High Density SMT Assemblies Based on Flex Substrates

Robert Larmouth, James Keating
Teledyne Electronic Technologies
110 Lowell Rd., Hudson, NH 03051
(603) 889-6191

Abstract

The industry trend to shrink semiconductor device packages while increasing I/O count results in demands on the printed circuit boards to which these devices are assembled. An increase in wiring density is required at the board level, often equating to higher costs and/or layer counts. In many cases, designers are looking to multilayer flexible circuits as the next level of interconnect for a wide range of packaging technologies from fine-pitch surface mount to chip-scale packages to direct-chip attach. Challenges associated with a flex-based solution include assembly compatibility, material costs and reliability.

This paper reviews work by Teledyne Electronic Technologies (TET) to address these board level interconnect challenges for several custom applications. An approach employing flexible multilayer substrates which incorporate fine-line circuitry, small vias and flexible soldermask is examined. A test vehicle designed and built to accommodate micro-BGA packages is used to illustrate the density achieved and to provide a platform for demonstrating assembly and reliability attributes. This test vehicle is also being used to evaluate materials and process technologies applicable to high density SMT assemblies.
(Keywords: rigid-flex, microBGA, flex innerlayer, via-in-pad, microSMT, MCM-L)

Background

TET is a major supplier of electronic components, assemblies and systems to a wide variety of applications in the military and commercial sectors. These products are generally characterized by a high level of complexity, in terms of both functionality and physical packaging. Examples of customer end products include avionics, medical implantables and high capacity computer disk drives. Although it draws upon a broad spectrum of enabling technologies, two of TET's most widely used, internally developed technologies are ceramic-based hybrids/multichip modules (MCM-C) and rigid-flex printed circuits and assemblies. Figure 1 shows a current high volume SMT product - an eight-layer rigid-flex with an average pad density of 115 pads/in^2 (18 pads/cm^2).

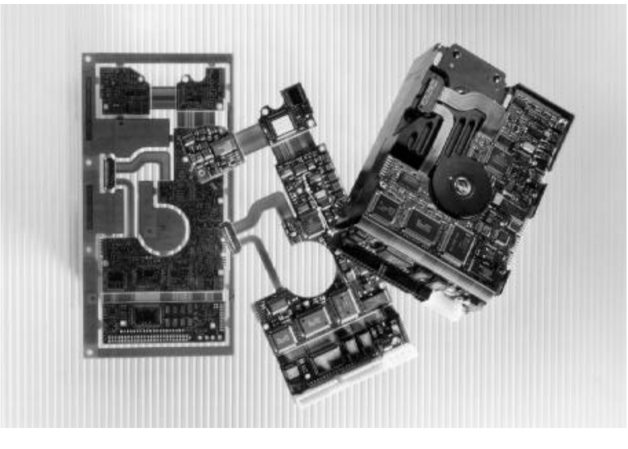

Figure 1.
Disk drive SMT assy: 115 pads/in^2 (18 pads/cm^2)

Figure 2 shows a typical MCM-C product with an average pad density of 303 pads/in^2(47 pads/cm^2). Industry tracking and forecasting of trends in these two technologies, in conjunction

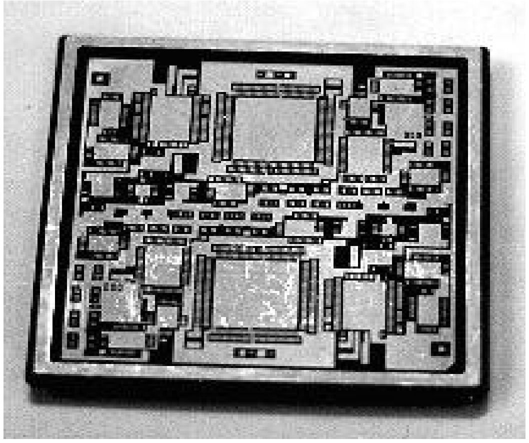

Figure 2.
Avionics microprocessor MCM-C: 303 pads/in^2
(47 pads/cm^2)

with internal tracking of customer demands for packaging new product applications identifies major challenges for the technologies:

For MCM-C:

- lower cost
- shorter design and fabricaton cycles

For Rigid-Flex assemblies:

