LTCC IN MICROSYSTEMS APPLICATION

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INVITED PAPER
MIDEM 2002 CONFERENCE
09.10.02 - 11.10.02, Hotel Klub, Lipica

Key words: LTCC technology, MCM package, microsystems, sensors, activators

Abstract: Low Temperature Cofired Ceramic (LTCC) technology is used for many years as Multichip Module package. Recently LTCC found very wide area of application in microsystems thanks to very good electrical and mechanical properties, high reliability and stability as well as possibility of making three dimensional (3D) microstructures. The paper describes the new LTCC techniques developed for making microsystems. A short overview of various LTCC sensors, actuators, heating and cooling devices is given. The newest application of LTCC technology (fuel cell, microreactors, photonics and MOEMS packaging) are shortly described.

Uporaba tehnologije LTCC za izdelavo mikrosistemov

Ključne besede: tehnologija LTCC, tehnologija MCM, mikrosistemi, senzorji, aktivatorji

Izvleček: Tehnologijo LTCC (Low Temperature Cofired Ceramics) uporabljamo že mnoga leta za izdelavo MCM (Multi Chip) modulov. Zadnje čase tehnologijo LTCC uporabljamo tudi za izdelavo mikrosistemov, predvsem zaradi dobrih električnih in mehanskih lastnosti, visoke stopnje zanesljivosti in stabilnosti ter možnosti izdelave tridimenzionalnih (3D) mikrostruktur. V prispevku obravnavamo novo LTCC tehnologijo za izdelavo mikrosistemov. Podamo kratek pregled LTCC senzorjev, aktuatorjev ter grelnih in hladilnih komponent. Opišemo tudi nekatere najnovejše uporabe te tehnologije za izdelavo gorilnih celic, mikroreaktorjev, fotonike in MOEMS ohišij.

1. INTRODUCTION

Low Temperature Cofired Ceramic (LTCC) technology is known since eighties /1-3/. LTCC modules with conduction lines were made as first ones. After some years passive integrated elements (MCIC) were added. The technology is well established both for low volume high performance application (military, space) and high volume low cost application (portable wireless, automotive) /4/. LTCC module becomes more and more sofisticated. Recently, the module consists of conduction lines, passive elements and microsystems (sensors, cavities and actuators, cooling and heating systems). Moreover, MEMS and MOEMS package modules made from LTCC ceramics are developed /2,5-7/.

The paper presents general information on typical LTCC technology. New techniques developed for making microsystems (fine line patterning, micromachining of LTCC tapes, lamination, making of cavities, holes and channels) are described. A short overview of most popular LTCC sensors and actuators application is given (gas sensors, gas and liquid flow sensor, temperature sensor pressure sensor, proximity sensor, microvalve, micropump). Moreover, the information on newest application of LTCC technology, such as fuel cell, microreactors, photonics and MOEMS packaging are given.

2. LTCC TECHNOLOGY

Typical LTCC module consists of dielectric tapes, external and internal conductors, surface and buried passive components, thermal and conductive electrical vias. Additional elements are added on the top and bottom of the module using various assembling methods. Flow diagram of a typical LTCC process is presented in Figure 1. LTCC tape is cast on Mylar and stored in this way. Two basic materials are used in the tape fabrication - alumina filled glasses and glass-ceramic materials. After removing from the role, the tape is blanked to a specific size. In the next step the registration holes, vias and cavities are made. The vias and cavities are formed by mechanical punching, drilling, laser formation or photo patterning. The vias are filled with Ag or Au conductor inks. The conductor and passive components are printed by a standard screen printing method. The conductor (Ag, Au or PdAg) and resistors (RuO_2) films are made of almost typical inks. The use of these materials is possible because of the low cofiring temperature equal to 850°C. After printing and drying the sheets are stacked on a laminating plate and laminated in an uniaxial or isostatic laminator. The typical laminating parameters are 200 bar at 70°C for 10 minutes. After laminating process the structures are cofired in two steps (Figure 2). In the first step, at around 500°C, the binder is burn out. In the second step, at 850°C, the final structure is formed. The fired parts typically shrink 12±0.2% in the x- and y- directions and 17±2% in the z- direction. After cofiring the thick film or thin films components can be made on the top and bottom surfaces and additional active or passive elements are added using various assembling methods.

