Plastic Air Cavity QFN Coupled with an Innovative Ultrasonic Lid Process Achieves True Hermetic Performance

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Abstract

Devices such as Image Sensors, MEMS, and HB-LEDs are increasingly designed into automobiles and require greater package reliability particularly in high temperature, high humidity conditions. As a result, hermetic performance is becoming more important in today's packaging requirements. Traditional plastic transfer molded packages are mature, low cost packages but not a viable solution because of poor moisture absorption and other material related issues such as stress and non-linear properties. Similarly, plastic air cavity packages have never met true MIL 883 reliability, because of exposed leak paths at the lead frame-polymer interface and poor lid seal methods that fail to achieve hermetic levels. Hermetic package choices have been limited to ceramic packages which require specific lid attach processes – low melt glass, and seam weld. Nevertheless, high modulus, low CTE, limited flexibility and high costs have led companies to search for other alternatives. There has been a clear need for greater flexibility and improved packaging solutions that achieve hermetic performance.

By combining a unique new material technology, package design and an innovative processing, a plastic air cavity QFN has been developed to achieve hermetic fine leak performance, $5x10^{-8}$ atm cc/s He. This capability is the first in the industry. This paper will discuss material development based on Liquid Crystal Polymer derivatives, controlling mechanical properties such as CTE, key design features and an innovative ultrasonic lid process that enable a hermetic plastic package. Performance and reliability data will be presented on 8mmx8mm QFN's that meet fine leak requirements and serve as the package solution for hermetic, high reliability applications.

Key words: Package, Moisture, Hermetic, LCP, Quantech^{TM}, UltraSeal^{TM}

Introduction

Semiconductor packaging has been dominated by two classes of packages based on different material technologies: ceramics and polymers. In the case of ceramics, cavity packages have evolved to be the form factor of choice for high reliability applications. Ceramic is a material which has extremely low moisture permeability, and also can be "hermetically sealed". Polymer packaging is dominated by epoxies, also referred to as epoxy mold compounds (EMC) which are transfer molded and used for "encapsulation" of semiconductors. Epoxies are permeable to moisture but are still widely used for consumer product applications where device reliability is less demanding.

Semiconductor devices, when exposed to excessive moisture, will lead to electrical leakage, corrosion and ultimately electrical failure. The reliability of these devices relies heavily on environmental protection provided by the package enclosing it. The primary source for moisture inside the package cavity stems from moisture ingress through poorly sealed packages.

The reliability of cavity packages is strongly related to the "air-tightness" or hermeticity of the package. Hermeticity is a measure of a semiconductor package's ability to protect the device from various gas and moisture penetration. Traditional hermetic packages, are made from metal, ceramic, or glass materials. These materials have very low permeability, such that moisture and gasses cannot penetrate through the materials, and cause condensation on the device or contamination by corrosive gasses. In addition to permeation through the bulk materials, penetration can also occur though "leaks" at various interfaces. For a ceramic package, key interfaces include the lid to package seal which is usually soldered, along with the interface between the metal leads and the ceramic. Any small openings allow water or gasses to flow inside the package.

Hermeticity

The traditional method of evaluating the hermeticity of a cavity package is by performing a helium leak test (Mil-STD-883). In this test a sealed package is placed in a helium pressurized vessel (bomb). Helium gas will enter the package though any "leak channels. After removal of the package from the bomb, the package is connected to a helium leak tester, and the leak rate of the package is detected. The absolute amount of helium escaping depends upon the size of the leak channel and the helium pressure within the package. The helium pressure in the package depends upon the absolute amount of helium and the internal volume of the package.

The levels of hermeticity are governed by Mil STD 883 test Condition 1014. The following are the Hermetic rating and test methods:

Test Condition A: Fine Leak using helium tracer gas:
A1: Fixed Method
A2: Flexible Method
A4: Open Can leak for Unsealed Packages

Test Condition B: Fine Leak using radioactive tracer gas

Test Condition C: Gross Leak and Fine Leak Test techniques
C1: Gross Leak Bubble Test
C3: Gross Leak Vapor test
C4/C5: OLT Optical leak Detection (Gross and Fine Leak)

Test Condition D: Gross Leak using a Die Penetrant (Destructive)

Test Condition E: Gross Leak by Weight Gain Measurements

To be designated as a hermetic package, the helium leak rates of a cavity package must meet the following criteria:

Table 1 He Leak Rates and Hermetic Ratings

Package Volume (cc)	**Maximum Leak Rate (atm-cc/sec)**
<= .01	5×10^{-8}
0.01 < V <= 0.4	1×10^{-7}
>0.4	1×10^{-6}

Typical leaks in packages are very small features whose cumulative effects create paths for moisture and gasses to permeate. The ability of a gas or liquid to flow through a leak is inversely proportional to the molecular weight of the gas species and directly proportional to the pressure. As a reference, listed below are the properties of various molecular species of concern from the standpoint of device degradation. Helium is an extremely small molecule and is selected for its sensitivity to test the integrity of a package. The lower the helium leak rate of a package, the better its integrity.

