

**A Low-Cost Near-Hermetic Multichip Module Based on
Liquid Crystal Polymer Dielectrics**

Thomas E. Noll,

K. (Jay) Jayaraj and Brian Farrell

Foster-Miller, Inc.

195 Bear Hill Road, Waltham, MA 02154

(617) 290-0992

Fax: (617) 290-0693

and

Robert S. Larmouth

Teledyne Electronic Technologies

110 Lowell Road, Hudson, NH 03051

(603) 889-6191

Fax: (603) 882-4457

Abstract

This paper describes a generic low cost multichip module technology that uses a highly impermeable liquid crystal polymer (LCP) both as a MCM/L substrate material and as part of a near-hermetic assembly to bring electrical I/O out while providing a thermal management path.

The approach has a number of advantages over other conventional approaches, including:

- 1) Homogeneous self-reinforcing dielectrics with very low moisture absorption and excellent dimensional stability, available in any thickness from 25 μm up, with laminated copper foil of any thickness required,*
- 2) Good thermal expansion match throughout the package to minimize stresses during assembly and operation,*
- 3) Low thermal impedance achieved by attaching devices directly to a CTE matched, high conductivity heat sink,*
- 4) Excellent electrical performance up to microwave frequencies due to the low dielectric constant (<3 @ 1 GHz), and low loss tangent of the LCP, and*
- 5) Completely compatible with low-cost MCM-L processing methods as well as higher density via forming using plasma or laser drilling.*

This packaging technology is very flexible and compatible with a widevariety of chip and package interconnection techniques such as wire bonding and perimeter/ball grid array SMT and is especially suited for direct chipattachment using flip chip bonding methods. This paper describes the fabrication and testing of a six-layer MCM/L with application in high speed data processing.

Keywords: Multichip Modules, Electronic Packaging, Liquid Crystal Polymers, Hermetic Packaging

Introduction

This Paper discusses a joint effort between Foster-Miller and Teledyne Electronic Technologies (TET) to develop a new approach to low cost, high performance, near hermetic polymer multichip modules based on biaxially oriented liquid crystal polymer film dielectrics, which can be referred to as “MCM/LCP” since it is an enhancement of laminated MCM/L technology. TET is actively developing a high density MCM-L capability and this unique new material has many advantages over conventional substrates.

Multichip packaging approaches have been in use for many years for digital ICs [1-3], where providing the necessary signal wiring densities (to interconnect high I/O ICs), heat removal, availability of known good die and testing are the primary issues. Recently MCM technologies based on advanced PWB technologies have gained prominence due to low cost, large area processing, and elimination of hermetic packages. As with the other techniques an MCM/L must provide:

- Physical and environmental protection.
- Thermal management.
- Signal I/O and power distribution
- Interconnection between the devices in the module.

Foster-Miller has been developing a materials technology for meeting these needs over the last few years [4-8]. Because of the low moisture permeability of the LCPs, the packages can be made near-hermetic without heavy expensive housings, and can be two to four times lighter and one fifth the cost of conventional ceramic based modules. The liquid crystal polymer selected is a thermoplastic material, has excellent barrier properties and is inexpensive with the following unique physical and chemical characteristics:

- The in-plane coefficient of thermal expansion (CTE) can be matched to ICs using a proprietary extrusion process which imparts selected biaxial orientation.

- LCPs are strong, tough engineering plastics which can support large modules without cracking or breaking.
- It is suited for PWBs and MCMs - dielectric constant ~ 2.9 , $\tan d < 0.005$, no moisture absorption, and can be made into films of various thicknesses.
- The temperature capability is over 220°C for this LCP and other higher temperature LCPs are available.
- LCP is a thermoplastic and can be sealed with the application of temperature and pressure or ultrasonically.
- The LCP is highly impermeable to water, ions and other gases.

The thickness of the barrier film is determined by the barrier protection and mechanical protection requirements, and for our material that minimum thickness is about $300\ \mu\text{m}$.

