Selected Applications and Processing for Low Temperature Cofired Ceramic

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Abstract

Low Temperature Cofired Ceramic technology has proven itself in microelectronics, microsystems (including microfluidic systems), sensors, radio frequency (RF) features, and various other non-electronic applications. We will discuss selected applications and the processing associated with those applications. We will then focus on our recent work in the area of electromagnetic isolation (EMI) shielding using full tape thickness features (FTTF) and sidewall metallization. The FTTF is very effective in applications with -150 dB isolation requirements, but presents obvious processing difficulties in full-scale fabrication. The FTTF forms a single continuous solid wall around the volume to be shielded by using sequential punching and feature-filling. Sidewall metallization provides another method for shielding. We discuss the material incompatibilities and manufacturing considerations that need to be addressed for such structures and show preliminary implementations.

Key Words: LTCC, RF, EMI, Channels,

1. Introduction

Novel applications for Low Temperature Cofired Ceramic (LTCC) technology are becoming commonplace with many implementations in packaging and multichip modules for electronics and microsystems, radio frequency (RF) applications, microfluidic devices and sensors—frequently at the meso scale. The meso scale, in this case involves dimensions on the order of the tape thicknesses available and the circuit feature sizes (~50-250 µm). Feature sizes are by no means limited by these values, as sacrificial materials and material modifications can be performed at the nano scale. This has been possible based both on need and initial materials properties evaluations that have paved the way. Advances have been made in using the structural properties of the material to support channels, cantilevered bridges, manifolds (e.g., Figure 1), windows, fibers, and other optical elements, moving parts, and various other types of structures including electromagnetic isolation (EMI). LTCC is a versatile integration technology that has found wide application in microelectronics and microsystems as well as many non-electronic applications. Literature documents the appeal to ceramic sensor and system applications (macro-, meso-, and micro). [1,2]

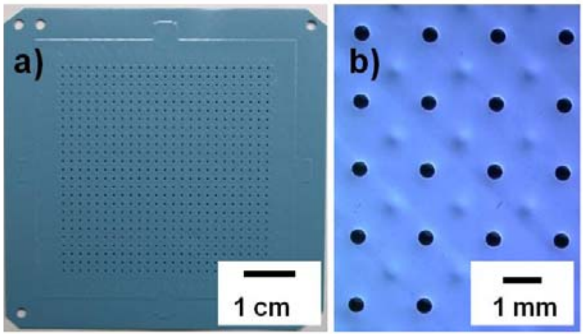


Figure 1. Pneumatic manifold constructed in LTCC. a) Overall manifold. b) Magnified view of manifold openings and attachment points.

2. Shaped Devices

LTCC is based on a consolidation of individual tape layers that can be formed, molded, thermally slumped and otherwise modified in the unfired state. We have taken advantage of many of these processing techniques to make shaped devices as shown in Figure 2. The micro-pressure measurement device shown in b and c is a pressure measurement device which works by measuring the strain in a pressurized device using a strain gage.

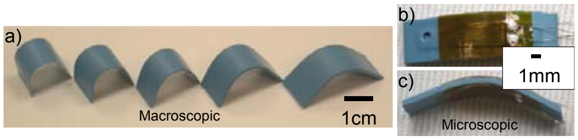


Figure 2. LTCC devices operate in shaped configurations as well as flat boards. a) Thermally slumped demonstration samples set the stage for a micro-pressure measurement device (two views: b) and c))

Other shaped devices have been fabricated by rolling unfired tapes and laminating the shape on a mandrel. These tapes have previously been printed with the desired surface and buried circuitry. The mandrel is removed and the self-supporting cylinder is fired on-end. Figure 3 shows several views of one such application in an ion mobility spectrometer drift tube. Figure 3a shows the end of the tube with ion trap elements in-place. Figure 3b shows the overall tube with leads attached. The dark band on the exterior surface of the tube is one of two banks of 50 cofired thick film resistors. Figure 3c shows an end view highlighting features on both surfaces of the tube, and Figure 3d shows a cross-sectional view cut from a laminated unfired wall section illustrating stacking of the main wall layers and an embedded heater layer.