Table 2 Properties of Gasses and Certain Liquids

Gas	Molecular Weight (Grams)	Diameter (X 10-8 cm)	Molecular Mass (X 10-24 Grams)
Helium	4.0	2.2	6.64
Neon	20.2	2.6	33.5
Argon	40.0	3.7	66.2
Nitrogen	28.0	3.8	46.5
Oxygen	32.0	3.6	53.1
Air	28.7	3.7	47.6
Water	18.0	3.2	29.9
Carbon Dioxide	44.0	4.6	73.0

For a package to be compliant to Mil-STD 883D testing, leakage due to openings at interface must be extremely small.
For a package to pass the Gross Leak Test Condition C1: MIL STD 883, the following applies:

- He Leak Rate <= $1X\ 10^{-5}$ atm-cc/sec.
- Leak channels will all cross sectional dimensions greater than 1×10^{-4} cm, will cause a package to fail this test.

Flaws with Current Organic Air Cavity Packaging Technology

In the last decade, there has been an attempt to develop air cavity packages, utilizing new injection moldable thermoplastics, which based on extremely good barrier materials. The class of polymeric materials which is the most suitable for packaging applications is liquid crystal polymers. This is due to several interesting properties of LCP, including: barrier to moisture, stability, rigidity, and chemical resistance. (Ref 2, 3, 4, 5).

The inherent flaws in LCP for packaging applications include: inability to be robust during eutectic die attach (especially above 320^{o}C), inability to adhere to metal, glass or ceramic, extreme anisotropy in mechanical properties (X-Y directions have different CTE values), difficulty in joining LCP materials together.

Despite these flaws, the industry has tried to incorporate these materials into air cavity packages with the following compromises:

- Assembling package components using a glue, after die attach to substrate
- Using epoxy adhesives at LCP/metal interfaces for adhesion and at lid seal interface
- Accommodating lower reliability standards due to moisture ingress and lower levels of hermeticity.

Figure 1 shows the typical interfacial issues associated with a standard molded LCP package .Adhesion of the LCP material to the lead-frame is non-optimum. Die which is inserted in the cavity will eventually "leak" through the LCP/Leadframe interface (MIL STD 883Test Condition D: Gross Leak using a Die Penetrant). Because of this fundamental issue with LCP, the industry has developed inadequate solutions and hermetic levels are not achieved.

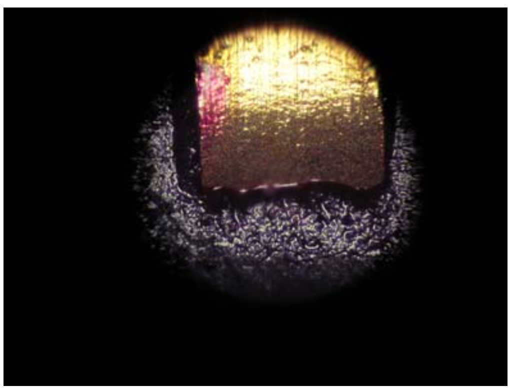

Figure 1: Die Leaking Through Conventional LCP Package (Non Hermetic)

Quantum Leap Technology
Materials

Quantum Leap Packaging has developed a material technology, which is based originally on a novel class of LCP materials and has a molecular structure and properties targeted to solve the current issues associated with air cavity LCP packages. These properties include:

- Moisture permeability equivalent to glass
- Temperature resistance of over 420^{o}C
- Isotropic properties (e.g., CTE)
- Ability to adhere to components without interfacial epoxy layers.

Permeability of Quantech^{TM}

Polymer materials developed for near-hermetic packages have permeabilities that allow easy moisture and gas penetration. As mentioned previously, in true hermetic packaging, materials are used which are very impervious to moisture, gases and other substances. Figure 2 shows various materials which are used in semiconductor packaging. As can be seen, the permeabilities of the "near-hermetic" materials are high, such that moisture can easily penetrate the package. Glass, ceramic, and metal have very low permeabilities, and thus are ideally suited for hermetic packaging. Also shown is the measured permeability of the Quantech ^{TM} formulation used for this package. As can be seen, the permeability is equivalent to glass, making it a very suitable candidate for "hermetic" packaging.

