A Low-Cost, Near-Hermetic Air-Cavity Package for Photonics Integrated Circuits (PICs).

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Abstract. This paper presents a low-cost package solution that can replace butterfly packages used in photonics. The solution is based on existing air cavity plastic package technology used in RF power applications and offers additional flexibility in geometry and leadframe/heatsink materials combined with shorter prototype delivery times, and near-hermetic package performance.

Keywords: optics, photonics, PIC, packaging, air cavity package, liquid crystal polymer, butterfly package

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1 Introduction

For photonics and Photonic Integrated Circuits (PICs), packaging is still an issue. Applications using photonic technology are at the eve of a potential breakthrough (communication, (medical) sensors, optical computing, etc.), but low-cost / high-volume production is still hampered by complex and costly packaging technology. Finding an affordable solution to photonics packaging could be paramount. To quote Barwicz et al: “Cost is more than a commercial consideration. It can define the accessibility of a technology and, in turn, its societal impact.” [1].

As a result, much effort is put on research to find efficient and effective packaging technologies for PICs. Among others, solutions include "pluggable optics," “heterogeneous integration,” and a technology shift from "active to passive alignment". Another viable solution is to adapt and modify existing packaging solutions from the semiconductor industry towards photonics. An example of such an adaptation, as presented in this paper, which is the near-hermetic air-cavity plastic (ACP) packages produced by injection-molding of low-moisture liquid crystal polymer (LCP) in the so-called "butterfly" layout. The traditional butterfly package is a hermetic metal package that is often used in photonic applications [2]. The butterfly package layout is widely used in the photonics industry not only because of its hermeticity and good thermal conductivity, but also because there are few alternative packages solutions available. Unfortunately, this package is relatively expensive, especially considering that some of its characteristics, such as hermeticity, are not always necessary.

In 2005, RJR Technologies pioneered an air-cavity RF-power package using LCP injection-molding technology [3,4]. For decades, the semiconductor industry used ceramic packages to provide the benefits of an air-cavity enclosure. RJR’s ACP package solution effectively replaced the majority of ceramic packages in the RF Power market by providing customers with the same electrical and higher thermal performance at reduced costs and faster time-to-market. This was not only true for this market, but also for any electronic application that requires the use of an air-cavity package. As such, this technology can also provide a cost-down solution for photonics while maintaining good thermal conductivity and providing near-hermetic performance. On top of the lower cost price, these packages can also be produced in strip format, thereby allowing strip-level assembly processes, a potential further cost-down in current assembly process of photonic devices where production is essentially still "piece by piece."

2 Air-Cavity Packaging Technology using LCP

Air-cavity packaging is used for high-performance RF and microwave semiconductor components. This is because air, as a dielectric, is lossless in comparison to the alternative overmolded packages using lossy epoxy mold compound. Similarly, free space optical and imaging devices cannot be surrounded with an opaque material that attenuates and/or diffracts light. Traditionally air cavity packages are assembled using metal, ceramic, or epoxy molded compound materials. The assembly process for molded air-cavity and fully transfer overmolded packaging is essentially the same, differing only in how the packages are "sealed." An overmolded package is transfer-molded around an assembled leadframe, hence has no internal cavity. In an air-cavity package, components are assembled into a pre-molded package which afterwards is sealed with a lid. The RJR Technologies air-cavity plastic (ACP) packages use a Liquid Crystal Polymer (LCP) compound molded around metal leadframes. A typical package construction is shown in figure 1.

Injection molding processes are very mature, and take advantage of the improvements in molding hardware, controls, high temperature steels, and mold design software over the last 50 years. Moreover, significant advances in polymer materials that are ideal for the construction and life cycles of electronic packages have been made [5,6,7]. The crystalline domains in the LCP material result in a polymer with very low water vapor transmission and moisture absorption characteristics (see figure 2). The low moisture transmission rate means that packages made with LCP are more nearly hermetic than any other type of plastic package. This water vapor permeability rate of LCP shows that it is like glass!

