HWF-QFN. Item 11.11-684. MO-220-I.