The LCPs are melt processable, long-chain aromatic copolyester polymers which maintain a crystalline structure above their melting point. Because of the orientation of these “rigid rod” molecules during processing, LCPs are often termed “self reinforcing.” LCP films for the test vehicle were produced using the counter-rotating die extrusion process in a thickness of $50\ \mu\text{m}$. The films were laminated with conventional high ductility copper foil of $18\ \mu\text{m}$ thickness. The tooth structure gives this material excellent adhesion over a wide range of temperature. These procedures are attractive for low cost applications since they can be readily scaled to a continuous or batch continuous process.

One major advantage of this approach is the ability to test the module prior to completing the assembly. The Foster-Miller approach enjoys many advantages of the chip’s first approach (separation of electrical and thermal paths, high device packaging density, low inductance, short chip interconnections) but overcomes the following limitations:

- Easier defective IC replacement - no need to rebuild the entire interconnect.
- ICs not subjected to processing stresses - chips last versus chips first.
- Weight and cost penalty due to the hermetic package.

Engineering the LCP MCM

The MCM, a generic dual digital signal processor currently used in a digital down converter for military communications, was originally design for ceramic technology (AlN). A direct translation (i.e. no re-routing required simply to conform to printed circuit design rules) from ceramic to laminate was accomplished by incorporating aggressive feature sizes of 75 μm linewidth and spacing and 200 μm drilled holes. Figure 1 shows the front and back of the design. The top side contains IC footprints, passive device footprints and a metal seal ring area as well as I/O pads outside the package for interconnection and 3-D stacking. Thermal vias under the larger devices conduct heat to the bottom which is bonded to a high conductivity, CTE matched heat sink. Although manufactured in panel sizes of 557 mm x 610 mm was considered feasible, a 305 mm x 557 mm panel size was chosen for the prototype phase to minimize potential problems with material handling and dimensional stability. The MCM was panelized in an 18-up configuration as shown in Figure 2, with appropriate test coupons. Both a signal layer and ground/power plane are shown in panel form.

The six-layer construction employed a base stock laminate of 75 μm thick, biaxially oriented LCP film extruded at Foster-Miller and then laminated with 9 μm ED copper foil on both sides. Several approaches to bonding multilayers have been evaluated including using a second LCP as a bonding film, using anisotropic adhesives, and using unreinforced thermoplastic or thermoset bonding films commercially available. To maintain the low dielectric constant of the MCM while minimizing the impact of lamination temperature ARLON 6700, a bond film often used with PTFE multilayers was selected. The actual construction of the MCM is cross-sectionally depicted in Figure 3.

Manufacturing Process Development

The LCP MCM manufacture was accomplished utilizing standard rigid board processing equipment at Teledyne Electronic Technologies (TET); although process parameters were optimized for this technology, no major modifications to equipment were necessary. This is a key part of achieving our low

cost goals with LCP technology.

Both the LCP and the 6700 are thermoplastic materials and hence required slight modifications to the lamination cycle. Although the LCP was found to be fairly stable material during manufacturing, the 6700 bond film presented a challenge in controlling movement. A proprietary process utilizing inner layer stabilizing materials was developed for this program and was successful in achieving the precise registration needed for the feature sizes mentioned above. Beyond the challenges normally encountered in small hole drilling, the LCP construction presented only minor problems in drill wander and entry material optimization. Hole cleaning responded to the plasma process, but did require slight modification of the parameters.

The second major challenge was in hole metallization. As with lamination, a special process was developed involving both electroless and plating agitation steps, a problem compounded by the small hole sizes and the wettability of the 6700 film. However, after a brief process development stage, consistent high quality plating was achieved. Figure 4 is a cross-section of one of the 200 μm diameter holes illustrating the typical plating, as well as the excellent layer to layer registration. The image and etch process followed TET's normal fineline process with virtually no deviation. Electrolytic gold plating was done per normal rigid MCM/L specifications. In final route, some precautionary measures were necessary to minimize separation and tearing at the edges. Table 1 summarizes the process flow, highlighting the differences between TET's typical fineline rigid board and the LCP MCM.

