APPLICATION OF THICK FILMS IN LTCC TECHNOLOGY

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Abstract: Typical thick film materials are widely used in Low Temperature Cofiring Ceramics (LTCC) technology due to its low cofiring temperature. This is a great advantage of LTCC in comparison with HTCC multichip modules. Thick film materials give a possibility of making not only network of conductive paths in a package but also building other electronic elements and devices. The number of thick film materials with various electrical properties used in LTCC technology is growing. The properties of these elements are very promising. The paper gives a description of LTCC technology and thick film materials used there. The information on construction and properties of buried and surface resistors, thermistors, varistors, inductors and capacitors is given. Moreover, non-conventional application of thick film materials is presented.

Uporaba debeloplastnih materialov v LTCC tehnologiji

Ključne besede: materiali debeloplastni, LTCC tehnologije žganja keramike nizkotemperaturne, HTCC TEHNOLOGIJE žganja keramike visokotemperaturne, MCM-C moduli multichip keramika, TFM materiali debeloplastni večplastni

Izvleček: Tipične debeloplastne materiale na široko uporabljamo v LTCC (Low Temperature Cofiring Ceramics) tehnologiji zaradi nizkih temperatur žganja. To je ena od velikih prednosti LTCC tehnologije v primerjavi s HTCC multičip moduli. Dodatno debeloplastni materiali omogočajo poleg izdelave prevodnih povezav, tudi izvedbo drugih elektronskih elementov. Število debeloplastnih materialov z različnimi lastnostmi, ki jih uporabljamo v LTCC tehnologiji stalno rase. Električne lastnosti iz njih izdelanih elementov pa so zelo obetavne. V prispevku podajamo opis LTCC tehnologije, uporabo debeloplastnih materialov znotraj te tehnologije, kakor tudi informacijo o strukturi in lastnostih pokopanih in površinskih uporov, termistorjev, varistorjev, dušilk in kondenzatorjev. Dodatno opišemo še nekonvencionalno uporabo debeloplastnih materialov.

1. INTRODUCTION

Ceramic based multichip modules (MCM-C) have been used in the electronics industry for over 25 years /1/. Three ceramic based technologies are used to make MCM-C structures: Thick Film Multilayer (TFM), High Temperature Cofired Ceramic (HTCC) and Low Temperature Cofired Ceramic (LTCC) /1-4/. TFM is the oldest, and LTCC the youngest one of MCM-C. In TFM technology multilayer is processed serially – layer by layer. Each layer is printed and fired separately. In HTCC and LTCC technologies the process is carried out in a parallel way and all foils are cofired in a single step, building a multilayer structure. Materials of the foil and firing temperature are the main differences between HTCC and LTCC elements. HTCC foil consists of alumina and is fired at 1600 ÷ 1800 °C in hydrogen atmosphere. Only W and Mo can be used as conductor because of the high firing temperature. LTCC foils are made from alumina filled glasses or glass ceramic material. Typical thick film materials can be used, because foils are cofired at 850 ÷ 1000 °C.The paper presents steps of LTCC technology. The review of thick film integral passives and other elements and devices in LTCC technology is given.

2. LTCC TECHNOLOGY

Typical LTCC structure is presented in Figure 1. It consists of dielectric foils, external and internal conductors, surface and buried passive elements, thermal and

