

Multi-lead Organic Air-Cavity Package for High Power High Frequency RFICs

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Abstract — A new air cavity package has been developed and qualified for packaging high power RF components. The package uses the standard outline of a conventional ceramic package. The ceramic dielectric is replaced with a high performance thermoplastic called Quantech™ (which is a modified Liquid Crystal Polymer). The package manufacturing technology provides for a cost effective means of creating a package with multiple leads. Such package is advantageous in the cellular base station market for high electrical and thermal performance, reliability and lower system level cost using a power RFIC. This paper outlines the construction of the package and the reliability test findings collected for a 18-Leaded version of the package.

Index Terms — RFIC, LCP, WiMax, LTE, air-cavity, power amplifier

I. INTRODUCTION

Explosive growth in ubiquitous wireless communication due to new subscribers, new products and services has driven the need to update and expand the wireless network infrastructure worldwide [1,2,3]. In 2007, the base station market numbered 3.6million and is expected to grow to figure of 5.7million, worldwide. Various geographic regions in world are driving a new subscriber base. The proliferation of mobile internet devices and services has driven wireless bandwidth growth. Operators are therefore updating to new generation infrastructure technology such as WiMax or LTE, for example, which typically operate at frequencies greater than 2 GHz.

RF power components used in the base station application usually require tradeoffs in the demands for high power, high linearity, and low cost. Ceramic air cavity package platform has historically provided for the discrete solution for high power and linearity. This platform has years of proven reliability and cost effectiveness. Ceramic air cavity packages, although well suited for high power applications, are not optimal for packaging RFIC devices (Radio Frequency Integrated Circuit). The primary constraint is related to incorporating large lead counts in the existing ceramic package platform, such as NI-780.

Higher power amplifier RFIC offered by Freescale provides the system designer an integrated solution that can yield overall lower cost system level solution in the base station

applications. Conceptually, the RFIC takes two or more board level discrete power amplifier RF devices and integrates them into single multi-stage RF device. Multiple inputs and outputs can be required in a given application. Single die RFIC solutions have been successfully offered for years in the overmolded plastic package platform. The new package that is described in this paper fills the market need for RFIC base station packaging between the reliable overmolded single RFIC die solution and the proven multi-die but smaller lead count ceramic air cavity package platform.

To leverage the key advantages of the above described ceramic and overmolded-plastic package platforms, Freescale and Quantum Leap Packaging have co-developed the ACOP (Air Cavity Organic Package). ACOP packages have the capability to accommodate large number of leads as it is not constrained by the standard ceramic package design rules for brazing leads to ceramic. The target application for the ACOP is to package large single or multi-die high power (>125W) high frequency (>2GHz) RFIC amplifier. The ACOP thermal performance is identical to that of ceramic air cavity package.

II. AIR CAVITY ORGANIC PACKAGE DEVELOPMENT

The ACOP package development began with the following objectives established for the technology: a) an 18-leaded package that would be a drop-in for the current ceramic assembly process; b) the package to have improved dimensional tolerances to better facilitate automated assembly; c) the same (or better) reliability than the current ceramic technology; and d) compatible with standard molding and assembly process technology and ability to be scaled for high volume production.

To achieve these challenging objectives, a polymer technology was developed by Quantum Leap Technology with the following fundamental properties: high temperature properties to withstand hard solder processing, direct bonding to metal components to satisfy necessary hermetic sealing requirements, toughness and ductility which allows the window frame to withstand high stresses during assembly (>100 lb RF test fixture loads and lead bending and high stresses on cross-sections). Other critical material properties include CTE matching to copper, low moisture absorption,

and electrical properties appropriate for RF applications. In addition, the material needs to be injection moldable for filling thin cross-sections and be capable to be scaled to high volume production.

III. MATERIAL DESCRIPTION

Traditional Liquid Crystal Polymers (LCP) have many of the outstanding properties required for RF packaging which include excellent electrical properties and low moisture absorption. However traditional LCP has several critical flaws which have prevented LCP from gaining widespread use in the RF packaging area. These include very poor adhesion to metal, thermo-mechanical properties (>320°C) not adequate for hard solder die attach, and mechanical and physical properties which are not adequate for the high levels of forces exerted on the package during assembly.