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 material, it can be recycled by regrinding and reused to mold new packages, unlike thermoset epoxy molding compounds. One of the most attractive properties of LCP is that the Coefficient of Thermal Expansion (CTE) is low and can be tailored. HTP-1280 is manufactured to have a CTE match close to copper, the most used leadframe material for ACP packages. This CTE compatibility results in a highly reliable, matched system that minimizes differential thermal stresses. 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 solution is to select the right LCP material and design features in the leadframe that enhance adhesion creating a near hermetic package capable of passing the most stringent semiconductor reliability requirements.

The second element of the ACP package is the sealing epoxies used to seal the package. RJR has developed a moisture barrier epoxy that is pre-applied to package lids and sidewalls used to seal packages during the backend assembly process. These epoxies are both solvent and solvent-free and meet ROHS and REACH requirements. For ease of use in the assembly process, RJR B-stages its epoxies. The B-staging, is a process that utilizes heat to remove the majority of solvent from an adhesive, thereby allowing a construction to be “staged”. In between adhesive application, assembly and curing, the product can be held for a period of time, without sacrificing performance.

The third material used for ACP packages is the metal leadframe, which form the conductive elements of a package. Copper is the leadframe material used for ACP packages and the HTP1280 LCP molding compound is formulated to be a close CTE match. Copper is a very versatile choice for leadframes with great electrical and thermal conductivity at low cost. As mentioned before, RJR adds features in the design of the leadframe to improve adhesion in order to provide a near hermetic package.

The fourth material used in an ACP package is the thermal base. Unlike ceramic packages that have limitations on base material choice because of the CTE mismatches, RJR’s package solutions can use different base materials, CuW, CPC, Copper and diamond materials, because the thermal base is glued to the sidewall as opposed to high temperature brazing. RJR epoxies can easily deal with the CTE of the different materials. Figure 3 is a representation of this flexibility.

This technology has meanwhile been proven to be mature and reliable and has been used ever since.

3 LCP Butterfly package

Using the technology described in section 2 we have designed a package in a butterfly layout to demonstrate the useability of this concept for photonics and PICs. It is relatively easy to optimize package form, fit and (IO) function for any application, provided sufficient volume justifies the design and tooling costs. To maximize the applicability and flexibility of our demonstrator package, we made the following design choices:

1. A relatively large internal package space measuring 40.2 x 25.0 x 7.85 mm (L, W, H). Outside dimensions of the package are 45.7 x 30.7 x 9.35 mm (L, W, H)
2. A lead frame design offering 40 pins DC connectors and 20 pins RF connectors (< 30 GHz). Through a relatively easy lead frame design change for instance also a package with 4 x GSG (> 60 GHz) pins can be offered (replacing the 20 pins RF) without changing the package (tooling) design. In principle a variety of lead frame design can be considered at relative low cost as long as the mechanical interfacing towards the package body remains unchanged.
3. One optical feedthrough including a mechanical strain relieve design. The optical feedthrough is a separate part that is glued into the package during package assembly. Keeping the feedthrough as a separate created more flexibility since i.e. a

supplier/manufacturer of fiber blocks/arrays can include this feedthrough in their fiber assembly which would otherwise not fit in through the feedthrough. Finally, the section of the package that contains the feedthrough is realized using an insert in the injection tooling. Again, through a relative easy insert design change, the package could also be designed with two optical feedthroughs.

Figure 4 shows the design of the butterfly package, including the different lead frame and feedthrough options. This modular approach to create package flexibility is similar to the configuration flexibility shown in figure 3. Figure 5 shows real (assembled) prototypes (left: LCP prototype for demonstration purposes (different design), right: 3D printed prototype (not LCP) for demonstration purposes).

In principle the optical feedthrough creates a fully non-hermetic package. If you want to utilize the near-hermetic capability that this technology in principle provides, the optical feedthrough needs to be sealed after or during assembly. We think that the the moisture barrier epoxy that is used to seal the lid (see section 3) could in principle also be used to seal the optical feedthrough. The surface area of the moisture barrier epoxy exposed to the inside would increase somewhat, leading potentially to a slightly larger outgassing. For a product or application running in high-volume this could be optimized by reducing the diameter of the optical feedthrough to the minimum dimension needed to fit the application, thereby reducing the outgassing to the minimum possible.