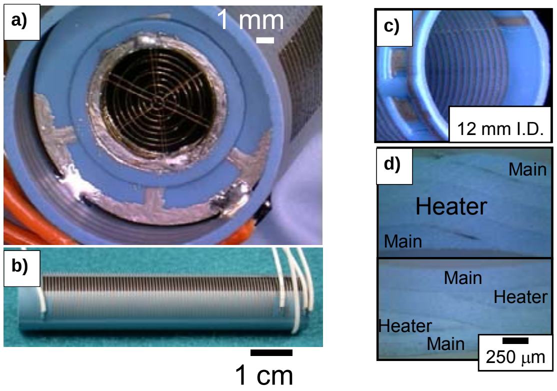


Figure 3. Tubular device: Ion Mobility Spectrometer drift tube.

3. Sacrificial Volume Materials (SVM)

The use of SVM expands the roles that LTCC can fill. Structures that would otherwise sag or slump under the influence of lamination pressures or sintering temperatures can be provided additional support by thermally sacrificial supports. These supports are applied in various ways. Figure 4 shows several possible implementations of SVM with a carbon-based filler in mind.

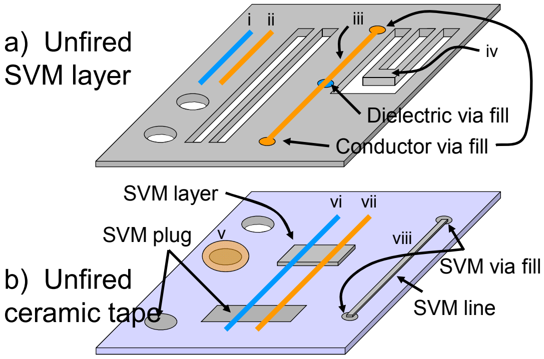


Figure 4. Schematic view of uses of SVM as a) an unfired SVM layer and on b) an unfired glass-ceramic tape.

4. Channels

Channels, open and closed cavities, and other open structures have been used. Several such techniques are illustrated in Figure 5. Channels that have been predefined by punching in the unfired state and fitting carbon tape inserts are shown in Figure 5a. Channels formed by simply laminating unfired LTCC tape layers around these same inserts with no predefinition are shown in Figure 5 b. A relatively small channel is shown in cross-section in Figure 5c. The minimum size can be much smaller than this. A larger channel in a LTCC manifold is shown in Figure 5d.

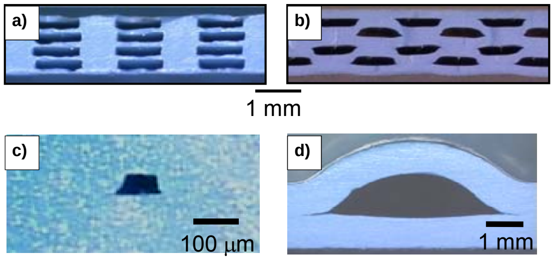


Figure 5. Channel cross sections illustrating channels that are predefined (a, c, and d) and defined during lamination (b).

5. Manifolds/Interfaces

Manifolds for of test structures have been realized with annular soldered 'donuts' as shown in Figure 6. Densely channeled thin boards with surface ports are used to make the modular microfluidic manifolds. Figure 6a shows the sub-element whose embedded channels surface at the annular ports shown. Figure 6b shows an array of 25 such devices on a modular motherboard. Figure 6c shows a similar structure but with eight distinct ports on each sub element position. Figure 6d shows the layered channel schematic which is realized in a board thickness less than 2 mm, and e shows a soldered close up view of a sub element.

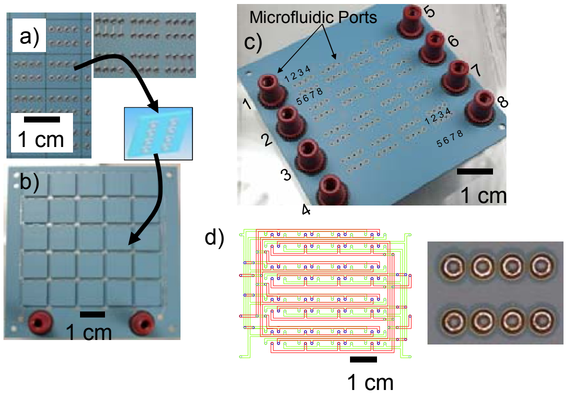


Figure 6. Complex manifolds can be formed in dimensions <<2mm thickness.