- higher density
- higher performance

More recently, other factors such as relaxation of hermeticity requirements and increased availability of cost effective known-good-die suggest a converging of laminate and ceramic technologies for certain segments of the broad markets. This convergence helps to provide focus for one set of solutions which can meet the challenges posed by a significant portion of the product demands. High density laminate-based packaging, such as MCM-L, appears to be a viable approach. Because of the custom solutions nature of TET’s business, its “brand” of MCM-L is not likely to resemble the standard footprint modules now appearing in some high volume products, but rather will employ mixed technologies like COB and SMT on a single substrate. For this reason, an interconnect substrate which accommodates these (and potentially DCA) is pursued.

Approach

In approaching a laminate based solution for packaging, it was important to ensure that the laminate could achieve the features and wiring density required to support emerging technologies such as chip-scale packages, in particular microBGA, as the latter is being considered by many end-product designers. Additionally, compatibility with bare die assembly processes was deemed a necessary requirement. The table below summarizes the attributes of a high density laminate substrate to suit the diverse requirements.

Requirement	Relative Importance*
low cost	4
manufacturable in high volume	3
compatibility with bare die and SMT assembly	5
density to accommodate MCM and CSPs	5
ability to preserve MCM-C form factors	3
compatibility with rigid-flex technology	4

* 1 = lowest, 5 = highest

Table 1.
High Density Laminate Substrate Requirements

Although identification of a specific target for interconnect density is difficult, the range sought was between the 100 pads/in^2 (15 pads/cm^2) and 350 pads/in^2 (54 pads/cm^2) typical of the SMT and MCM-C products, respectively. The approach to satisfying these requirements was not one of a comprehensive materials and process development program, but rather one of maximizing utilization of existing capabilities. Such capabilities resident or already under development internally include the ability to incorporate multiple materials systems (such as epoxy/glass and polyimide in rigid-flex), fine line imaging/etching and small via formation/plating. Moreover, steady advancements in the printed circuit industry infrastructure validated the decision to pursue laminate-based packaging.

High Density Substrate Construction

As rigid-flex circuits and assemblies became more widely used in the 1980's, the applications demand for increased density was met by going to higher layer counts. This caused reliability problems related to Z-axis expansion, as the majority of flex-based materials used acrylic adhesives. One answer to this was the REGAL^{TM} technology, which eliminated acrylics in the rigid multilayer sections. REGAL 1 uses prepreg in the flex section with polyimide/acrylic covercoat to impart flexibility, while REGAL 5 is a true hybrid construction of polyimide/acrylic only in the flex section and epoxy/glass only in the rigid section. Now, with adhesiveless flex materials becoming more available and affordable, the incorporation of flex layers in a multilayer section is feasible, and this is one type of basic construction around which a family of high density laminate substrates can be developed. Figures 3 through 5 illustrate the progression of rigid-flex based interconnect substrates used for microelectronics assembly applications. To achieve the wireability and assembly compatibility of both bare die and high density SMT components, TET has incorporated an adhesiveless layer pair concept into its multilayer substrate. The layer pair is capable of implementing non-drilled microvias, which, upon sequential lamination of the layer pairs, become buried vias. Small drilled through vias are later added where needed but the number of these required is dramatically reduced by the use of the buried microvias. The cross-section in Figure 5. illustrates the rigid-flex version of this construction. The high density laminate was first built as a 2-layer multi-purpose test vehicle. The test vehicle was designed to demonstrate and/or develop the following features:

- adhesiveless flex innerlayer pair construction
- wiring density for ultra-fine pitch SMT
- microBGA assembly reliability
- evaluation of microvia formation technologies
- evaluation of microvia-in-microSMT pad
- evaluation of flexible LPISM materials

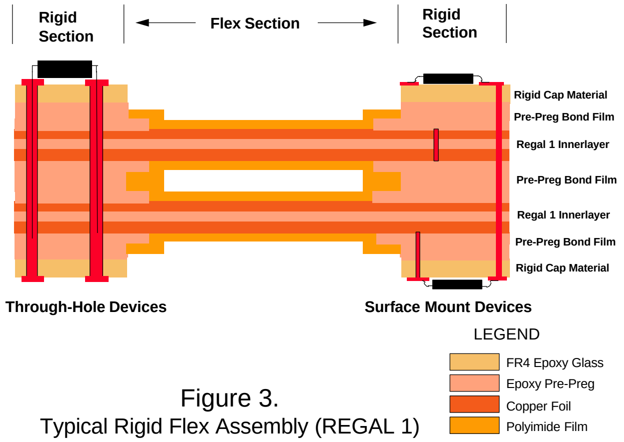

Figure 3.
Typical Rigid Flex Assembly (REGAL 1)