Injection molded packages have in principle a rather large freedom in geometrical design. It’s easy and relatively low-cost to design variable dimensions and shapes, much more than in metal package designs. Furthermore, as described in section 3, the metal base in the package can be chosen from different materials (Cu, CuW, CuMo, COVAR, etc) to meet the cost and performance requirements for the specific application. This adds further to the flexibility of this package technology.

Overall the proposed package solution in this paper is set to significantly reduce costs of individual components for photonics when compared to traditional hermetic Kovar, metal or ceramic packages. This innovative solution is expected to bring about a remarkable cost decrease of 50% at the outset. This reduction is made possible through the utilization of more affordable materials, such as molded LCP plastic, the implementation of copper preplated leadframes and the adoption of epoxy sealing, among other advanced techniques. As indicated earlier, RJR has already proven the effectiveness of this approach in the RF Power market with a similar package platform, known in the industry as ACP, rendering ceramic packages obsolete for this market. The results were a 50% reduction in costs, along with notable improvement in prototype delivery time (4 weeks versus 8-16 weeks) and a 20 % improvement in thermal performance. Furthermore, there is the potential for additional savings in assembly operations as the process can be conducted in strip form rather than individually, although the exact magnitude of these savings is yet to be determined. For the assembly process, RJR makes a fully automatic cassette-to-cassette sealing system that further optimizes costs versus existing sealing systems used in Photonics applications.

4 Conclusions

This paper provides an overview of the design and manufacturing processes for RJR Technologies' injection molded air-cavity plastic package (ACP) in a butterfly package layout suitable for photonics and PICs applications. The RJR ACP process uses proprietary sealing methodology to take maximum advantage of the properties of the starting low-moisture liquid crystal polymer (LCP) material. This solution is based on a similar adaption and modification using LCP material to replace ceramic packages for RF power applications. The LCP package solutions is not hermetic but can provide near hermetic performance as proven by the results in the RF power use case.

The proposed package solution offers additionally flexibility in geometery and leadframe/heatsink materials combined with short prototype deliver times, and potentially near-hermetic package performance. Package dimensions can be changed with relative short prototype delivery times (4 weeks). Similarly leadframe designs and/or metallizations can be changed relatively easy (even within an existing package design) and drop-in heatsinks can be chosen from different materials depending on cost, CTE expension and/or heat conductivity requirements. Options include Cu, CuW, CuMo, super CMC, KOVAR and more.

Prototype samples will be made available to several European photonic OSATs and R&D centers to be tested in different applications. Upon successful completion of these tests CITC and RJR will evaluate further research into near-hermetic performance, reliability and strip-level assembly capability of this package solution.

Acknowledgements

The authors would like to thank Rob Roach from ALTER TECHNOLOGY TÜV NORD UK Ltd, Padraic Morrissey form Tyndall University Ireland, Jeroen Duis from Phix Photoncis Assembly BV Netherlands, Peter Harmsma from TNO Delft the Netherlands, and Gai Vanstraten, David Lam and John Ni from RJR Technologies for their input, support and stimulating discussions.

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Photographs for the other authors are not available.

Wil Salhuana is the CEO of RJR Technologies, Inc. He received his B.S. in Electrical Engineering from the University of Colorado in the USA. Wil has led several industry breakthroughs in the semiconductor industry that resulted in commercial success, such 2.4GHZ wireless personal area network (PAN) for handheld gaming, fully integrated cable set top box system-on-a-chip device, tape-automated (TAB) packaging, and ball grid array (BGA) and air cavity plastic (ACP) packages, amongst others.

