Presented at IMAPS 2000
Boston, Massachusetts September 20th, 2000

Advanced Multilayer Polyimide Substrate Utilizing UV Laser Microvia Technology

Scott Corbett, Jeff Strole, Ben Ross,
Phil Jordan, Joe Ketterl, Thayer Hughes
MicroSound Systems, Inc., 34925 SE Douglas Street, Snoqualmie, WA 98065
Phone: 425-396-5707, Fax: 425-396-5861, corbetts@microsnd.com
http://www.microsnd.com

Abstract

This paper presents ongoing work on an advanced flexible circuit interconnect substrate featuring a 24 x 24 (576 element) pad grid array pattern at 300 micron pitch. This eight metal layer circuit is being developed as a high-density, pixel-level interconnection substrate for a two-dimensional (2D) ultrasound imaging transducer MEMS device. The flexible circuit substrate is constructed using laminate fabrication methods, whereby multiple sets of two-sided metallized and patterned 1 mil polyimide circuit pairs are laminated together using dielectric adhesive sheets to form a multilayer structure. UV laser-drilled via-in-pad blind vias are used to connect buried trace elements in the circuit stack to the array pattern on the top surface. The flex circuit has feature patterns as small as 35 µm traces and spaces. The UV laser (Electro Scientific Industries, Portland, OR) is used in several other process steps to fabricate the multilayer device including patterning precisely registered pin alignment features in the circuit pairs.

Construction of the multilayer device is also possible using advanced substrate materials with improved electrical performance characteristics, including laminate materials such as liquid crystal polymers (LCPs). LCP substrates have a significantly lower dielectric constant, improved dimensional stability and lower TCE compared to polyimide. Although being developed as part of an ultrasound transducer imaging array project, the advanced substrate has wide applicability to new chip-scale packaging and MEMS electronic integration efforts.

Keywords: Flex Circuit, Substrate, Laser, Microvia, Multi-layer, Polyimide, High-density, LCP, MEMS

Background

Medical ultrasound imaging has played a tremendous role in providing real-time diagnostic imaging for cardiology, obstetrics, urology and other critical medical fields. The handheld medical ultrasound transducer device, which transmits and receives ultrasound energy to the patient, has undergone significant changes over the last twenty years. Early systems relied on mechanical motion of the transducer to create the scan pattern for the image. In the early 1980’s, phased array technology, originally developed for military radar systems was applied to ultrasound systems. This resulted in hand-held, solid-state transducer devices containing hundreds of individual elements, each of which must be connected to an individual channel in a beam-forming scanner system. The interconnect challenge for these devices was and remains considerable and resulted in the development of miniature coaxial cable interconnects and custom level-one interconnect schemes, primarily flex-circuit based.

Newer developments over the last decade have lead to increased spatial “sampling” of the acoustic aperature for better beam control and dynamic focusing in the “out of plane” acoustic axis. So called 1.5D, 1.75D and 2D (two-dimensional) transducers have increased channels counts and concurrently increased interconnect density requirements. In the case of the 2D array, the acoustic aperture is fully sampled, much like a CCD optical array, however,

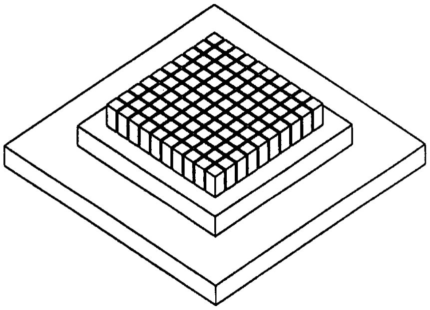

Figure 1 2D Array Footprint.

each channel within the array must be separately controlled. This requires a "pixel-level' interconnect strategy. Typical array element dimensions for these devices range from 100-300 microns, dimensions on the order of die attach requirements for semiconductor die. Due to interconnect constraints, most of these devices are only "sparsely sampled", but still require up to 500 or more individual interconnect channels.

This paper describes a flex circuit developed to interconnect a fully samples 24 x 24 acoustic array. The flex was developed as part of a larger effort to design and develop a portable, battlefield ultrasound imager, under the auspices of a three-year ONR/DARPA contract. The flex contains 576 individual channels and interspersed ground connect channels.

