Mechanical Properties of Bent Modules Based on LTCC
Alena PietrikOVá and Stanislav SlosarčíK

Abstract—The top of a bend in flexural laminated LTCC (Low Temperature Cofired Ceramics) module has been found to cause warping and cracks. Experiments have been concentrated on the effects of various manufacturer’s bending on the structural integrity of DuPont’s Low Temperature 951 and 851 Cofired Green Tape™ modules and on the delimitation of optimal (marginal) conditions for bending: the bend angle and the number of bent layers. Bend strength and stress concentration factors of LTCC multi-layer modules were measured. This model was able to predict the cracks observed in bent samples and provides a design guideline for unconventional utilization of bent ceramic laminates based on LTCC which should be used for the bent shaped thick film modules. The presented results of investigations and simulations have been realized on the multilayer module made in 8 versions, 5 thickness and two types ceramics: as a plane module and ceramic modules warp under the angle up 90° based on Low Temperature 951 and 851 Cofired Green Tape™. Measurement system, which was built to characterize the failure and bend strength, is described. The results of the investigations can be summarized in design rules for LTCC bent modules (maximum number of layers, maximum bend angle, arrangement and stocking conductor lines in the middle of bent laminated electronic modules).

Index Terms—Electronic ceramics, LTCC, MCM-C, mechanical properties.

I. INTRODUCTION

LTCC is the appropriate technology suitable for design flexibility compared to conventional thick film, thin film and high-temperature cofired technologies in electronics. Ceramic materials are usually brittle, and this behavior often limits the use of ceramics in bent shapes. The approach of materials science emphasizes the relationships between processing, structure, and mechanical behavior as a way to understand a material, and to identify processes for improving its properties. Bent laminates are available to generate new electrical functions.

The main objective of this work was to investigate the mechanical properties of LTCC bent laminated modules by three-point bend test, and to do a visual inspection of the partially or fully fractured surfaces of bent laminated samples. LTCC layers were produced from Low Temperature 951 and 851 Cofired Green Tape™. Progress of Green Tape™ LTCC materials is reviewed in this paper with particular emphasis on new bent multilayer structures useful for unconventional electronic applications. Mechanical properties and behavior of bent ceramic modules often limit their exploitation in both sensor and unconventional electronic applications. These include materials and structures in the shape of bent conductors or bent multilayer dielectrics.

II. MATERIAL AND FABRICATING PROCESS OF BENT LAMINATED MODULES BASED ON LTCC

A. Material

Low Temperature Cofired Green Tape™ is a high strength glass/ceramic tape which contains about 40% of Al2O3, 45% SiO2 and 15% organics, such as B2O3, MgO, CaO and other materials. Both Green Tape™ systems are available in three different thicknesses: 114 µm ±7% (4.5mils), 165 µm ±7% (6.5mils), 254 µm ±7% (10 mils), respectively. For our research we used the 165 µm thickness only. Brittle fracture properties of LTCC are usually the source of the greatest benefits as well as the most severe limitations of ceramic materials. Basic understanding of mechanical behavior of ceramics and their failure processes were investigated under both conventional and unconventional conditions. Material systems include glasses for spacecraft windows, thermal barrier coatings, and aluminum oxide substrates. During sintering, the aluminum grains are bonded to each other through a silicate glass neck. Such type of ceramic modules can guarantee a relatively high value of Young’s modulus in unfired state (about 152 MPa for Low Temperature 951 Cofired Green Tape™ and 124 MPa for Low Temperature 851 Cofired Green Tape™) which is an essential precondition for the successful required bending of LTCC modules.

B. Fabricating Process

LTCC is a unique technique in which up to 60 layers of ceramic tape are stacked and fired in one step for production of a single multilayer rigid substrate. Usually, the multilayer modulus is made by cutting tape foil to a standard substrate size, punching the interconnecting vias, filling the vias with thick film paste, and patterning the interconnect lines on the tape. The operation is repeated for as many layers as the design requires. The separate layers of the module are then collated, stacked, and laminated, becoming the "green" multilayer. Once the multilayer is fired and cut to required dimensions, thick film resistors and either gold or silver conductor stripes complete the top layer.

For the fabrication of multilayer non-conventionally bent modules based on LTCC, a modification to these (existing)
technological methods is required; such samples were obtained by the following procedure:

1) Cutting of Stripes
Cutting of stripes with proper orientation and dimensions (considering shrinkage) were done. Final dimensions of under-layer laminates were 5 mm x 47 mm, 5 mm x 42 mm, 5 mm x 37 mm, 5 mm x 32 mm, respectively and from the 5th layer up to the 10th dimensions were 5 mm x 27 mm.