6. Windows

There is frequently a short term need for visual access or a long term need for an optical component. Several such applications are illustrated in Figure 7. Figure 7a shows sapphire windows that have been cofired into LTCC lids. Figure 7b shows a channel intersection in a single tape of LTCC with a cofired window on the front and back surfaces. This was used to observe the time-lapse fluorescent particle flowing stream shown in Figure 7c. A window on a single side of a channel formed by the use of SVM is shown in Figure 7d. Figure 7e and f show a window that was made from a single optical fiber. The window was polished after being captured in a cofiring process.

7. FTTF

Full tape thickness features (FTTF) are simple structures based on via fill techniques and have been fabricated by punching channels in the tape and stenciling the full thickness channels full of conductor at the same time as via fill. Because they result in a material discontinuity that can be fragile in the handling that follows drying of the vias and thick film, it is sensible to limit the length of the channels. Figure 8 shows the benefit of a FTTF structure when current carrying capability is important.

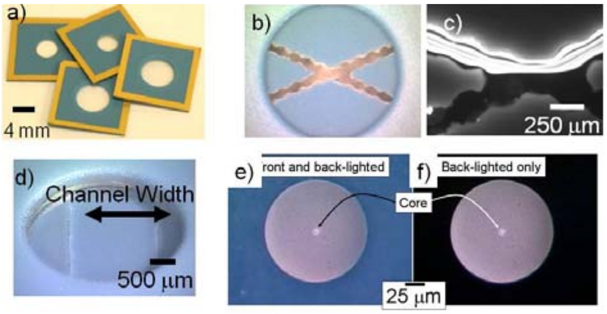


Figure 7. Transparent windows of various forms have been cofired into LTCC.

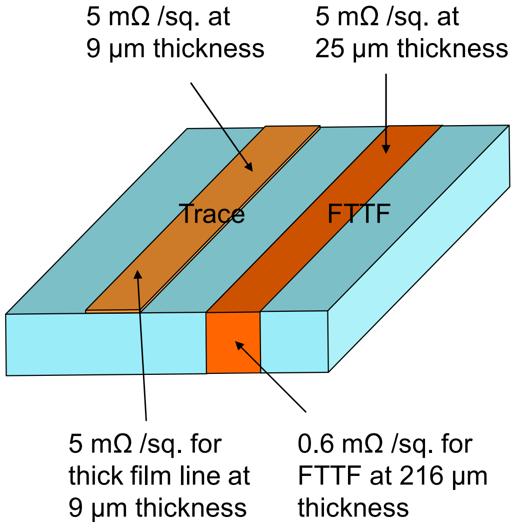


Figure 8. Illustration of the differences between a trace and FTTF structure.

8. FTTF EMI protection

New EMI requirements exceed 150db. Previous use of via fences and meshed ground planes failed to deliver this isolation level. Through a combination of better layout, solid ground planes, and solid walls surrounding individual circuit functions, the isolation requirements have been achieved. This has been demonstrated functionally although not measured quantitatively. Figure 9 shows a schematic of the fabrication of such a solid wall FTTF. The actual tape layers have been hidden in order to show a ground plane one layer below the surface of the part and to show which portions of the solid wall are above this ground plane and which portions are below. The segments punched in a single layer are shown in the top layer of the circuit after they are filled. While they are solid, they are not continuous. The solid wall in the top layer is made continuous by secondary punching which is performed after the two tapes are laminated together. This results in segments which also protrude below the ground plane, but these are not harmful to the circuit function.

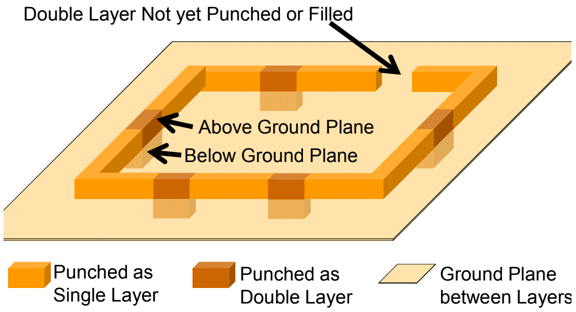


Figure 9. Illustration of the structure of an FTTF solid wall for EMI.

Figure 10 shows a single section of a wall which exhibits no gross cracking in the thick film or substrate. This is representative of 8 different cross-sections examined.