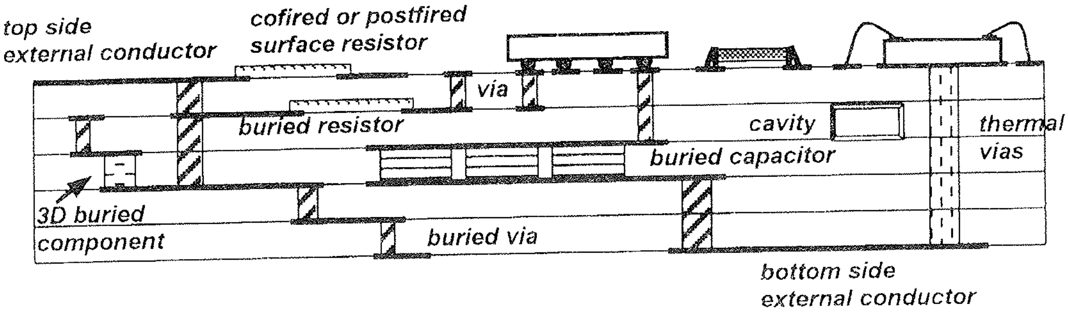

Fig. 1: Cross-section of a LTCC structure with integral passive elements

electrical conductive vias. Additional circuits and elements are added on the top of the structure using various assembling methods.

LTCC MCM-Cs have a number of advantages over HTCC structures. Because the cofiring process takes place at 850°C, typical thick film materials and processing are used. Metals of higher conductivity like gold, silver or copper replace tungsten or molybdenum. The basic LTCC ceramic foil can be modified producing dielectric materials with different electrical and physical properties. The dielectric constant can be varied in a wide range from 4 to 12000 /5/. The coefficient of thermal expansion can be adopted to match alumina, gallium arsenide, or silicon. Standard thick film conductor, resistor and capacitor materials are used in LTCC circuits as buried (2D or 3D) or surface elements. Lower mechanical strength and thermal conductivity are the main disadvantages of LTCC, in comparison with HTCC.

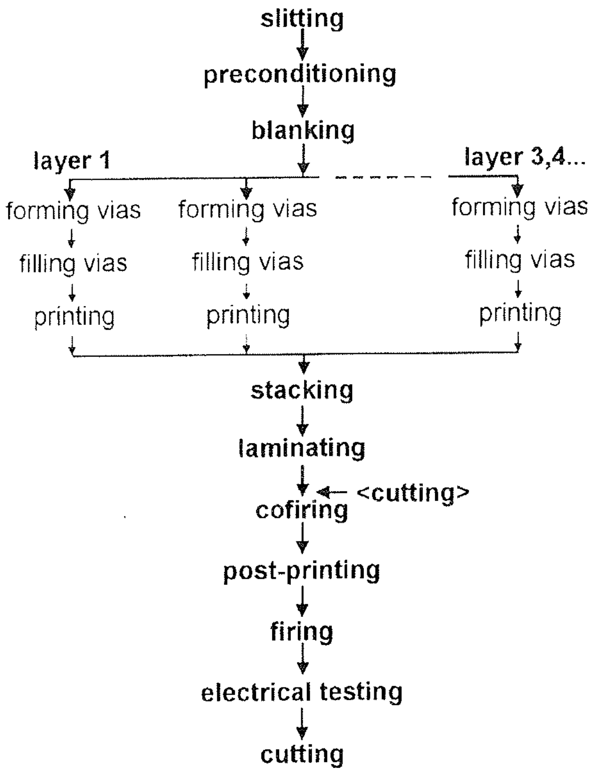

Fig. 2: Process flow diagram for LTCC

Two basic materials are used in LTCC fabrication – alumina filled glasses and glass-ceramic materials. Flow diagram of a typical LTCC process is presented in Figure 2. Tape is cast on mylar and stored in this way. After removing from the roll, the tape goes through a low temperature preconditioning bake to stabilise it. Then the tape is blanked to a specific standard size and registration holes are made. In the next step vias are formed in the individual sheets of tape by mechanical punching, drilling, laser formation or photo patterning. The vias are filled with a special via fill conductor inks (Ag or Au). The conductors and passive elements are printed by a standard screen printing method. After