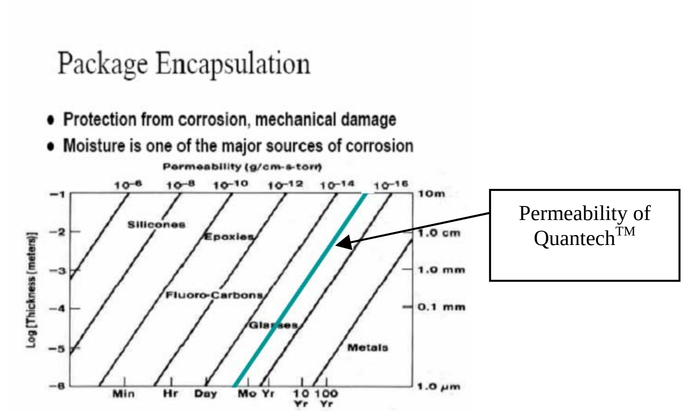

Figure 2: Permeability of various materials with QuantechTM

Anisotropy vs Isotropy

One of the challenges with traditional LCP materials is its anisotropic properties. The thermal coefficient of expansion or CTE is dramatically different in the x-y-z directions. During high temperature excursions, the material will expand at different rates dimensionally. This will introduce varying thermal stresses across the package and lead to delamination and failures at different material interfaces, such as the metal lead/polymer interface.

Quantech^{TM} was developed with isotropic properties, dimensionally balanced CTE, which is a fundamental need to minimize stresses across the package configuration. Table 3 compares the CTE of traditional LCPs to Quantech^{TM}. Note the significant CTE values in the X-Y directions with standard LCP verse the balanced CTE of Quantech^{TM}.

Table 3: CTE of Traditional LCP vs Quantech™ showing anisotropy and isotropy properties

Product	X - Mold Direction (ppm/^{o}C)	Y- Tranverse (ppm/^{o}C)
Standard LCP A	6	104
Standard LCP B	9	83
Quantech™ 135-8	**27**	**31.5**
Quantech™ 135-10	**19**	**20.5**

Temperature Resistance and Interfacial technology

One of the most challenging and critical issues for hermetic package construction is the issue of interface technology and the ability of the package to resist delamination at temperature extremes. Along with isotropic performance, QLP has developed a material system that inherently provides direct and robust adhesion to metal components, without an epoxy or glue. Extremely high adhesion at the polymer-metal interface is achieved preventing any potential moisture leakage. The combination of Quantech's™ low permeability and direct bonding to metal enables interfacial technology equivalent to the glass-metal seal technology used in ceramic packaging.

Quantech™ is thermally stable up to 490 C. Figure 3 is a picture of a QLP 7x7 package which has been exposed to Au-Sn reflow (peak temperature = 320^{o}C). After reflow, the helium leak rate of the package remains 5 x 10^{-8} atm/cc/sec. Red die is used to illustrate that the package maintains integrity.

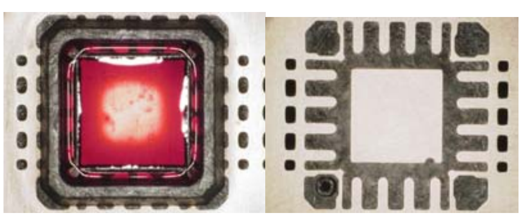

Figure 3: Hermetic Plastic Package from QLP using QuantechTM (No leakage from Red Die)

Lid Seal Technology

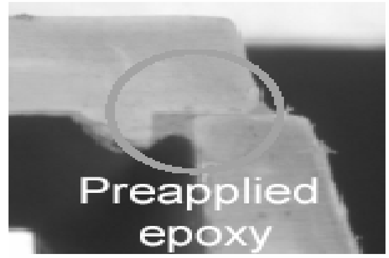

Figure 4: Cross section of Lid attach using Epoxy

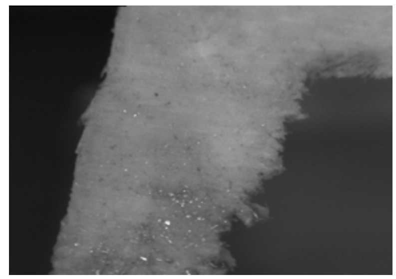

Figure 5: Cross section of Lid Attach using UtlraSealTM Ultrasonic process

Figure 4 shows lid seal technology utilizing standard LCPs with a B-stage epoxy. This solution compromises the integrity of the package, because of the high permeability of the epoxy. Figure 5 shows a QLP solution where the lid seal is made with a hermetic ultrasonic weld. A complete seal is created with no possible leak path for moisture. QLP's Ultraseal™ solution is utilized with Quantech™ material to minimize moisture ingress into the package.