2) Screen-printing Process
Fabricating process carried on by screen-printing process on the top of the first four LTCC tapes used silver inner conductors. The paste was specially formulated to be compatible with LTCC. Signal conductor line was based on DuPont’s silver 6158 paste. Typical design topology of conductor line has 300 µm width with pads for soldering.

3) Drying
Drying was done in a box oven at 120 °C for 5 minutes.

4) Stocking Multilayer Modules
Thickness of the fired samples which varied from 0.8 mm (4 layers) to 2.0 mm (10 layers) depend on the number of layers. After firing the thickness is reduced to 0.140 µm (15% shrinkage).

5) Vacuum Sealing in a Plastic Bag
Vacuum sealing in a plastic bag was done to prevent LTCC modules against the pressing medium (water).

6) Isostatic Lamination
Isostatic lamination was performed for 10 minutes by standard presses 20.7 MPa at 70°C, at isostatic laminator. Isostatic lamination gives very good preconditions for 3-D formed devices or for 3-D formed sensors on the base of homogeneous lamination.

7) Flex LTCC Multilayer Modules
Flex LTCC multilayer modules was done using the special shaping tools at the angle of 20°, 40°, 60°, 80°, and 90°. The samples have been bent at an external and at an internal angle by using a shaping tool (Figs. 1, 2).

Fig. 1. External and internal shaping tools and example of bent samples under various angles.

Fig. 2. (a) Bent laminate with micro crack in position of maximum bent angle (60° and over), (b) Ideal bent laminate - bend under 20° bent angle and 40° bent angle, and (c) Bent multilayer laminates.

Failure process should then cause interruption of the conductor thick film lines. Formation of micro-cracks depends on the degree of bent angle and the number of layers.

8) Re-lamination Process
Re-lamination process was done under the same conditions as mentioned before and bending of the unfired laminate with the goal to adapt it to the shaping tools and to realize a functional shape of multilayer ceramic.

9) Sintering Process
Sintering process was realized by cofiring profile typical for LTCC. The firing temperature for LTCC is 850 °C, substantially above the melting temperatures of high conductivity conductors. This enables the use of higher conductivity conductors such as silver or gold - a significant advantage for LTCC. The cofired process (that is, dielectric and conductor fired at the same time) reduces the number of firing steps compared to conventional thick-film technology.

10) Electrical Measurements and Tests of Mechanical Properties
For LTCC substrates, various bent angles were used from the plane module to the bent module (up to 90°).

The same tape-coated laminates were stacked together and the whole stack up were placed on top of a special bent tool and after than put into the vacuum pocket. The number of laminates and the bent angle that can be stacked depends on many factors such as type of laminates material, thickness of laminates; and the selection of angle type (external or internal). In order to achieve optimal conditions for forming of LTCC bent modules, 100 µm width silver conductors were situated in the central tapes of the sample and were processed by conventional process.

Discussed technique is suitable for formation of LTCC modules of small dimensions due to the versatility of the materials, and should be used in a variety of sensor applications. These notes summarize some of the applications that use thick film today.
III. THREE-POINT BEND TEST FOR BEND STRENGTH MEASUREMENT

Bend strength and stress concentration factors of substrates were measured in three-point bend test of a ceramic bent LTCC module, consisting of multilayer laminates. For this test, a universal test machine was used which were equipped with fixtures and adjustments to measure extraordinarily low loads and strains on this brittle LTCC modules (Fig. 3).

The bending moment $M_0$ (N.mm) is given by,
\[ M_0 = \frac{F \times l}{4} \]  
(1)
where $F$ (N) is the applied force and $l$ (mm) is the span of bent samples. Span dimension $l$ was fixed (35 mm).

Cross-section module $W_0$ (mm$^3$) was calculated from the following equation,
\[ W_0 = \frac{b \times h^2}{6} \]  
(2)
where $h$ (mm) is the thickness of samples (thickness varied according to the number of layers) and $b$ (mm) is the width of multilayer bent laminates. The sample thickness $h$ varied from 0.8 mm to 2.0 mm depend on the number of layers (i.e., from 4 to 10 layers), and $b$ was equal to 5 mm.