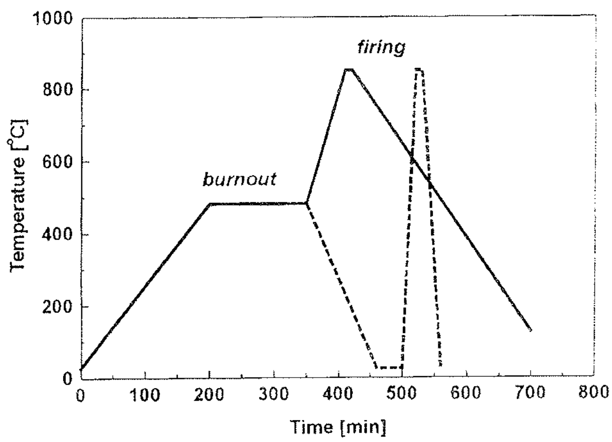

Fig. 3: Various cofiring profiles of LTCC

printing the cavities are made using automatic punch or laser. Finished sheets are stacked on a laminating plate and laminated in uniaxial or isostatic laminator. The typical laminating parameters are 200 atm at 70°C for 10 minutes. After the lamination process the structures are cofired in two steps (Figure 3). The first step, typical at around 500°C is the binder burnout step. The second, at 850°C, makes the ceramic material to densify. The firing process is carried out in one programmable oven or in two separate ovens. The second step can be made in an ordinary thick film furnace. The fired parts typically shrink 12% ±0.2 in the x- and y- directions and 17% ±2 in the z-direction. After cofiring and postfiring operations the structures are singulated using dicing saw, ultrasonic cutting, laser cutting or green tape punching /6/.Typical LTCC properties are presented in Table 1, whereas the design guidelines are given in Table 2.

The limitations of LTCC technology are shrinkage variations and poor thermal conductivity.

To eliminate shrinkage, some manufacturers have promoted a "tape-on-substrate" (called also "tape-transfer") technology /1,3,7/. Shrinkage is eliminated by laminating and firing each layer of tape on a substrate made of alumina, BeO or AlN. Sheets of dielectric tape, with performed vias, are registered and laminated to substrate at a fixed temperature and pressure. The tape adheres to the substrate and does not shrink in the x- or the y- direction. It shrinks only in the z- direction.

Another method of suppressing the lateral shrinkage for LTCC laminates of 15 layers or less is to fire the tape on suitably prepared thin metal plates of Cu-Mo-Cu /8-10/. Early in the sintering process the glass ceramic layer adheres to metal plate which totally suppresses the lateral shrinkage.

Using 0-shrinkage alumina foils on both sides of the structure allows to avoid the shrinkage of the LTCC structure. The foils are removed after the process by sunblaster methods /11,12/. The use of constrained sintering minimizes process shrinkage variability. Two methods of constrained sintering of LTCC are in use – pressure assisted constrained sintering (PAS) and

Table 1: Typical LTCC properties /1,3,6/

Material composition	Glass ceramic or alumina filled glasses
Coefficient of thermal expansion	3 ÷ 8 ppm/K
Thermal conductivity	2 ÷ 6 W/mK
Relative permittivity	4 ÷ 12 (1 MHz)
Dissipation factor	15 ÷ 30 x 10^{-4} (1 MHz)
Insulation resistance	10^{12} ÷ 10^{15} Ω cm
Breakdown voltage	800 V / 12 μm
Flexural strength	150 ÷ 250 MPa
Shrinkage z – axis x -, y – axis (tolerance)	15 ÷ 25 % 12 ÷ 16 % (±0.2 %)
Number of layers	1 ÷ 75
Thickness (fired)	95 ÷ 210 μm

Table 2: LTCC design guidelines /1,3,6/

Conductor material	inner Ag	3.3. mΩ/□ (6 μm)
	inner Au	5.0 mΩ/□ (6 μm)
	outer Ag	2.0 mΩ/□ (15 μm)
	outer PdAg	15 ÷ 40 mΩ/□ (15 μm)
	outer Au	4.0 mΩ/□ (8 μm)
	outer PtAu	80 mΩ/□ (15 μm)
	outer Cu	2.0 mΩ/□ (15 μm)
Resistor values	0.1 Ω ÷ 1MΩ	
	Standard	possible
Line width/spacing/pitch (min)	200/250/400 μm	100/100/200 μm
Via diameter/spacing/pitch	250/500/500 μm	125/300/300 μm
Via cover pad	2x via ϕ	1x via ϕ
Thermal via diameter/pitch	250/500 μm	600/1250 μm
Cavities min/max thickness	400/1500 μm	400/2500 μm
Cavities size min/max	1500/not limited μm	1000/not limited μm
Windows max depth	1000 μm	2500 μm
Windows size min/max	1000/not limited μm	500/not limited μm
Circuit size	≤5" x 5"	≤8" x 8"
Circuit thickness min	1 mm	0.4 mm