Ray Bregante is the co-founder and Executive Chairman of RJR Technologies, Inc. He has been the technical lead for many of RJR's advanced technologies, such as fully automatic sealing systems, high reliability air cavity QFN package, and air cavity plastic packages for oscillators, LiDAR and Photonics applications. In addition, Ray has been the patent holder for RJR's key innovations that resulted in commercial success, such as, US6511866B1 – "Use of diverse materials in air-cavity packaging of electronic devices", amongst others.

Fig. 1 A typical example of an Air Cavity Package (ACP) in Cross Section

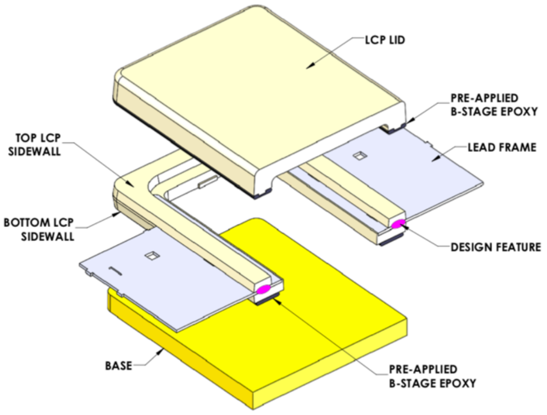

Fig. 2 Water Vapor Permeability versus Oxygen Permeability for different LCP materials

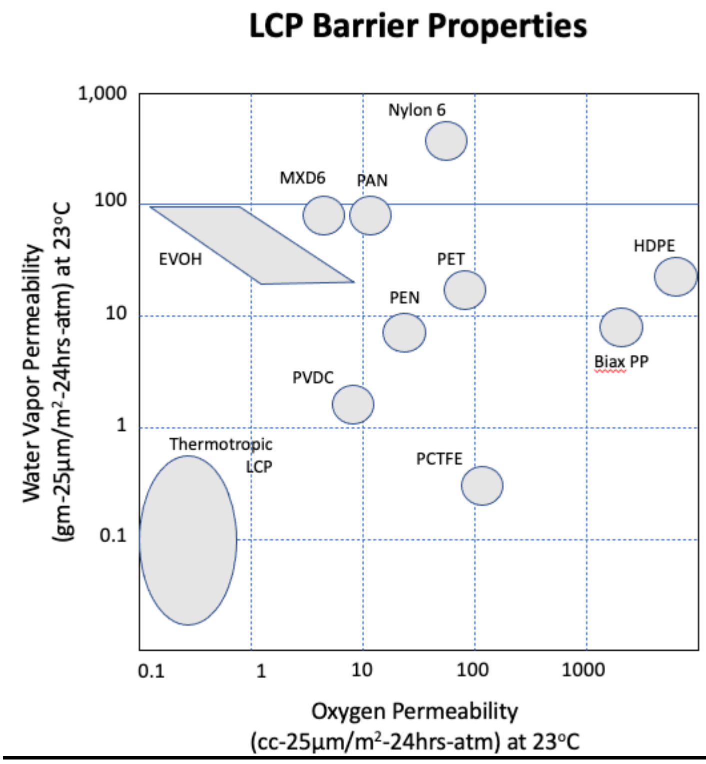

Fig. 3 The Flexibility of LCP Package Configurations as shown for RF Power Solutions