Using (1) and (2) the bend strength $R_0$ (MPa) was calculated as the ratio bending moment to cross-section module:
\[ R_0 = \frac{M_0}{W_0} \]  
(3)

Ultimate bend strength for flat samples cannot be derived from these tests and experimental methodology was fixed on bent modules only [4]. The samples were loaded to failure (fracture) in three point-loaded stress. The pressure strength of bent samples in the three-point bend test has shown a large scatter of obtained results. Significant difference between the results of Low Temperature 951 and 851 Cofired Green TapeTM was not remarkable. The obtained results from three-point bend tests shown in Figs. 4, and 5, give the relationship between influences of the number of layers and the bend angle of LTCC modules. There was only one case (Fig. 5) that fractured at higher stress level than 425 MPa. Several samples were affected by incorrect lamination in the fabrication process and broke before three-point bend test (at the start of measurement). Failure usually started in the core, but crack propagation was arrested on the top layer of LTCC modules.

Visual inspection of bent multilayer surface modules shows defects, which are usually not detected after typical lamination process conditions:

1) Burns are typical if fragments of excess material or foreign particles are adhering to the surface.
2) Pits or holes are characterized as a deep depressions or voids.
3) Blisters or bubble at the surface that, if broken, could form a pit or hole.
4) Scratches and score marks occur if the surfaces of shaping tools are not ideal.
5) Chips, very often as open or closed, occur along the edge or most frequently on the top of the bend. The LTCC part usually breaks off or individual LTCC layers are separated.
6) Cracks or fracture lines, without complete separation.

IV. CONCLUSIONS AND FUTURE DIRECTIONS

This research has developed an unconventional bent laminate process based on LTCC technology. The authors introduced the concept of using the bent multilayer ceramic modules in unconventionally shaped electronic devices or in the field of sensors. The new technique adds flexibility to the fabrication of three-dimensional patterns based on thick film technology. Modification of existing technological methods based on LTCC opens new ceramic device applications, for instance in a 3-D shaped multilayer modules. 3-D multi-layer devices or sensors allow special material properties and variations of technology and initiates further development of materials and technologies.

The properties of LTCC modules are suitable for advanced shaped electronic sensors. Shape flexibility of LTCC is very good, but there exist irregular distributions
of residual stresses and micro-cracks damage in highly bent multilayer ceramics as a function of thickness and bent angle. The lamination bent angles higher than 60° or the number of layers more than 6 were found to be problematic. Realized bent LTCC modules permit higher extension in good quality if the transforming process was performed under typical lamination conditions. LTCC tape is visco-elastic material and bending at higher temperature than the room temperature would have allowed flow and possibly minimized cracking.

Research is currently going on to further investigate this technique to determine the marginal mechanical conditions in bent LTCC modules, the internal multilayer conductive interconnections, and to study the signal cross talk between conductive layers. Bent modules based on LTCC are available to generate new electrical functions. These include materials and structures in the shape of bent conductors or bent multilayer dielectrics.

REFERENCES


Alena Pietriková was born in Prešov, Slovakia, in 1956. She received the M.Sc. degree in Physical metallurgy and limiting states of materials from Department of Material Science, Technical University in Košice, in 1980 and the Ph.D. degree in Material Engineering from Technical University in Košice, in 1986.

In 1980 she served as Ph.D. student at Department of Material Science, Technical University in Košice. In 1981, she joined the Department of Hybrid Microelectronics at Technical University of Košice as an Assistant Professor and was promoted to Associate Professor in 1998 after defense of habilitation lecture “Evolutionary trends of thick film materials” in the branch of Material Engineering. She is now head of the Department of Hybrid Microelectronics at Faculty of Electrical Engineering and Informatics. Her research interests include electronics materials and technologies with accent to thick materials and their application in multichip modules, in printed circuit boards and new materials and technologies applied in thick film technologies and thick film sensors.

Dr. Alena Pietriková is a member of the International Steering Committee for International Spring Seminar on Electronics Technology – ISSE, from 1999.

Stanislav Slosárčík was born in Humenné, Slovakia, in 1956. He graduated in electronics from the Slovak Technical University of Bratislava, Slovakia, in 1980. He received Ph.D. degree in radio-electronics from the Technical University of Košice, Slovakia, in 1987. Since 1982 he works firstly as Assistant Professor and than, since 1996, as Associate Professor at Department of Hybrid Microelectronics, Faculty of Electrical Engineering and Informatics, Slovakia. His research interests include electronics structures and electronics technology with accent to the thick film, sensor and LTCC technology.

Dr. Slosárčík is a member of the International Steering Committee for Microelectronics and Microsystems Technology conference, from 1999.