Flex Circuit Design

A schematic cross section of the interconnect system is shown in Figure 2. The flex connects the back side of the densely patterned transducer array to circuit boards or coax cabling (not shown) in a manner analogous to TAB tape. However, rather than bonding flex leads to the periphery of a die, the flex must be connected directly to the array pattern, as in a flip-chip direct-attach scheme. The flex circuit must also be acoustically transparent, to allow ultrasound energy to propagate into the acoustic backing, which further complicates the interconnect scheme.

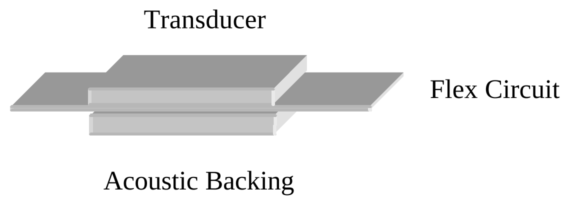

Figure 2 Interconnect Scheme.

The bottom portion of the ultrasound array is first patterned using direct-write UV laser ablation with an Electro-Scientific Industries (ESI) 5100 laser machining system. The system features a tripled-YAG laser output producing a wavelength at 355 nm. This laser has several advantages over the more traditional UV excimer laser systems, in particular, a well controlled, long depth-of-focus beam combined with precise control over and power and pulse repetition frequencies. While originally developed as a flex circuit drilling tool, this machine allowed very precise direct–write UV laser micromachining of planar substrates as well as via drilling. The resulting circuit pattern is shown in Figure 3.

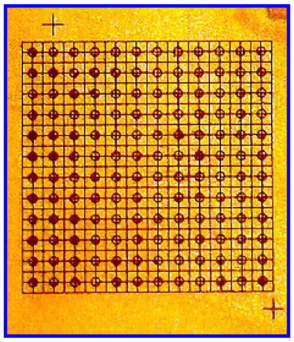

Figure 3 Array Electrode Pattern.

The required matching flex footprint pattern is shown in Figure 4.

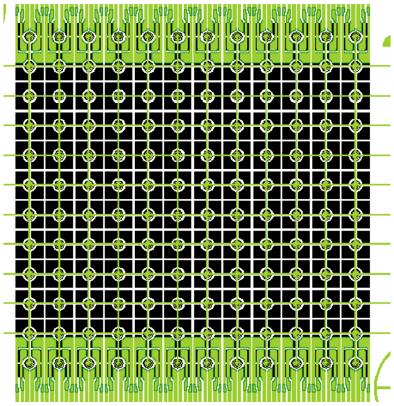

Figure 4 Interconnect Pattern on Upper Flex Layer.

The flex 2D array footprint consists of 300 micron (0.3 mm) spaced interconnect pads, with portions of grounds interspersed at the cluster of every four array elements. The flex is directly bonded to the array using a proprietary lamination approach. This is analogous to a fully populated chip-scale package containing 576 elements at 0.3 mm pitch.

Methods

To create such a densely patterned flex circuit required a new technique which we have developed (1). A traditional approach to very high density flex interconnections is to use thin-film, build-up technology whereby polyimide is spin-coated, etched, sputtered and patterned in individual additive layers which complete a finished circuit. A major disadvantage of this approach is the inherent high cost due to the low yield and a lack of commercial sources.

Our approach was patterned on a laminate technology (MCM-L) using metal-sputtered 1 mil polyimide as the circuit media. Most laminate constructions utilize a trace pattern that allows through-hole drilling, which simplifies fabrication and allows conventional mechanical drilling. However in the case of a 2D array pattern at 0.3 mm pitch, there is no way to route the inner traces using through-hole methods. The approach we developed uses proprietary layer alignment and blind laser-drilled vias (via-in-pad technology) [7]. Elements closer to the center of the array are accessed by buried traces progressively deeper in the laminate stack. This scheme is shown conceptually for a slice of the flex circuit in Figure 5.

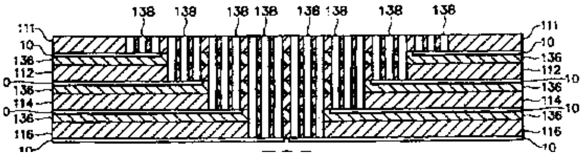

Figure 5 **Blind via Construction Pattern.**

Using this method, an eight-layer, laminate flex circuit was produced with a pad grid array pattern corresponding to the 24 x 24 array signal and ground elements using 2 mil trace/ 2 mil space lithography. The completed circuit contained an upper pad layer, four trace routing layers and three interspersed ground layers.

