A Novel Methodology (Low Temperature Laminated Organics) for 3D Integration Using Multilayer Organics

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Abstract

This paper presents for the first time a new paradigm in the construction of multilayer RF, digital and mixed signal circuits using conventional low-loss organic laminates. The new process termed Low Temperature Laminated Organics, LTLO™ [1], is a multilayer parallel process where individual layers are circuitized, tested and co-laminated at temperatures below 280°C to form a multilayer structure. Both stacked and staggered via structures have been realized with LTLO, thereby allowing for the realization of any layer, and any via interconnection schemes. The LTLO technology also facilitates the introduction of embedded active and passive components allowing for true 3D package integration. To date up to 24 metal layers have been demonstrated using LTLO.

Introduction

Ceramics have long been the substrate of choice for most high frequency RF substrates with embedded passives. However, this paper presents a different approach to multiband RF integration; Multilayer Organics (MLO™).

MLO takes advantage of thin, disparate layers of high performance dielectrics coupled with copper metallization. The authors have shown that low loss dielectrics such as Liquid Crystalline Polymers (LCP), and high k (Oak Mitsui), PTFE ceramic composite dielectrics, integrated into a unique multilayer stack up can provide a pathway to achieve overall package size reduction and high performance. These high performance polymer dielectrics exhibit stable electrical properties over temperature and frequency (>20GHz), superior thermal stability, lead free solder compatibility, and very low moisture absorption [1-3].

One of the major drawbacks of current printed wiring board manufacturing techniques and those presented in [1-3] includes a) costly sequential build-up (SBU), b) the need for core package layers for rigidity, c) minimal stacking of microvias limiting the density, d) high loss materials compared to those required for RF and mixed signal integration from DC-20GHz, e) moisture absorption (>0.2%) causing moisture sensitivity to become an issue, f) overall thickness of substrate limited by thicknesses greater than 50 and 100 micron materials.

This paper discusses LTLO which addresses these concerns by introducing a) parallel process similar in nature to LTCC, b) thin, stiff coreless package, c) stacked vias with any layer via interconnect, d) low loss tangent < 0.002, e) low moisture absorption (<0.04%) providing a near hermetic material set, f) 25micron thick material sets allowing less than 0.5mm substrates with more than 15 metal layers. This technology thus becomes ideal for mixed signal functions for high density, and high frequency applications. Embedding very small compact RF structures such as diplexers, multiplexers, filters and baluns is very attractive, while also achieving good signal and power integrity.

The paper is organized as follows: section I discusses the LTLO stackup and processing of multiple layers; section II discusses the design partitioning choices available with LTLO, followed by a discussion on existing RF libraries available in LTLO; lastly section III discuss fabrication results, reliability and future developments.

I. LTLO Processing and Stackup

The first stackup fabricated is a nine-layer LCP stack up, shown in Figure 1. Layers of high temperature LCP (RO3860) are adhered together using a low temperature LCP (RO3908). The blue metal lines (M1, M3, M5, M7, and M9) are the top/bottom metal layers which are clad to the high temperature LCP. The green metal lines (M2, M4, M6, and M8) are the top/bottom metal layers which are clad to the low temperature LCP. Using metal layers clad to the high temperature LCP minimizes metal shift or distortion; therefore, inductor windings and critical transmission lines are placed on these layers.

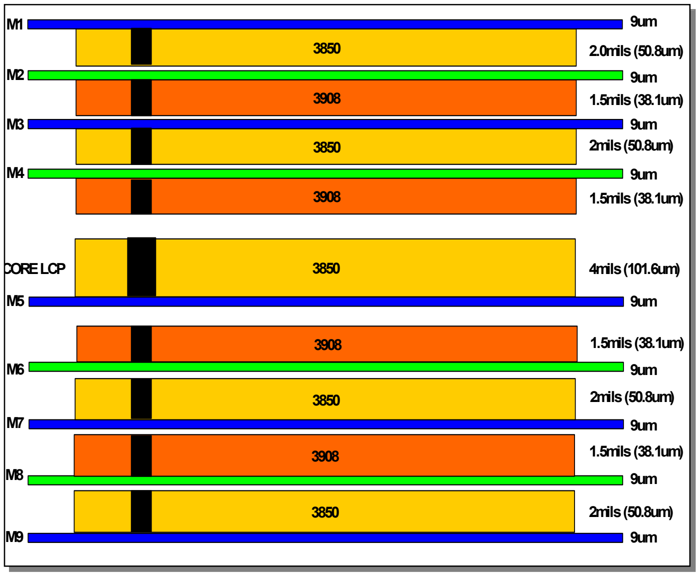

Figure 1: Nine-Layer LCP Stack-Up

Figure 2 represents a flow of the process steps for the fabrication of LTLO. The construction shows the simplicity of the process. The process is simpler by a factor which is proportional to the number of layers that would be aimed at using a SBU process. An eight metal layer stack up, referred to as a 2+4+2 stack in SBU, would take approximately eight times as long compared to the LTLO process. Inspection and