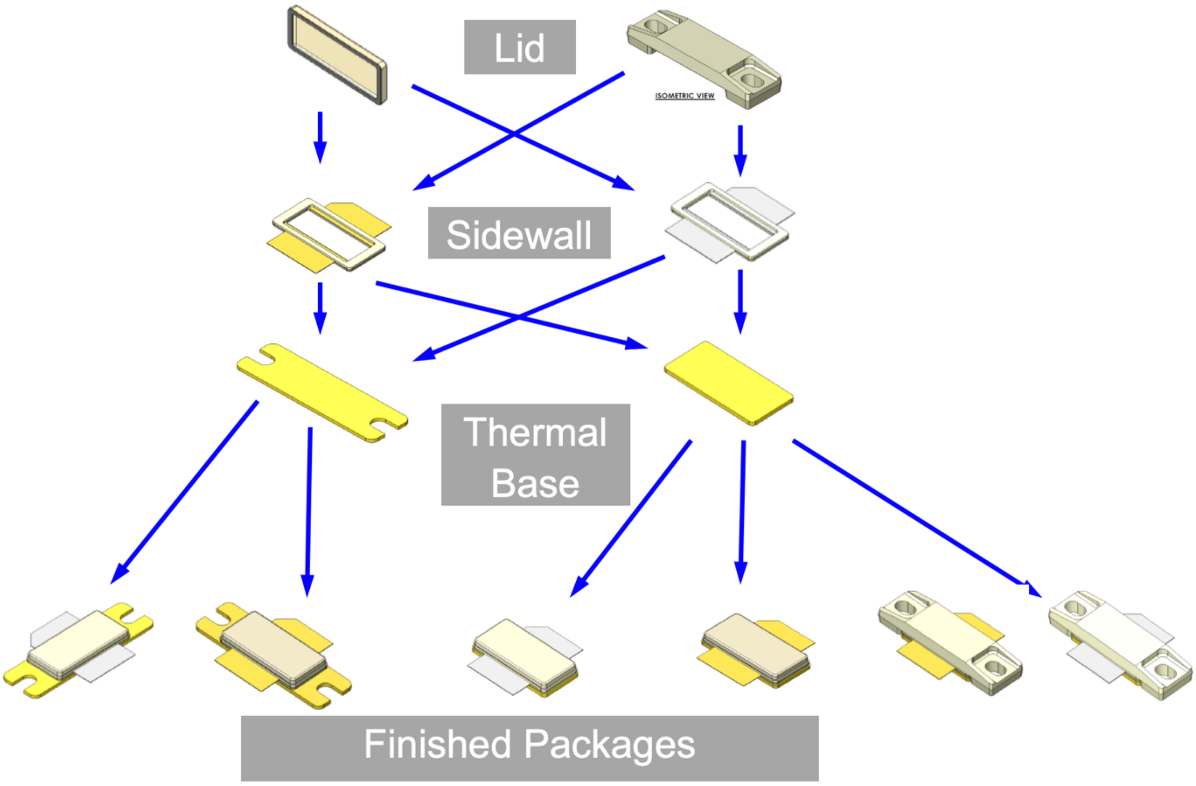

Fig. 4 The current butterfly package design for photonic applications using the LCP Air Cavity Packaging technology. Left: package without lid. Right: package with lid. For more details see the text.

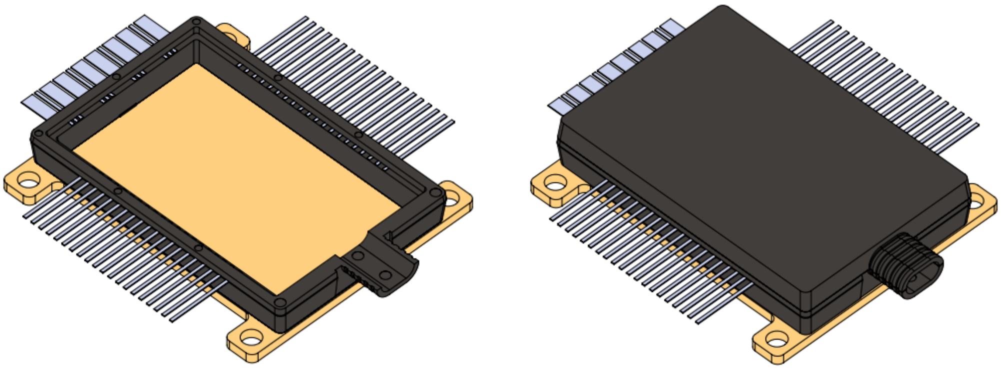

Fig. 5 Real (assembled) prototypes, left: LCP prototype with optical assembly for demonstration purposes (different design), right: 3D printed prototype (not LCP) for demonstration purposes with the 3 stages of assembly: leadframe only (left), with thermal base (middle) and with lid (right)