pressureless constrained sintering (PLAS) /13,14/. PAS technology was developed by Du Pont /15/ to sinter glass filled dielectric systems to full density at low temperatures (850°C), low pressure (<0.068 MPa) and short times (10 min). Firing requires sandwiching the unfired laminate between constraining die, a refractory porous plate, and a refractory porous release layer. PLAS technology does not require special tooling /11-13,16/. The laminate is sandwiched between refractory constraining tape layers on the top and bottom surfaces of the green multilayers before firing. After firing the refractory constraining the layers are removed. Shrinkage during firing for PAS and PLAS is only in the z- direction and is of the order of 41%.

LTCC's thermal conductivity of 2.0 ÷ 2.5 W/mK is a limitation to the structures dissipating many watts of power. The most common method of increasing heat transfer in the z-axis is through thermal vias /17/. Thermal vias are holes that are filled with silver or gold and are placed beneath the hot components. The thermal conductivity in the z- axis can be improved to 120 W/mK or 70 W/mK in the case of Ag and Au, respectively /18/.

Another method of spreading the heat is by the application of a thick film layer of gold on the back side or by the use of "transfer tape" method on higher conductive materials such as copper tungsten (CuW 190 W/mK) and copper-molybdenum-copper (Cu-Mo-Cu 160 W/mK) /17/. The additional weight is the disadvantage of the using of those materials.

LTCC offers the possibility of fine lines and spaces. The following methods are used to achieve better resolution:

- fine line printing through steel screens or metal masks /19,20/,
- gravure offset printing /21-23/,
- photoimageable gold and silver FODEL inks /19,24-27/,
- photo-patterning process (etching) /28,29/,
- laser patterning /30,31/.

Moreover, after cofiring thin film deposition process can be used on the outer layer. However, it is a very expensive one, and the surface of the fired tape must be extremely smooth for good adhesion /17/.

3. INTEGRAL PASSIVES

Integral passives are defined as functional elements either embedded or incorporated on the surface of an interconnecting substrate /32/. **Discrete passive devices** are simply a single passive element (capacitor, resistor or inductor) in a leaded or surface mount technology (SMT) case. **Arrays** are multiple passive elements of more than one function in a single SMT case /33/. It is estimated that 1 trillion resistors and capacitors were built in 1997. Of that number, 55 billion were integrated into 11 billion arrays and networks. This doubles the number from 1996. The passive components technology roadmap predicts that the number of arrays and networks will grow to 15 billion replacing 75 billion discrete components in 1999 and to 32 billion replacing 160 billion in 2000 /33/. There are four great reasons for the integration: performance, cost, reliability and size /34/. The ratio of passive devices can be greater than 20:1 in some of today's high volume applications /35/. The PC microprocessor speed increased over the last 15 years from 4 to 4000 MHz and the microprocessor voltage has dropped by about 50%. Both these trends require much more passives /36/.

LTCC offers a possibility of high scale integration of passive components in one module. The elements can be made both inside the structure (buried) and on the top (surface) as presented in Figure 1. The buried elements are formed as planar (2D) or three – dimensional (3D) inside LTCC structure /37/. The basic electrical properties of 3D resistors, thermistors or varistors are similar to the planar ones /37/. The properties of LTCC integral passives are widely investigated. The aim of the research is to improve the element performance by a better understanding of the structure of LTCC system and the electrical conduction mechanisms in the components. In the Wrocław University of Technology the research is carried out on the properties of the integral passives in a wide temperature range (-180°C ÷ 130°C) /25,37-41/. We study also the influence of high voltage pulses on thick film integral resistors /41-43/ and long term stability of various integral passives /37,41,43/. Part of the investigation has been done as a close cooperation with Ilmenau University of Technology /41/ and Dresden University of Technology /25,40,41/.