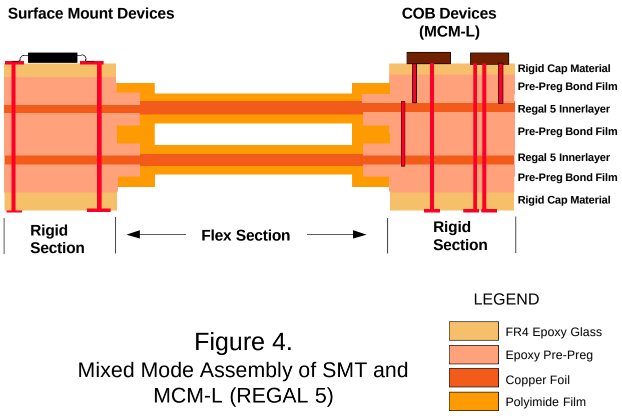

Figure 4.
Mixed Mode Assembly of SMT and MCM-L (REGAL 5)

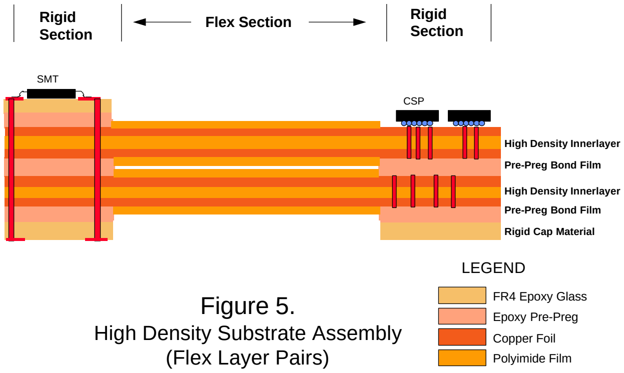

Figure 5.
High Density Substrate Assembly (Flex Layer Pairs)

The microvia-in-microSMT-pad construction serves to assess the attachment of chip scale packages, such as the microBGA, directly to pads without using separate vias. Routing studies have shown the need to incorporate such a construction when BGA pitches drop to the range of 0.025” (0.65mm). [1]

The innerlayer pair construction was then employed in an MCM-L product, an eight-layer design built with four layer pairs employing both microvias and drilled through vias.

Advantages

In addition to the obvious advantage of increasing wiring density in a multilayer structure, the layer pair approach allows for considerable flexibility in choosing a via formation process technology. Significant progress has been reported in low cost via array processing including such options as plasma etching [2], laser ablation, chemical milling, punching [3] and laminates prefabricated with vias [4]. Once the process is optimized, throughput is also increased, as the number of drilled through holes is minimized. Total thickness of a multilayer substrate is reduced as the dielectric layer is typically 0.001” - 0.002”, (25μm - 50μm) and often as thin as 0.0005” (12.5 μm).

An additional advantage, when considering the use of the flexible soldermask materials in a rigid-flex construction, is that SMT and microSMT components can be assembled to and routed through the flex section, if necessary.

Fabrication and Assembly

The majority of layer pair microvias in the MCM-L product are buried, while those in the microBGA test vehicle are intended to simulate blind vias within pads. (They are actually through vias, since the TV is only 2 layers.) In both cases, the microvias were processed as an innerlayer pair material and then imaged and etched to produce the circuitry. For the MCM-L, the circuit layer pairs were sequentially laminated to produce the eight-layer multilayer circuit and then finished in wire-bondable electrolytic gold.

The microBGA test vehicle was finished with HASL, with a number of soldermasking options being evaluated in the process. The earliest samples were produced using standard polyimide based coverlay materials with a spray-applied LPISM in four “patches”, one at each BGA site. Although this approach resulted in a robust construction, it was not considered to be cost effective. A second iteration utilizing the PI coverlay on the backside and flexible LPISM on the front side resulted in excessive curling of the substrate. The third and final version employed a newly developed flexible LPISM on both sides with very good results. The test vehicle is shown in Figure 6.