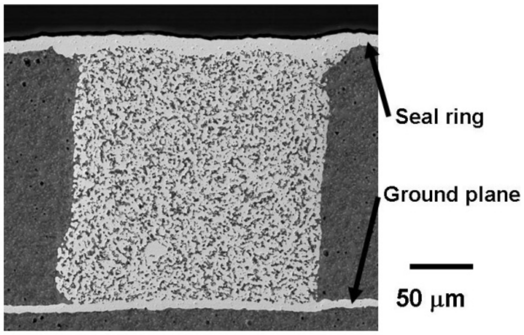


Figure 10. Cross sectional view of a solid wall in a single layer.

Two cross sections made along the length of the wall in mid-section are shown in Figure 11. The portion of the image that is two tape layers thick can be compared to the indicated area depicted in Figure 9. Certain discontinuities are present within the via material but the joints of the thick film to the ceramic appear to be good. This joint is also crack-free at the ends of the long segments of solid wall FTTF.

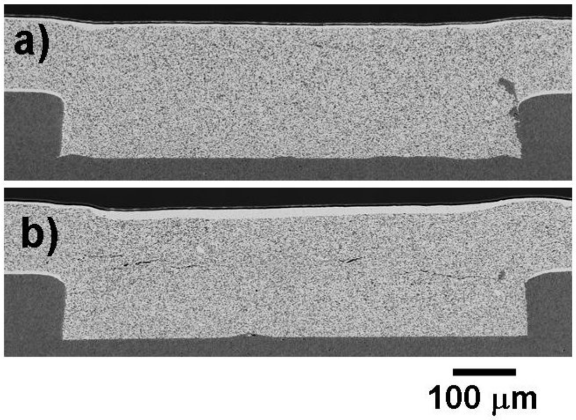
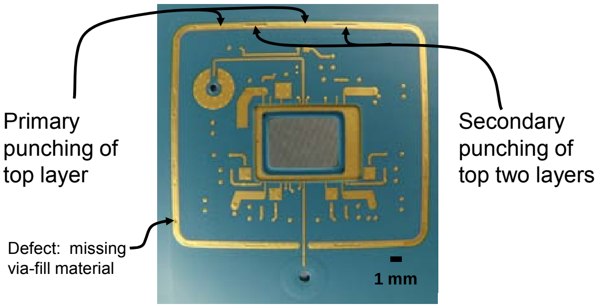


Figure 11. Longitudinal cross-sectional view of a single layer solid wall including segments that are two layers deep.

An example of a solid wall constructed in this fashion for a test circuit is illustrated in Figure 12. The primary punched and filled areas are in the top layer only, as shown in Figure 9. The secondary areas are punched in two layers in order to provide a continuous solid wall on the top layer.



Solid wall covered by cofired barrier layer; No cracks.

Figure 12. An overall view of a solid wall EMI structure in a test circuit.

Other features of the same type of structure can be seen in Figure 13. In Figure 13a, a signal line is shown passing between two segments of a solid wall. Figure 13b shows a location where a 4-layer stack of solid wall structures has been used to provide EMI for a coaxial through-board connection. Figure 13c illustrates a staggered stack of the regions where singly-punched FTTF is used. Figure 13d shows two sets of two layer punches stacked following via fill.

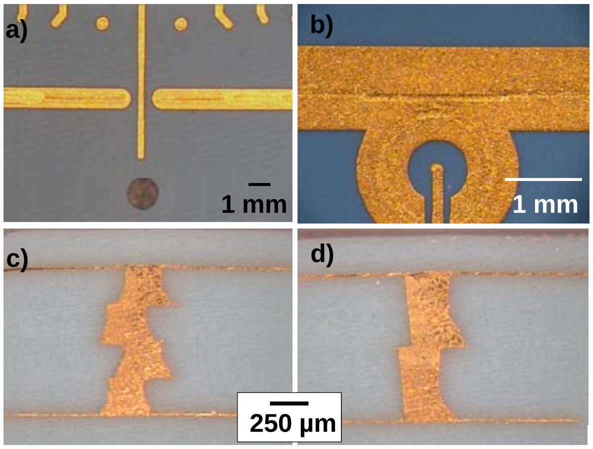


Figure 13. Different implementations of FTTF isolation structures.

This technique for providing EMI can experience difficulty in certain cases. Solid wall features have resulted in cracks in single level walls and in EMI structures around deep cavities. Techniques that eliminate these cracks in a production environment are being developed. One example of a serious crack in multiple levels is shown in Figure 14 for 16 layers of 250 µm tape.