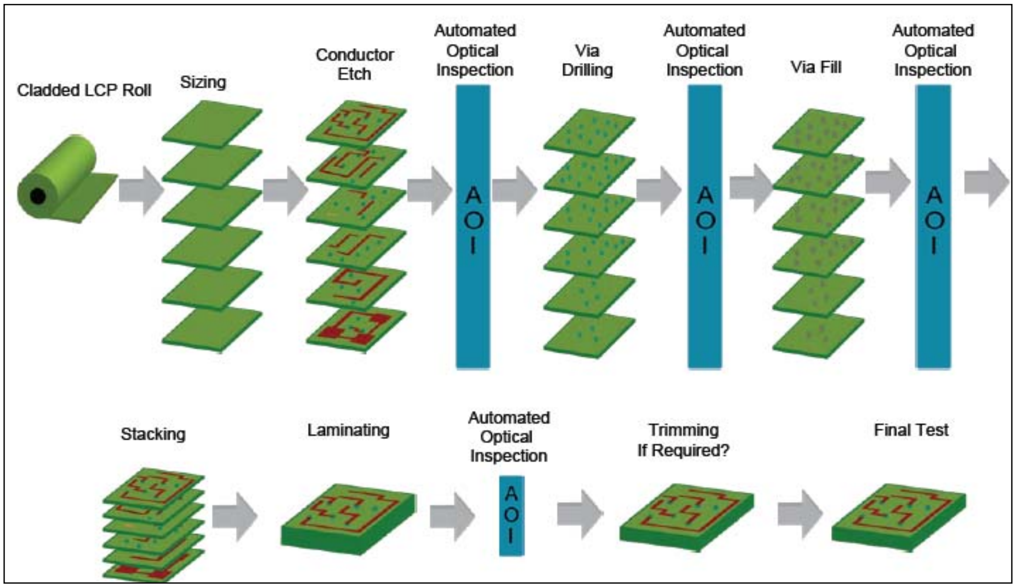

Figure 2.0 Process steps for LTLO

trimming may be required at each circuitized layer. This is possible but very difficult in a SBU process.

The first cross-sections and X-rays from the LTLO process are shown in Figure 3. It is important to note the lack of interlayer fiber and any separation between layers. This indicates complete fusion between layers and a homogenous laminate structure.

II. Design Choices and RF libraries

Several of the designs discussed in [1-3] can be designed and implemented in LTLO also. These are quasi-transmission line-lumped circuits that are used to integrated high quality factor (Q) inductors and capacitors which then constitutes in filters, diplexers, baluns and multiplexers. The stack-up shown in Figure 1 can be easily extended to more layers if needed. Using a large number of layers facilitates in the routing of dense ICs where the ICs can be either mounted on top side or both sides of the LTLO substrate.

The authors show the design of a 2.4GHz magnetically coupled bandpass filter (MCBF) in Figure 4.0. The principle parts of this filter are two vertically coupled 2 metal layer inductors L38 & L39, each located on vertically adjacent metal layers and separated by a thin layer of Liquid Crystalline Polymer (LCP). These designs have been previously disclosed in [1-4]. The degree of coupling which translates to filter bandwidth is a function of the LCP thickness and the alignment of the metalized layers. No other circuitry is needed to create the band due to the parasitic capacitance created between the magnetically coupled inductors. These filters are becoming imperative for multiple input multiple output (MIMO) based applications which can support data rates in excess of 100Mbps in the home office environment. Today, this is achieved using mostly LTCC [5] or MLO such as [1-4]. The 2.4GHz magnetically coupled bandpass filter (MCBF) was simulated using the Sonnet EM simulation tool. The results are shown below in Figure 5.