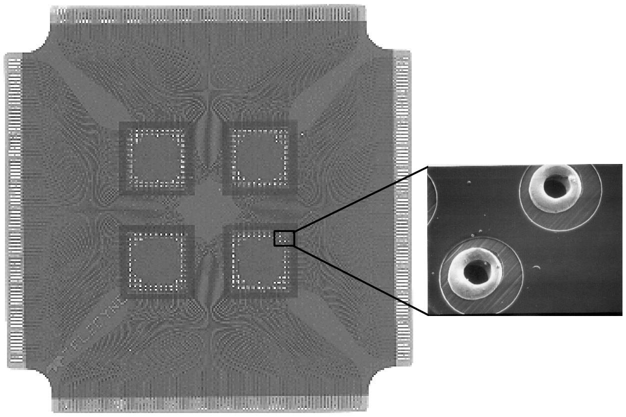

Figure 6.
Two-Layer microBGA Test Vehicle

The test vehicle has four 188 I/O microBGA sites, with half of the I/O fanning out on layer one and the other half routing through the vias and then fanning out on layer two. Linewidth and spacing is 0.003” (75μm); vias are 0.004” (100μm) with 0.010” (0.25mm) pads. This substrate demonstrates the ability to support average pad densities of about 175 pads/in^2 (27 pads/cm^2) and local densities up to 350 pads/in^2

(54 pads/cm^2) with only two layers. Assembly of the components was accomplished using screened solder paste and IR reflow. While the assembly process is not yet optimized, the assembled test vehicles offered an early look at the microBGA-solder joint-via/pad structure.

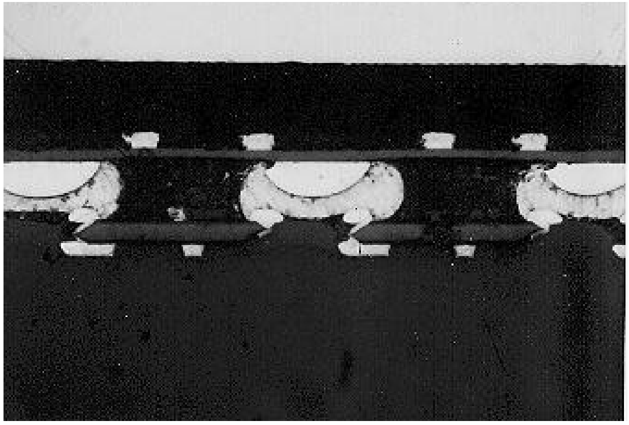

Figure 7.
MicroBGA Solder Joints on Test Vehicle

Figure 7 is a sample from the first assembly evaluations, and while it does show good solder joints between the microBGA balls and the microvia pads, there were minor problems of misregistration and via tenting. Slight misregistration in the axis normal to the plane of the cross-section causes the appearance of discontinuity in the microvia. The vias in the figure are tented, but those which did not tent exhibit better solder flow into the via. The via/pad structure promises to offer some degree of ball self-alignment for microBGA placement.

Reliability

Initial reliability tests on the high density laminate substrates have been encouraging. Multilayer constructions with flex innerlayers have undergone the routine regimen of thermal shock, cycling and moisture testing with no signs of any inherent failure mechanisms. Innerlayer pairs with microvias have been subjected to solder float testing with no via failures, other than those caused by known and correctable process defects. Reliability testing of assembled microBGA test vehicles is just now getting underway, and qualification testing of the MCM-L product will begin in the near future.

The integrity of the flexible soldermask materials is also being studied. Although the formulation of these materials is still being optimized for performance and ease of application, preliminary data indicates flex performance at least as good as that in a Regal 1 construction (where flex-to-install requirements are 25 flex cycles). Table 2 summarizes preliminary flex endurance data (per MIL-STD P-50884 3.65/4.8.45 and IPC-TM-650-2.4.3.2) on one of the more promising materials as deposited with the TET Unicote DSA spray system.