Image Sensor Packaging

The ability to customize Quantech™ and its hermetic technology enables design flexibility and package solutions. One example is image sensors packaging. Image sensors, whether CCD (charge-coupled device) or CMOS (complementary metal oxide semiconductor), are devices used to capture images for digital cell phone cameras, digital still and video cameras. These are mostly consumer products and typically do not require hermetic performance. However, image sensors have been increasingly designed into luxury automobiles, both internally and externally, for applications such as lane changers, auto dimming, and rear view cameras. For these automotive applications, package performance and requirements are more demanding and require a level of hermeticity not previously needed with consumer camera applications.

Current package designs for image sensors consist of a ceramic or plastic air cavity package with a glass lid attached using a UV epoxy. Ceramic packages offer the greatest reliability and moisture resistance. Still, the epoxy layer between the glass and ceramic is a weak moisture barrier and serves as leak path, resulting in a non-hermetic package. Package engineers have addressed this by increasing the all thickness of the package, increasing area of the epoxy layer and ultimately enlarging the leak path. This solution improves overall reliability but the epoxy remains a poor moisture barrier susceptible to moisture penetration over time.

QLP developed a glass lid embedded into a polymer ring, based on a specific Quantech™ material formulated to provide direct adhesion to glass, which forms a hermetic seal, shown in Figure 6 The glass lid configuration is then ultrasonically attached using UltraSeal™, QLP's ultrasonic attach process forming a hermetic weld between the lid and package. Figure 7 shows several image sensor packages: ceramic, plastic air cavity and Quantech™ package with glass lids.

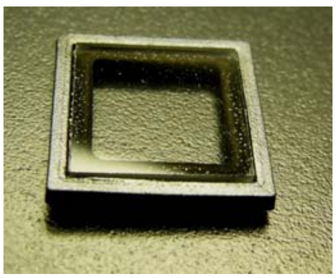

Figure 6: Glass Lid embedded in QuantechTM ring

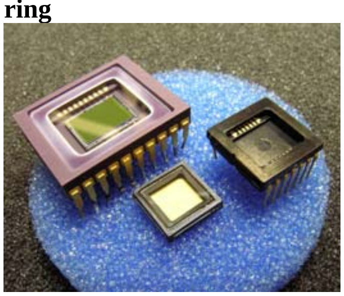

Figure 7: Image sensor packages with glass lid and QLP QuantechTM Package

By creating a direct bond and hermetic seal between the glass and Quantech™ ring frame, and then ultrasonically attaching the lid to the QFN, a hermetic package is achieved. Key advantages of this package are (1) elimination of UV epoxy and cure stage (2) extremely high throughput (3) package miniaturization where thin walls are possible (4) hermetic performance meeting automotive standards.

Dew Point Test

The Dew Point Test is a critical assessment that determines moisture resistance of an image sensor package. Sealed packages with a glass lid are preconditioned and then exposed to 85 C/85% RH up to 1000 hrs. Every 100 hr intervals, the package is removed and then set on a surface first set at 25 C for 10 seconds. The glass is then inspected under magnification for any moisture condensation within the package. If no condensation is observed the part is then set on a cooler surface, at 5 C lower for to 10 seconds. Again, the parts inspected for condensation. This cycle continues with lower temperatures until moisture is observed. The temperature that registered any moisture is identified as the dew point. When QLP's packaged with an UltraSeal™ glass lid was exposed to this test, it surpassed -35 C after 1000 hrs without any condensation. According to customer evaluations, this was the first reported package that reached this dew point level, outperforming ceramic packages with glass lid attached with a UV epoxy.

Summary

QLP has developed a unique materials technology which overcomes many of the traditional issues associated with LCP air cavity packages. By combing material technology and an innovative ultrasonic lid process, UltraSeal™, a plastic air cavity QFN was developed which achieves hermetic levels meeting MIL-STD 883D Fine Leak requirements, $5x10^{-8}$atm-cc/s. The issues solved include: stability at eutectic die attach temperatures, anisotropy of material properties, low moisture permeability, robust adhesion to metal components, and the ability to join LCP materials together thus eliminating epoxy "glue" from the package. Epoxy outgassing can be a major issue with devices such as image sensors, LEDs, MEMs structures.

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