Resistors

Cofired resistors must be chemically compatible with the material of the tape. The glasses in the resistors and in the tape interact with each other influencing the sheet resistance and Temperature Coefficient of Resistance (TCR). The electrical properties of the buried and the surface resistors are presented in /25,37,39,41,43-49/. The buried resistors can be trimmed by laser through the special hole in the upper foil, or through one thin layer /43,44,46-49/. The other possibility of trimming is by the use of the high voltage pulses. In this case deeply buried resistors can be trimmed without making any hole /42,43,46-50/.

Capacitors

The capacitors can be made by the following methods /47,51-56/:

- burried interdigital electrodes on one side of a tape,
- printing capacitor electrodes on both sides of a tape,
- filling vias with high permittivity materials,
- entering high ε tape into a hole in the typical low ε tape,
- adding thin tape with high ε.

Inductors

Inductors can be made as planar or 3 dimensional ones. The planar types are preferred for the coils, which are arranged serially to other elements and 3D – coils for inductors which are connected to the ground /22,47,52,53,56-60/

Transmission lines

Two types of integral transmission lines are made in LTCC technology: buried microstrip or the stripline realised as an off center stripline /47,58/.

4. OTHER APPLICATIONS

LTCC technology is now used not only for typical MCM applications as a package with conduction lines, but also for production of sensors or devices in the military equipment, avionics, medicine, automotive industry, wireless devices etc. The main reason for such wide area of application is their high reliability, hermeticity, usability of typical thick film materials and possibility of making 3D structure with various shapes and cavities inside.

The first application of LTCC in the sensors area was reported by Bansky et al. in 1993 /61,62/. They made multilayer green tape ion extraction optic with gold layers as grid for plasma application and reflection structure improving the performance of ion sources /61/. At the same year Bansky described 3D LTCC planar Langmuir sensor structure for plasma diagnostics /62/. Another 3D green tape sensor for "in situ" plasma diagnostics was made in 1995 /63/.

Platinum heater buried inside LTCC with a possibility of simultaneous measuring the temperature for gas sensor application is described in /64-68/. The tin oxide gas sensor design and properties are presented in /19,64,67,68/, the electrochemical ones in /69-72/. Thermistor based flow sensor made on LTCC in the meso scale microelectrochemical system is shown in /73/.

The temperature sensor on LTCC made by gravure offset printing with platinum line width 75 μm on 3.5x3.5 mm structure was presented by Leppävuori /21/.

The detailed description of the cavities technology is presented in /19,63,74,75/. It is very useful for making various sensors and devices. A very interesting application of cavities are active cooling systems /19,76/.

LTCC technology allows for easy making pressure sensors where piezoresistive effect is utilised /63/. The pressure sensor for the tissue pressure application in medicine is presented in /77/, whereas pressure/vacuum sensor in /78/.

A very interesting method of increasing current carrying capacity by making special ditches filled in with conduction material is presented in /79,80/.

Production of microwave devices is a great area for LTCC application. The design and electrical properties of various kind of thick film LTCC microwave elements are presented in /30,57,58,81-84/.

5. CONCLUSION

LTCC is one of the most important among MCM technologies for the future. This technology is used not only for typical MCM applications as a package, but also for sensors or devices in the military equipment, avionics, medicine, automotive industry, and wireless devices. The main reason for a wide area of application is usability of typical thick film materials, high reliability and good hermeticity. Standard thick film conductor, resistor and capacitor materials can be used in LTCC circuits as buried (2D or 3D) or surface elements. Moreover, a great advantage of LTCC is that the basic ceramic foil can be modified giving dielectric materials with different physical properties. The coefficient of thermal expansion can be adopted to match alumina, gallium arsenide, or silicon.

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