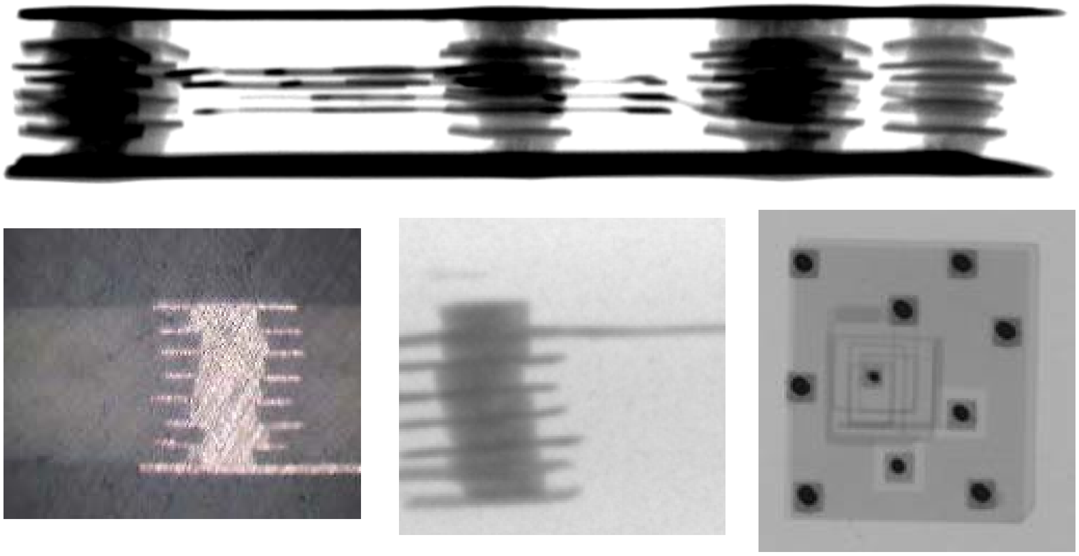

Figure 3. Cross-section and X-rays of structures fabricated using LTLO

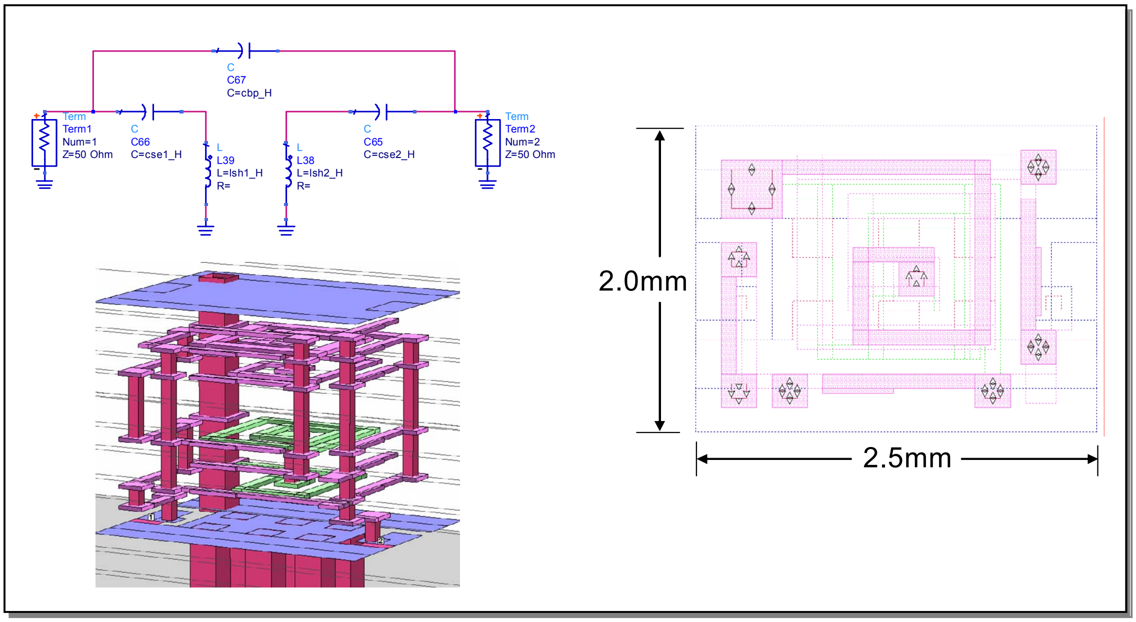

Figure 4.0 2.45GHz Magnetically Coupled Bandpass Filter

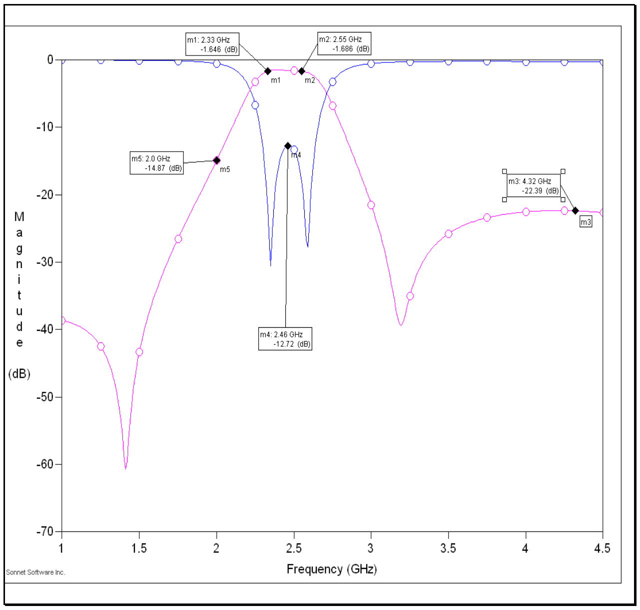

Figure 5: 2.45GHz Magnetically Coupled Bandpass Filter Modeled Performance

The 2.4GHz MCBF can be modified to accommodate any band and/or bandwidth. As stated previously, the bandwidth of the filter is a function of the inductive coupling between two inductors to ground. To showcase the band/bandwidth flexibility, Figure 6 displays the layout, dimensions, and performance of a 2.3-2.7GHz, 3.3-3.8GHz and 4.9-5.9GHz triplexer. This triplexer would be intended for WIWI (combination WiFi and WiMAX) applications.

The MCBF is also stackable; meaning, any number of dielectric/metal layers can be added to the dielectric/metal layer stack-up shown in Figure 1. This allows the designer to stack multiple MCBFs' creating any number of bands connected to a common input, and reducing the overall dimensions to the size of a single MCBF.