The sheet resistance of Ag and Au conductor lines is equal to 2 ÷ 5 mΩ/sq. The passive elements may be placed on the top of the substrate (surface) or inside the structure (buried). The buried elements are formed as planar (2D) or three dimensional (3D) /8-13/. Schematic cross-section of 2D and 3D LTCC resistor are shown in Figure 3. To increase the final inductance LTCC integrated inductors can be fabricated as planar windings or as a multilayer structure (Figure 4) /11,14/. Capacitors are usually made of two or more plate electrodes with dielectric layer between them. High k dielectric ($BaTiO_3$ or relaxor materials) are widely used for capacitor pastes.

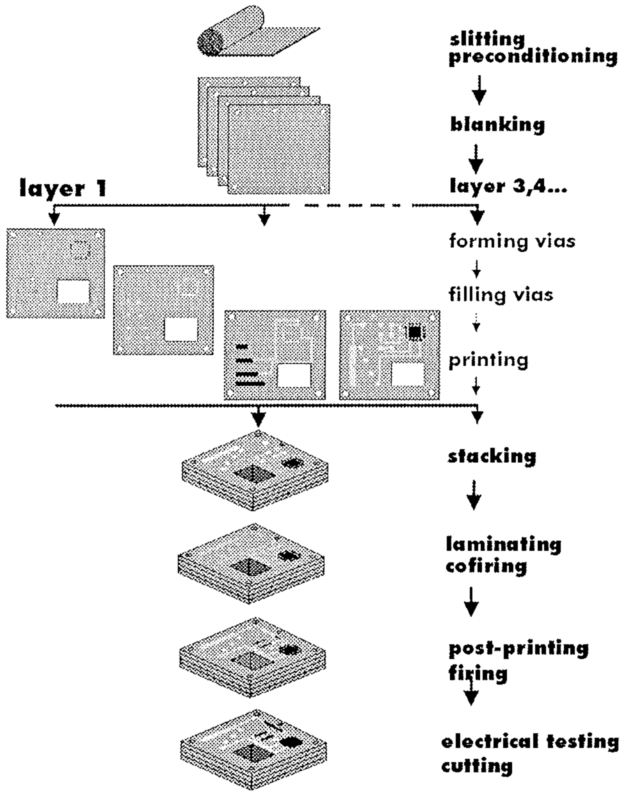

Figure 1: LTCC process flow

New materials are used for tape casting (high k, piezoelectric, piroelectric etc.) and new LTCC techniques are developed for making LTCC microsystems. These techniques are connected with the following processes:

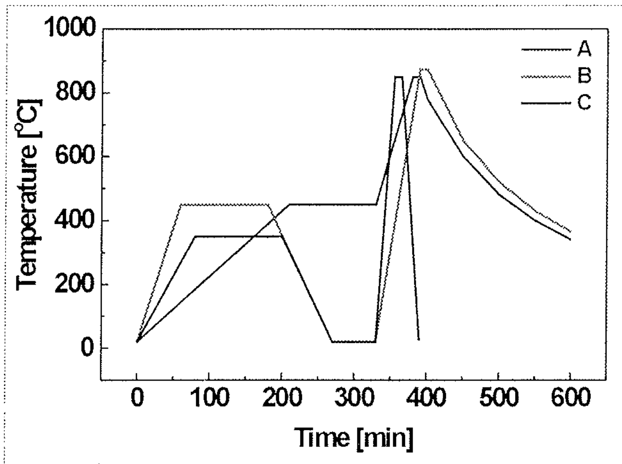

Figure 2: Cofiring profile

- fine line patterning,
- micromachining of LTCC tapes,
- lamination,
- making of cavities, holes and channels,
- bonding of LTCC tapes to other materials.