The sequential fabrication process of the flex circuit is outlined below:

1. All inner layers are patterned on the top and bottom using pre-sputtered and electroplated 25 micron polyimide media. Patterning is performed using subtractive photolithography with positive image masks.
2. The two outer layers (top and bottom) are patterned on the inner side only.
3. All layers are laminated together.
4. Blind vias are drilled from the top layer to all inner layers in one drilling step.
5. The blind vias are plated.
6. The outer layers are imaged and patterned.

Using the newly developed lamination, alignment and drilling technologies allows blind vias to be accurately landed to buried traces that are as small as 60 microns in width.

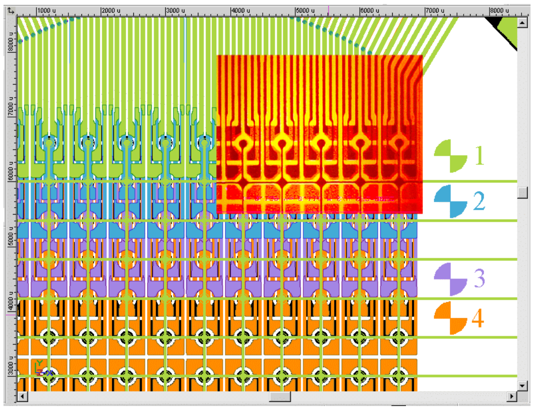

Figure 6 **Top Diagram of Multilayer Flex Assembly Showing Top and Buried Layers With Actual Circuit Imposed in Upper Right Corner.**

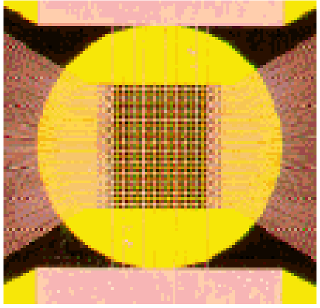

Figure 7 **Detail of Completed 24 x 24 PGA Substrate.**

The drawing below shows a top view of the circuit with a photograph of the actual circuit superimposed in the upper right corner. This circuit was then laminated to the transducer array assembly, mounted in a package and then backed with acoustic absorption backing to complete the assembly.

Liquid Crystal Polymer Dielectric

A significant challenge in constructing the multilayer circuit with polyimide media, is the structural instability and high moisture absorption of polyimide, which compromises the ultimate performance of the substrate. We therefore have a high interest in investigating new dielectric media, which is compatible with the laminate process technology described.

An interesting new material- liquid crystal polymer (LCP)- is becoming available in sheet dielectric form, with potentially wide application for high performance electronic substrates. Initially developed as an engineering plastic for high temperature, low-expansion applications such as electronic connectors, LCPs are cousins of the substances used in LCDs, and are long chains of aromatic polyesters. LCPs have several properties that are important for high performance circuits including:

- The coefficient of thermal expansion (CTE) can be designed in,
- The material has a low dielectric constant of 3.0 at frequencies as high as 10 GHz,
- The glass transition temperature is higher than 220°C,
- The material has good thermal conductivity and very low moisture absorption,
- The material has excellent dimensional stability, and can be processed using conventional photolithography.

The following table outlines the material properties of several common substrate dielectrics including the new LCP substrates.

Table 1. **Properties of Common Substrate Materials used in Electronic Multilayer Substrates.**

	FR-4	Polyimide	PTFE	LCP
Density (g/cc)	1.2	1.42	2.17	1.4
Tensile strength (MPa)	63	231	21.6	207
Coefficient of Thermal Expansion CTE (10^{-6} ppm/°C)(X-Y)	20	20	9-12	3-17
Glass transition temperature T_g (°C)	134-178	250	*	>220
Degradation temperature T_x (°C)	280-295	>300	>300	>350
Continuous service temperature	>100	>200	>200	230
Thermal conductivity (W/m/°K)		0.12	0.3	0.3
Moisture absorption (%)	1-1.5	1.0	0.02	0.02
Flammability (UL-94)	V0	V0	V0	V0
Dielectric strength (V/µm)		276	240	220
Dielectric constant (1 GHz)	4.4	4.06	2.6-4.0	2.9
Dissipation factor (tanδ) (1 GHz)	0.018	0.006	0.001	0.002
Volume resistivity (Ω·cm)	10^{14}	10^{17}	10^{13}	8×10^{15}
Relative cost (relative to FR4)	1	2-4	4-100	2-4

* T_g is too broad to define.