Preliminary Flex Endurance Data
Flexible Soldermask "A"
(cycles to failure)

Sample Type (1 oz. Cu)	**Mandrel Diameter**	
	.125" **(3.2mm)**	**.250"** **(6.4mm)**
Adhesiveless Flex	2,147	16,798
PI/Acrylic Flex	11,431	41,937
Prepreg	73*	428*
Prepreg w/PI covercoat (typical range)		250-500

* 2 oz. copper

Table 2.
Flexible Soldermask Performance

Potential Applications

There are several constructions possible using the high density laminate; the final configuration depends on the product application. Options include, but are not limited to the following:

- rigid-flex
- MCM-L with flex I/O: MCM-L(F)
- multilayer flex
- rigid MCM-L

The first practical TET application of the high density laminate substrate is not SMT, but rather the MCM-L product shown in Figure 8. This is a fiber-optic transmit/receive module used in an airborne communications system. The original design was rendered in ceramic, but the innerlayer pair with microvia construction enabled the transition to lower cost laminate without increasing the module footprint. An average pad density of 220 pads/in^2 (34 pads/cm^2) was achieved, even with the addition of thermal vias under the devices. This substrate incorporates the integral flex I/O legs, making it a good example of the MCM-L(F) construction.

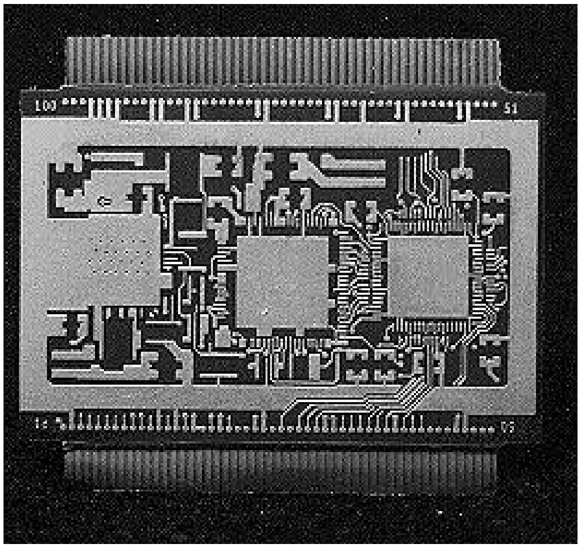

Figure 8.
MCM-L(F) Substrate with Flex Innerlayer Pairs

By incorporating the flex innerlayer pair construction into this product, the number of drilled holes was reduced by 73%, thermal vias aside. Since this product had an area constraint specified, the microvias also resulted in reducing the layer count from ten (possibly twelve) to eight, without increasing the circuit area.

Several custom applications employing microBGA and other chip-scale SMT devices are currently under development, some of which are based on a rigid-flex construction. Two such applications are in the medical market, one for an implantable device and one for a wearable biological sensing/recording device. In the former, the primary driver is lower cost redesign of ceramic substrate technology, while in the latter it is to increase density of memory devices in a PCMCIA-like card format. There are also several applications under development for portable products in the communications and computer markets.

Summary

A high density laminate substrate, capable of accommodating microSMT and COB devices, has been developed and demonstrated for use in a wide variety of constructions and applications. The substrate utilizes materials of construction standard to the rigid-flex industry and benefits from the ability to incorporate any of several microvia formation technologies. Average interconnect densities of up to 175 pads/in^2 (27 pads/cm^2) have been achieved in a two-layer test vehicle, with local densities of 350 pads/in^2 (54 pads/cm^2). The assembly and routing of microBGA packages has also been demonstrated by incorporating vias into the SMT pads. The substrate has been successfully designed into a multilayer MCM-L product, achieving average pad densities of 220 pads/in^2 (34 pads/cm^2) in addition to accommodating thermal vias.

To a large extent, the high density laminate offers a viable solution to TET's interconnect substrate gap which has existed between conventional rigid-flex-based SMT assemblies and ceramic-based hybrids and MCMs. Development work is ongoing to further characterize the fabrication and assembly processes (e.g. selection of microvia formation process which best fits TET manufacturing), and to develop design rules to assist in tradeoff

analyses between feature sizes and layer counts. Reliability and qualification testing will continue to ensure integrity of the laminate construction as well as the microassembly processes.

Acknowledgements

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