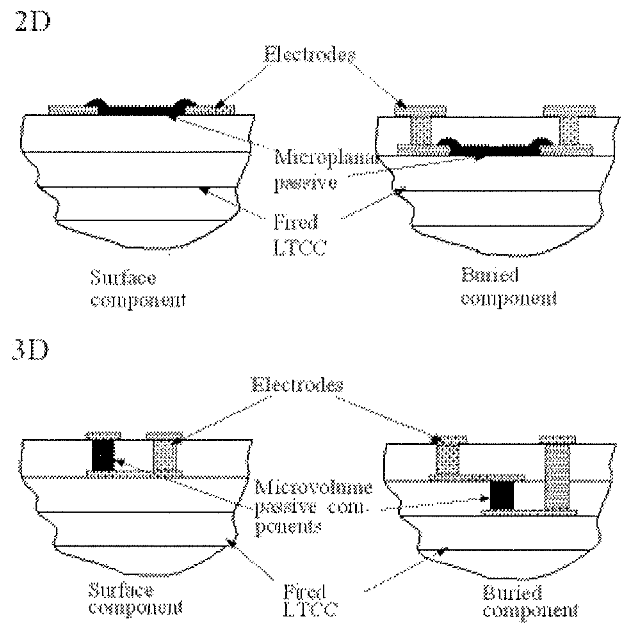

Figure 3: Schematic cross-section of 2D and 3D LTCC resistor

2.1 Fine line patterning

Narrow and precise thick film lines are very important for miniaturisation of electrical equipment and proper work condition for sensors and actuators. Various methods are used for fine line patterning:

- fine line printing,
- FODEL photosensitive pastes (etching of unfired films),

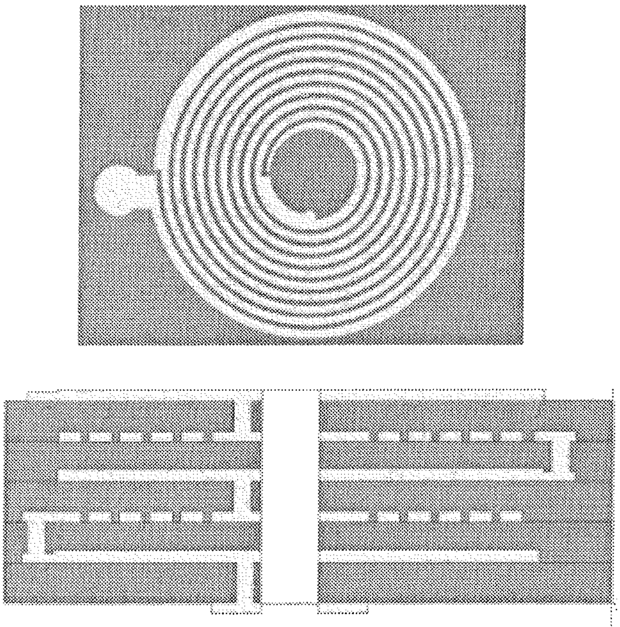

Figure 4: Top view and cross-section of five layers LTCC inductor

- photoimageable paste (etching of fired films),
- gravure printing method /15-17/,
- laser patterning.

Examples of FODEL and laser fine line patterning are shown in Figures 5 and 6.

2.2 Micromachining of LTCC tapes

Making of three dimensional structures, channels and cavities is possible due to special methods of LTCC tape micromachining. The most frequently used methods are:

- laser micromachining /19-21/,
- numerically controlled milling method /7/,
- jet vapor etching /7/,
- photolithographic patterning /7,18,22/,
- using of photoformable LTCC tapes /7,23/,
- casting /6/,
- embossing /6/.