Although yield projections would be difficult to make at this time, given the low number of panels built to date, the prototype manufacturing team feels confident that the LCP process could be ramped up to a stable process with similar yields, costs and throughputs to rigid boards of comparable complexity built with standard material. Moreover, this can be done without the need for special chemistry or capital additions. The most significant change may be a high temperature lamination capability (up to 300°C) if an all-LCP construction were required. For this product an approach with a high performance bonding material is an acceptable and lower cost alternative.

Approaches to Packaging Near Hermetic MCM

The most desirable MCM packaging approach would involve an all-LCP package. An all-LCP package combines the advantages of low-cost materials, low-cost assembly process, and excellent barrier properties (for near-hermetic packaging) to make this package a very attractive proposition. Two feasible packaging approaches have been identified and a discussion of each approach follows:

(1) All-LCP Packaging Approach #1

The cover of this package, shown in Figure 5, is an all-LCP assembly that seals the ICs inside the barrier polymer. It is comprised of an LCP picture frame ultrasonically bonded to an LCP cover substrate. The picture frame is cut from a 8 mm thick LCP laminate to be a 45 mm x 45 mm substrate. The center of this substrate is then cut out to leave a 2.5 mm frame width. The thickness of the picture frame is set to give clearance to all of the components on the top layer of the MCM. The cover substrate, taken from a 5 mm thick LCP laminate, is cut to 45 mm x 45 mm. The picture frame is attached to the cover substrate using an ultrasonic bonder equipped with appropriate tooling.

The top layer of the MCM substrate, shown in Figure 1, features a metal (gold on copper) frame (100 μm frame width) surrounding the MCM circuitry. This metallic frame would be textured via a mechanical or chemical etch to present a suitable surface to which the LCP cover would bond during a hot-air knife assembly process. Figure 6 illustrates the hot-air knife sealing process. The cover substrate is held in place by a pick and place tube and is brought down over the metallic frame on the MCM substrate. The hot-air knife directs hot-air streams on all sides of the assembly to melt the picture frame and seal the package.

(2) LCP Packaging Approach #2

This packaging approach is very similar to the previous packaging approach, discussed above. The inherent difference in this approach is that the cover is attached to the MCM substrate using solder (see

Figure 7). The cover is assembled using almost the exact same procedure as the previous approach, with the picture frame ultrasonically bonded to the cover substrate. The difference is that the picture frame is cut from a 8 mm thick LCP laminate that has 9 μm copper foil laminated on one side. As with the previous approach, the thickness of the picture frame is set to give clearance to all of the components on the top layer of the MCM. When the cover substrate is assembled it will have a metal frame on the bottom side of the picture frame. Solder is put down on the metal frame on the top layer of the MCM substrate. The cover substrate is held in place by a pick and place tube and is brought down over the metallic frame (and solder) on the MCM substrate. The hot-air knife directs hot-air streams on all sides of the assembly causing the solder to flow and consequently seal the LCP cover to the MCM substrate.

Figure 8 shows one of the MCMs after device assembly and just before package sealing. The two large data processors, memory and other digital ICs, and discrete components have been bonded to the top layer. The LCPs have been shown to be tolerant of a wide range of attachment methods including soldering [6] and wire bonding [9], and we have successfully assembled the MCMs here with a combination of techniques. The metal frame seen on the periphery of the substrate in the photo is used to solder seal the cover, separating the I/O pads on the perimeter and thus maintain the near-hermeticity of the completed package. Recent Helium fine leak testing performed to MIL-STD-883 on test packages has consistently given numbers in the range of $1-3 \times 10^{-7}$ for both methods of cover attach. Functional electrical testing is in progress.