To overcome these inherent problems, a new class of polymer termed Quantech™ has been developed. Quantech™ has higher operating temperatures than standard LCP with typical melt temperatures exceeding 400°C. Quantech™ is therefore compatible and can withstand Freescale assembly processing temperatures that exceed 350°C and in addition can withstand and resist stresses and deformation that result from process clamping during assembly. The Quantech™ formulation, results in a polymer which is extremely tough (~5% elongation), and has tensile strengths better than glass-filled LCP's. In addition, the material system does not suffer from the anisotropic problems associated with glass-filled polymers. Table 1 shows the key physical properties of this material.

TABLE I
SUMMARY OF MATERIAL PROPERTIES

Heat Deflection Temp (°C)	Elongation (%)	Coefficient of Thermal Expansion (ppm/°C)	Dielectric Properties	Dissipation Factor
370	5	17 (X,Y)	3.2	.003 (2 GHz) .002 (10 GHz)

A. Adhesion Technology

A significant challenge for RF LDMOS packaging used in the typical RF base station applications is the 20 year life requirement. Ceramic package technology has set the standards for reliability. A major component of reliability is the integrity of the package, and the ability of the package to maintain MIL-STD-883 hermetic leak rates. In this case, Gross Leak capability has been established as necessary for meeting reliability. To pass a hermeticity test, the gap at an interface can be no more than 1 micron for gross leak compliancy, and even tighter for fine leak.

Commercially available LCPs tend to have poor adhesion to plated metal surfaces. This is seen by the loss of interfacial adhesion when the assembly is exposed to simulated stresses that maybe seen during the base station component lifetime.

The delamination results in gross leaks at the failure site. This has been primary reason why LCP has, not to date, been widely used for semiconductor component packaging. As previously mentioned, solutions have been tried to mitigate this shortcoming, by applying epoxy to the interfaces as a sort of glue. The inherent weakness of this strategy is that epoxy strength degrades significantly over a 20 year life, and is compromised by high levels of moisture absorption.

For a polymer/metal system, to meet these criteria, adhesion of the polymer to the metal is necessary, but not sufficient. To maintain hermeticity there has to be a continuous band of the polymer adhering to the metal at all interfaces, with no discontinuity > 1 micron.

The Quantech™ polymer developed for this application has active chemical groups which are bonded directly to the metal components. This eliminates the need for applying epoxy to the polymer/metal interface. Also, the strength of the interface is such that a “cohesive failure mode” is generated when shearing the window frame from the metal components. This establishes that the bonding between the polymer and metal is stronger than the actual bulk property of the polymer itself. This material condition is maintained after accelerated life testing of the package.

IV. AIR CAVITY ORGANIC PACKAGE CONSTRUCTION

The leads are molded and secured together by the Quantech™ LCP dielectric. The package geometry features, handling, and assembly tooling are similar to it's ceramic counterpart. The leadframe is plated with Ni and low Au to facilitate soldering to the printed circuit board.

The leadframe shown can be interchangeable for multiple lead counts. The proven design is best suited for the RFIC application which has 18 leads with similar pitch to standard over molded IC packages. The Quantech™ molding technology allows for flexibility of other lead configurations that can quickly fill the domain of lead geometries to meet the RF device application need. Quantech™ polymer and molding technology allow for insert molding a pre-etched leadframe into the package with a high degree of dimensional accuracy. The LCP material has a nearly matched coefficient of thermal expansion (CTE) to the metal piece parts.

The molding produces a package of significantly tighter piece part tolerance. The typical variation is well within +/-2mil. Plating process of leads is identical to standard ceramic package.

The exposed bottom of the Quantech™ window frame (Fig. 1) provides a surface that can be metallurgically attached to the air cavity heat sink or flange. The lead free attachment provides a reliable and hermetic interconnect to the flange.

Moreover, this is vastly superior interconnect when compared to epoxy attach to flange used in Ref. [4].

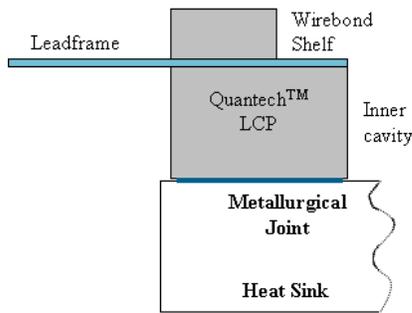


Fig. 1. Typical cross section of ACOP.

The first step in the package assembly process is to bond the window frame to the heat sink (Fig. 2). The Quantech™ material is formulated to withstand the high temperature rigors of the hard solder attachment while the bond between the Quantech™ window frame and metallic interfaces are not compromised.