To machine the LTCC tapes with the smallest tolerances Nd-YAG and excimer laser can be used. Computer controlled x-y movement of the workpiece produces complex shapes. Laser cut vias in LTCC tapes from various materials are shown in Figure 7. The channel in LTCC module made by laser is presented in Figure 8.

a)

b)

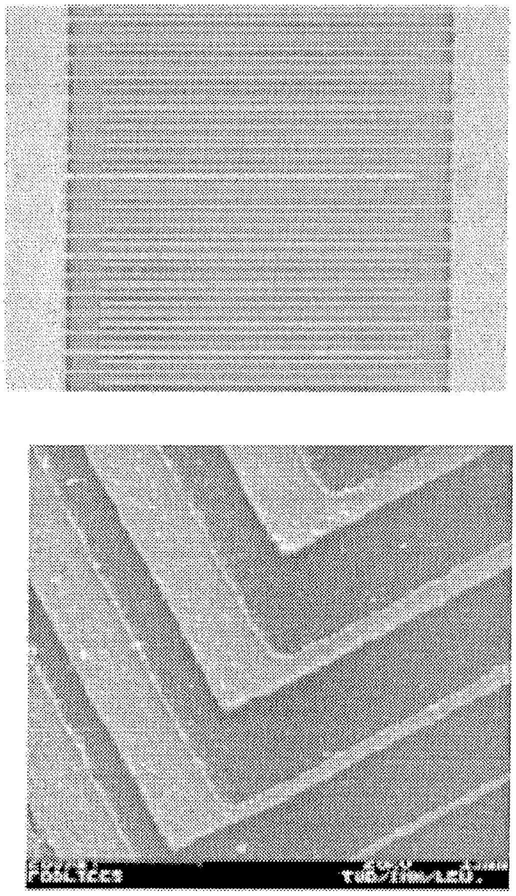

Figure 5: a) Example of an capacitor pattern with 40 μm line width and space realized by the FODEL Q170P on alumina b) test pattern of FODEL Q170P on LTCC /18/

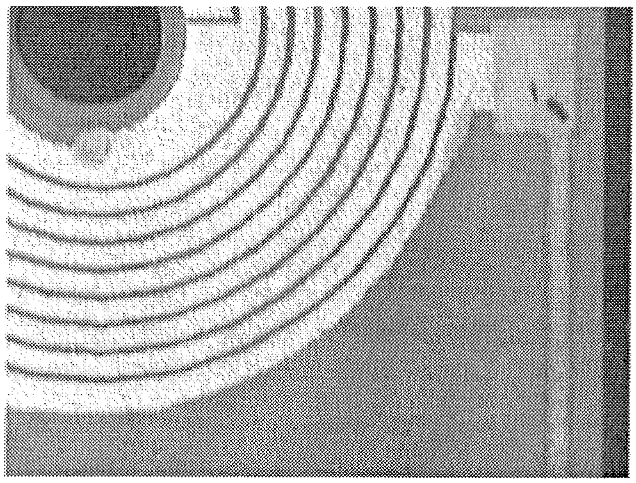

Figure 6: Fine-line laser patterned top layer inductor spirals /11/

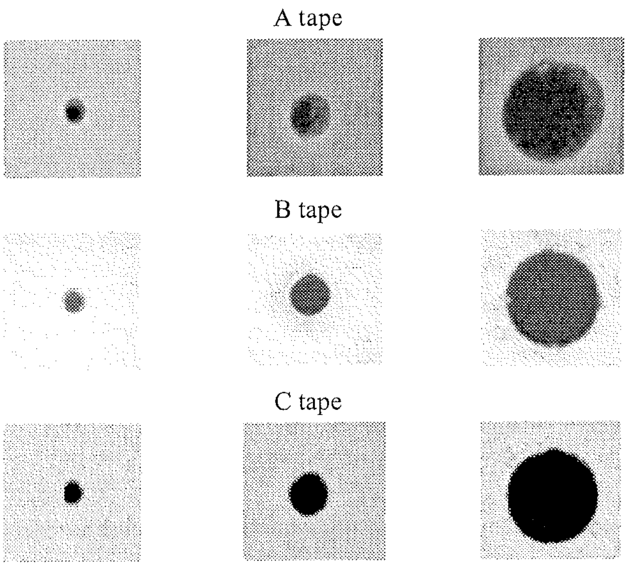

Figure 7: *Holes with 75, 150 and 300 μm nominal diameter made in various LTCC tapes by laser /21/*