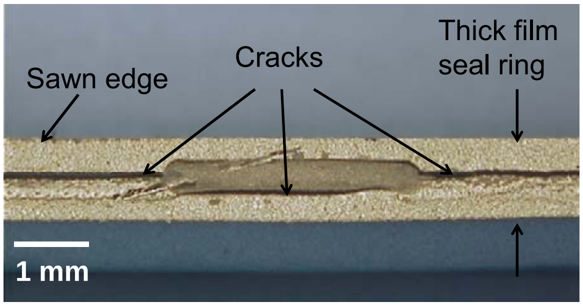


Figure 14. Example of cracking experienced in a thin wall made up of 16 layers of 250µm tape.

9. Sidewall metallization

There are alternatives to the solid wall fabrication technique, one of which is illustrated in Figure 15. Sidewall metallization is another technique that is capable of delivering EMI protection. It takes advantage of the existing LTCC fabrication infrastructure and can be performed during a metallization step. Our preferred practice is to coat the sidewall from both sides to assure uniform coating. As shown in Figure 15a, the first print is like the thick film via wall coating applied to a long edge. Figure 15b shows an example of a single tape cavity with sidewall coating. Figure 15c shows a rendition of the technique used to coat the second side of the tape. Figure 15d shows a four layer structure wherein one wall has been collated, and Figure 15e shows a schematic cross section that is stacked and laminated for firing. An example of an actual structure is shown in Figure 16. Figure 16a shows a collated cavity wall, Figure 16b shows a laminated internal corner, Figure 16c shows a fired panel of 4 lids, and Figure 16d shows a single fired lid. At the time the original evaluation was performed, the manufacturability and volume of material used was thought to be prohibitive, but the technique is being re-evaluated in view of good results on deep cavities.

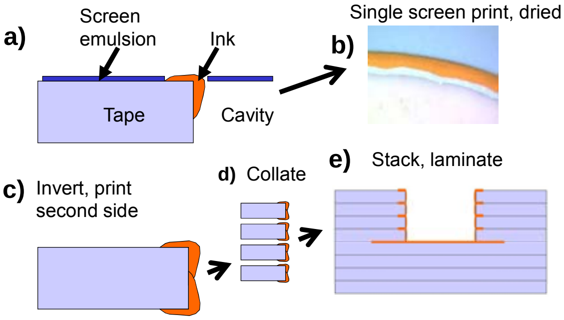


Figure 15. Sidewall metallization using screen printing. a) Printing the first side. b) An example of an edge with a first print. c) Conceptual image of printing second side. d) Collating a single cavity wall, e) Example of 4 cavity layers and a floor, stacked and laminated.

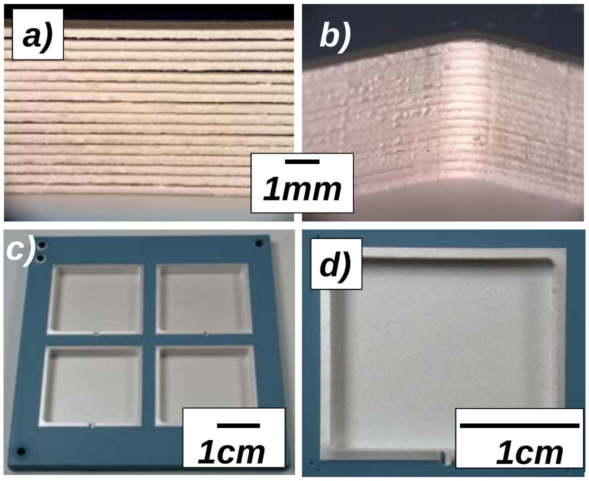


Figure 16. Sidewall-metallized cavity a) after collating (prior to lamination) b) after lamination, c) following firing (panel), d) following firing (individual lid).

10. Summary

LTCC is a versatile technology. Novel processing techniques have been used to make structures outside the norm for new functions using LTCC. We have presented some of these resulting in channels, tubes, manifolds, EMI structures. EMI protection in the form of embedded solid walls and sidewall metallization has been investigated. Functionality has been demonstrated but production readiness requires additional work.

11. Acknowledgements

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12. References

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[1] M.R. Gongora-Rubio, P. Espinoza-Vallejos, L. Sola-Laguna, J.J. Santiago-Aviles, "Overview of low temperature co-fired ceramics tape technology for meso-system technology," Sensors and Actuators A 89 (2001) 222-241.

[2] L.J. Golonka, "New application of LTCC technology," Proc. 28th Int. Spring Seminar on Electronics Technology, (2005) 148-152.