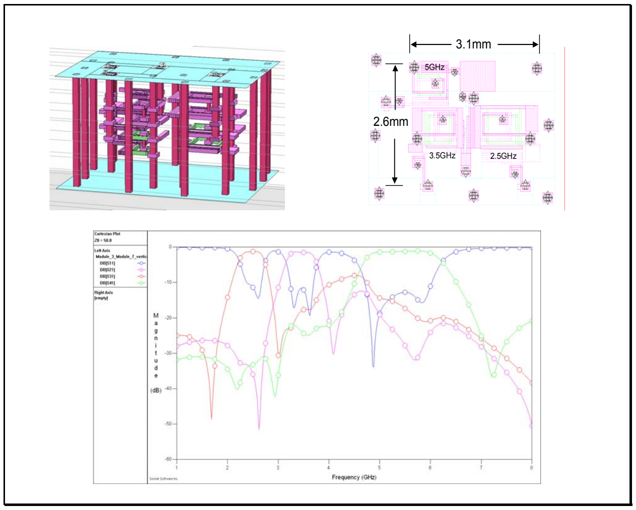

Figure 6: 2.4GHz, 3.0GHz, and 5.0GHz Magnetically Coupled Bandpass Triplexer

III. Fabrication and Initial Reliability

The authors fabricated several filters in addition to the ones discussed earlier in this paper. Figures 6a, 6b show data for 2 different filters. The following is a summary of the data:

- Measurements were done using GS and SG 450um pitch probes
- SOLT calibration performed
- All filters are fully shielded using top and bottom metal layers using stripline topolgies
- Sample is approximately 0.45mm thick
  - Includes 9 metal layers
  - 8 LCP layers

Figure 7 shows initial data for pre and post moisture sensitivity level tests at MSL 2 @ 260. Little to no change is observed for a 6GHz filter showing the inertness and near hermetic nature of the material set as discussed earlier.