The only other electronic substrate material with comparable performance to LCP is PTFE, which has a much higher cost and is more difficult to process. The superior electrical and mechanical properties of LCP substrates, plus the compatibility with traditional planar fabrication techniques make LCPs compelling candidates for high density substrates, particularly with the laminate multilayer process developed by MicroSound.

We have performed preliminary patterning of LCP substrates for the multilayer construction described previously. Figures 8a and 8b below show an LCP substrate patterned with one of the inner trace layers of the multilayer circuit. Initial results appear to be quite positive; the material was patterned with features as small as 1.5 mil traces and spaces using photolithography techniques developed for the polyimide substrate material. In addition the material is compatible with the UV laser via drilling process described previously.

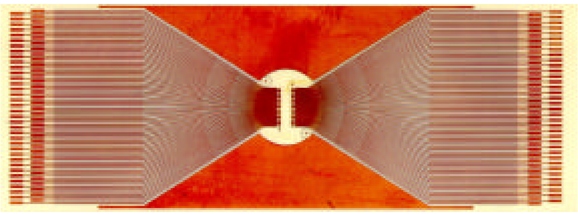

Figure 8a Upper view of Patterned Inner Trace Layer on 2 mil LCP Copper-Coated Substrate.

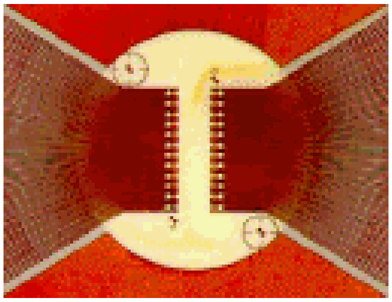

Figure 8b Detail of Patterned LCP in High Density Trace Region.

Summary

We have described a novel, laminate-based multilayer flex circuit substrate utilizing UV laser blind via drilling methods. In addition, the process appears to be compatible with a new high performance LCP substrate. While, further process development and testing need to be completed before the high-density substrate is available as a commercial product, initial results point to a substrate technology with significantly improved capability for high performance applications.

Acknowledgements

We would like to acknowledge Rogers Corporation (Rogers, Connecticut) for supplying the LCP substrate materials.

References

[1] C. F. Jr., Coombs, Ed., Printed Circuits Handbook, 4th Edition, McGraw-Hill, 1995.

[2] B. Chou, S. Beilin, H. Jiang, D. Kudzuma, T. Massingill,, M. Peters, and V. Wang, “Ultra-High-Density Interconnect Flex Substrates,” High Density Interconnect, Dec. 1998, pp. 14- 21

[3] C. A. Harper, Editor-in-Chief, “Electronic Packaging & Interconnection Handbook, 2nd Edition,” McGraw-Hill, 1997.

[4] K. Jayaraj, L. Felton, B. Farell, and T. Tiano, “The Preliminary Development of a Novel Corrosion Resistant Plastic Package,” Proc. Pacific Rim/ASME International Intersociety Electronic and Photonic Packaging Conference, INTERpack ’97, Advances in Electronic Packaging, 15-19 June 1997, Kohala Coast, Hawaii, pp. 201-208.

[5] K. Jayaraj, T. E. Noll, and D. R. Singh, “A Low Cost Multichip Packaging Technology for Monolithic Microwave Integrated Circuits,” IEEE Transactions on Antennas and Propagation, **43**(1995)992.

[6] Property values compiled from vendor data sheets.

[7] Strole, J. et al, “Method of Creating an Electrical Interconnect Device Bearing an Array of Electrical Contact Pads, U.S. Patent Application 09/310, 873. MicroSound Systems, May 1999.

[8] J. G. Aday, T. G. Tessier, H. Crews, and J. Rasul, “A Comparative Analysis of High Density PWB Technologies,” 1996 International Conference on Multichip Modules, 17-19 April 1996, Denver, Colorado, SPIE Vol. 2794.