Future Work

After evaluating the results of this manufacturing phase the next step will be the development of even higher density processes for this technology. The LCP material can easily be laser drilled or plasma etched to form blind vias. By slight adjustments to the design package the layout will be re-configured to incorporate blind vias. Linewidths down to 25 μm , chip footprints to accommodate a flip chip or direct chip attach assembly, and all-LCP constructions are planned for this phase of development over the next

year. Substrates of LCP have also been fabricated with thin film metallization. The most efficient designs will combine the via and imaging techniques to maximize the density while maintaining reasonable cost targets.

Acknowledgments

The authors wish to express their appreciation to DARPA and our TPO, Dr. James Murphy, who have supported this program under contract number DAAH01-92-C-R285; to Mary Parker (Raytheon E-Systems) and Mark Montesano (K Technology) who provided the design and the product focus; and to Sandra Jean and Lee Millette of Teledyne Electronic Technologies for their efforts in producing parts in an aggressive development schedule.

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Biographies

Thomas E. Noll received the B.S. degree in chemical engineering in 1971 and an M.B.A. degree in 1973 from the University of Wisconsin, Madison. He currently manages several SBIR programs at Foster-Miller, Inc. in Waltham MA on microwave, optoelectronic, and multichip module packaging technology development. He has published a number of papers in the area of new dielectric materials and advanced printed wiring boards, and is active in IEEE and ISHM. Previously he was an Engineering Manager at Teradyne, Inc., Digital Equipment Corp., and Rockwell International.

Brian P. Farrell received the B.S. and the M.S. degrees in applied physics and electronics in 1990 and 1992 respectively, from University College Galway, Ireland. He currently works as an engineer/program manager in the electronic materials group at Foster-Miller, Inc. In his current role, he works in electrical and thermal characterization of materials and contributes to efforts in microwave, optoelectronic, and multichip module packaging technology development.

Dr. K. (Jay) Jayaraj received the B.Tech degree in chemical engineering (summa cum laude) from the University of Madras, India and the M.S. and Ph.D. degrees in chemical engineering from Clarkson University, Potsdam, NY. He is currently employed as Electronic Materials division manager at Foster-Miller, Inc. He is the inventor of near-hermetic multichip packaging technology using liquid crystal polymers and has been responsible for its development since 1990. Prior to joining Foster-Miller, he worked as a Principal Research Scientist at Honeywell's Sensors and Signal Processing Laboratory. He has published numerous papers in the areas of multichip module fabrication and characterization, dielectric materials, and materials processing in space.

Robert S. Larmouth is Director, Advanced Development for Teledyne Electronic Technologies in Hudson, NH. Previously he was an Engineering Manager at Digital Equipment Corp.

Table 1. Process Flow Comparison

Process Step	Standard	LCP MCM
Panel size	557 mm x 610 mm or 305 mm x 557 mm	Same
Movement control	None	Innerlayer stabilizing
Lamination		
Pressure	200 psi	Lower
Temperature	190 C	Lower
Time	2.5 hr	Shorter
Vacuum	Yes	Yes
Drilling (small hole)		
RPM	110,000	Same
Feed rate	055	Same
Entry material	Copper	Same
Cleaning	3-step plasma	Slight modification in cycle times
Hole metallization	Electroless	Slight modification to process; controlled agitation required
	Pattern plate	Panel plate
Imaging	GA film	Same
	Fully collimated light	Same
Surface metallization	Electrolytic gold	Same
Route	Mechanical	Slight modification to hold-down

Figure 1. MCM Design Top and Bottom Layers

Figure 2. Panelized Layup of Signal and Plane Layers

Figure 3. Construction of MCM LCP

Figure 4. Cross-section of Vias Showing Excellent Plating and Dimensional Stability

Figure 5. Ultrasonically Bonded LCP Cover

Figure 6. Hot Air Knife Sealing Process

Figure 7. Solder Sealing Technique for LCP MCM

Figure 8. Assembled LCP Based Multichip Module