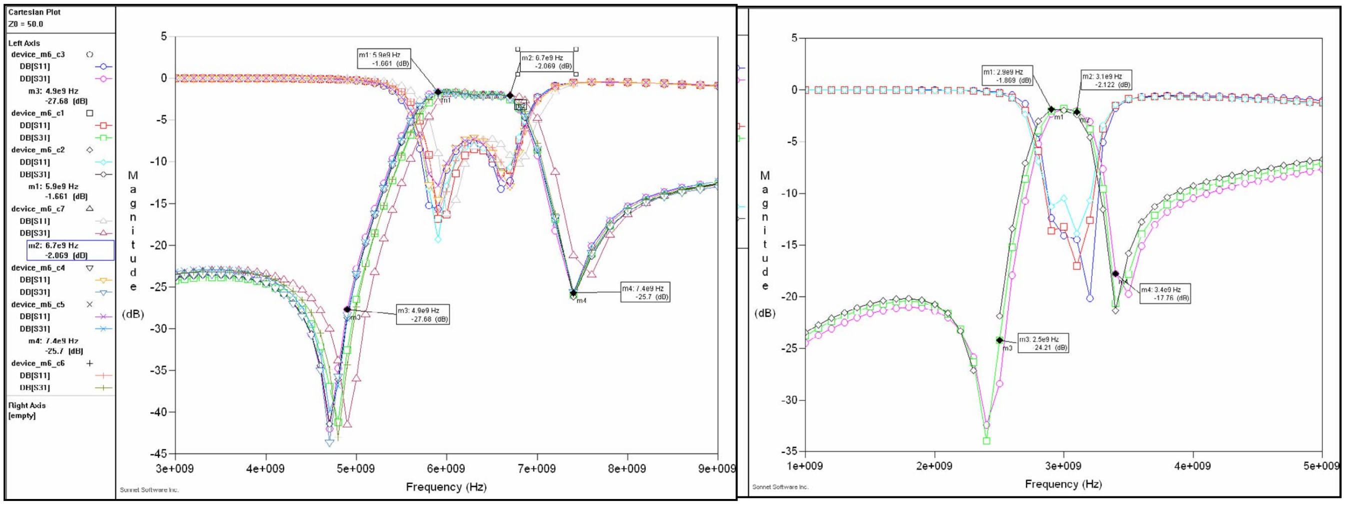

Figure 6a) 6GHz filter, 6b) 3 GHz filter

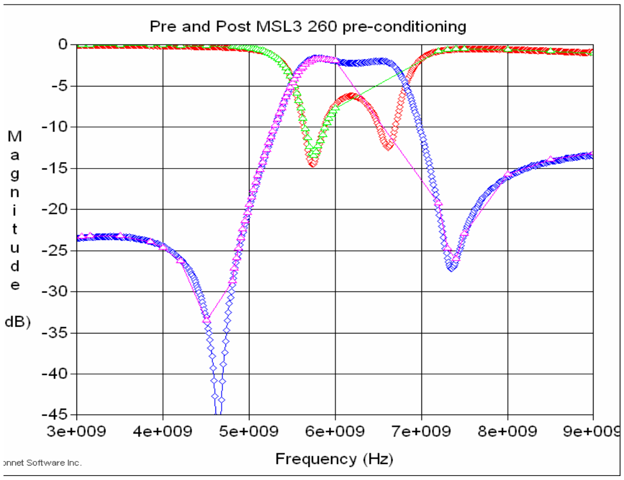

Figure 7.0 Pre and post MSL 2 data at 260

IV. LTLO as an Enabler for Embedded Components

The authors have also embedded a number of RF components including GaAs switches and low noise amplifiers. SMT components as small as 01005's have also been embedded in the LTLO stack up. The process allows for the integration of these components directly within the wiring layers thereby allowing for the highest level of component integration at a very low cost. Current work is ongoing to integrate power amplifiers, thereby allowing for the highest level of RF and mixed signal integration in an organic laminate.

Conclusions

In conclusion the authors would like to specify the key differences with LTLO vs LTCC.

a) Starting material is single clad copper
    a. Copper can be 3um to 36um thick
b) Traces are etched on single clad copper
    a. Excellent line width control (<< 5%)
    b. Highest Qs with minimal surface roughness
c) Back side laser drilling and via filling
    a. Ability to use multiple pastes depending on the application (e.g.,Cu/Ag and Ferrite)
    b. Ability to form cavity structures
d) Compatible with at least two commercially available paste formulations; a third formulation is under evaluation
e) Lamination temperature much less than LTCC (< 280^{o}C)
f) Minimal distortion
g) Low raw process time (RPT)

References

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