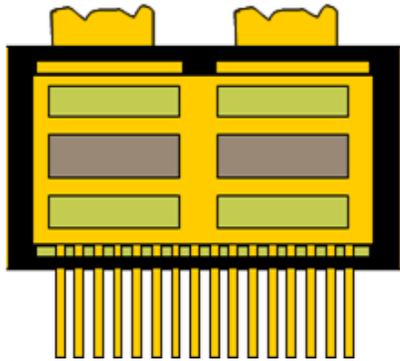


Fig. 2. Schematic of die bonded ACOP-18L prior to lid attach

Following window frame attach, the process flow for the device and package assembly is identical to standard ceramic process. After wirebonding, the lid is assembled to the package which is made from the same material as the Quantech™ dielectric body of the window frame. The lid is attached by a B-stage epoxy which is pre-applied to the lid. The lid is assembled and cured using the same methods as a ceramic lid with B-stage epoxy. The finished assembled 18L unit is pictured in Fig. 3 and the units are stored in tubes for final test prior to being inserted into tape and reel.

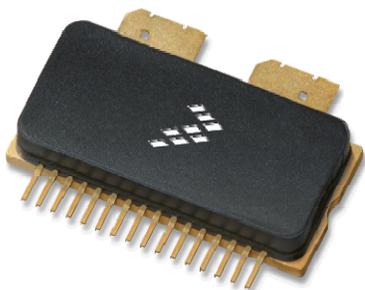


Fig. 3. ACOP-18L Package Assembled

V. QUALIFICATION TESTING

Freescale has long legacy in producing and marketing products of high integrity by meeting stringent manufacturing and reliability standards. The standards are established to assure that the product performance will meet the long life time required. The expectation for reliability performance is identical or better than the ceramic air cavity platform for high volume sampling from production.

The ACOP package platform was tested to Freescale reliability standards. Active RFIC die were included in these studies to demonstrate electrical performance. Multiple lots of window frame materials were procured that varied molding and plating lots. Assembly was performed using production equipment and sequenced for three builds on various days. Given the window frame tends to have higher bulk CTE than the flange, the resulting flatness of the assembly has a small convex flatness. Convex shape results in very good surface contact to the next assembly.

The accelerated testing included H3T, Thermal Cycling, Solderability, Solder Seepage, and Multiple Reflows, performed to Mil-Std-883B standards. The purpose of the testing was to evaluate the robustness of the individual materials and the interfaces and interconnects between these materials. Monitored were changes in electrical performance and gross leak (Mil-Std-750, method 1071).

TABLE II
SUMMARY OF RELIABILITY TESTING CONDUCTED

Reliability Test	Duration (Cycles or Hours)	Req'd Testing	ACOP-18L
Thermal Cycling (Air to Air): -65C/150C, 15 min dwell	500 cycles	DC & RF	PASS (45/45)
DC IOL (Tc delta = 40°C to 140°C, not to exceed Max Tj, Opt. Voltages)	5000 cycles	DC & RF	PASS (45/45)
HTOL (High Temp Op Life) (RT, bias to Tj=200C)	504 hours	DC & RF	PASS (45/45)
H3T (High Humidity/Temp) (T = 85C, RH =85%, NO BIAS)	504 hours	DC & RF	PASS (45/45)
HTGB (High Temp Gate Bias) (T = 150C, 80% MAX BIAS)	504 hours	DC & RF	PASS (45/45)
Multiple Reflow (3X 260C) (+260°C +5°C/-5°C, 3 Cycles)	3 cycles	DC & RF	PASS (45/45)
Lead Deflection Test (Eared Part - separate EWR build)	n/a	G/L	PASS (15/15)
Leads Solderability	n/a	Visuals	PASS (45/45)
Solder Seepage	n/a	Visuals	PASS (45/45)

ACOP testing was successfully completed. The test findings shown in Table II demonstrated the robustness of the package, inclusive of the interconnects and interfaces. No issues were identified in hindering electrical performance.

VI. Conclusion

A new package has been developed for the base station industry which is expected to grow with network infrastructure expansion and updating to implement newer higher bandwidth wireless technologies. The package, called

ACOP, leverages the traditional air cavity package platform and allows for a much larger number of input and output leads. The dielectric uses a high performance thermoplastic material called Quantech™ which is matched to the interconnecting components. Assembly and reliability studies concluded for an 18-Leaded devices shows that the ACOP has improved manufacturing tolerance and have equivalent reliability performance as it's air cavity ceramic counterpart. The ACOP, therefore, provides packaging solution option for high power (>125W), high frequency (>2GHz) multi-lead RFIC to Freescale customers.

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