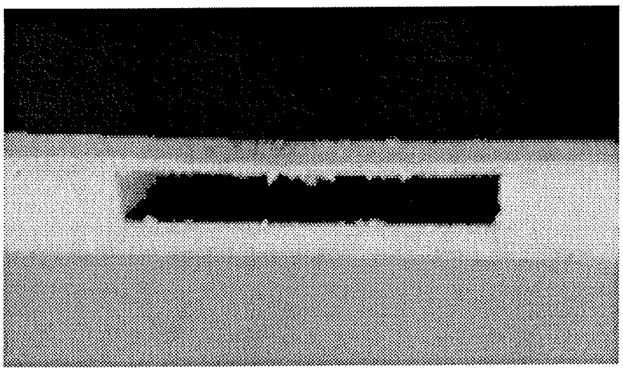

Figure 8: *LTCC structure with 2 μm wide channel cut by laser /21/*

In the processing of LTCC modules sagging of suspended structure is a problem. The plastic deformation takes place during lamination or cofiring processes /24/. Utilizing Mylar inserts or using lower lamination pressure prevent lamination deformation. Cross section of laser cut channels laminated at various pressures is shown in Figure 9. To avoid sagging during cofiring process the following methods can be used /25/:

- deposition of thick films to compensate auto-supported structures,
- use of sacrificial materials,
- use of fugitive paste,
- bonding of fired LTCC tapes

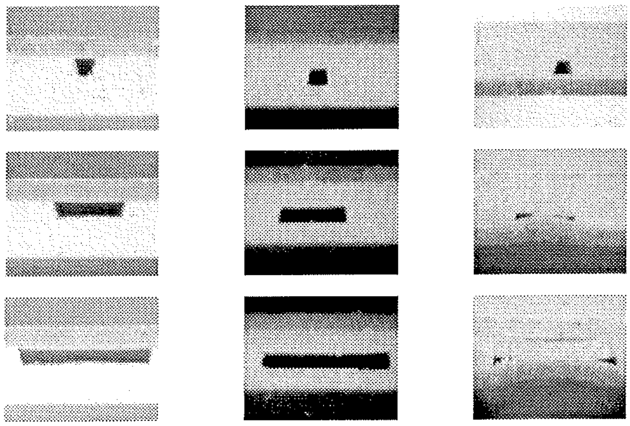

Figure 9: *Cross section of laser cut channels laminated at various pressure P (channel width 100, 500 and 1000 μm) /21/*

3. SENSOR AND ACTUATORS

Various kind of LTCC sensors and actuators are made in LTCC microsystems. The most popular ones are:

- gas sensors /26-32/,
- gas and liquid flow sensor /25,33/,
- temperature sensor /34/,
- pressure sensor /35,36/,
- proximity sensor /37/,
- microvalve /38/,
- micropump /39/.

There are two kinds of gas sensors. The first is based on tin oxide compositions. The construction of such sensor is shown in Figure 10 /40,41/. The second type of LTCC gas sensors is based on electrochemical processes /30-32/. RTDs, thermistors and thermocouples are typical LTCC temperature sensors. An example of pressure sensor with thick film piezoresistors on the LTCC membrane is shown in Figure 11. There are three main different types of LTCC microvalves: with heater and heated liquid moving the valve /38/ (Figure 12), with moving piezoelectric membrane and hybrid contained silicon membrane with magnet and LTCC coil. Magneto hydro dynamic (MHD) effect is used in LTCC liquid mixer and pump /39,42/. Another interesting application of LTCC are three-dimensional shells for miniature system /43/. Magnetostatically actuated curved LTCC shells are used in three degree of freedom spherical stepper motor.

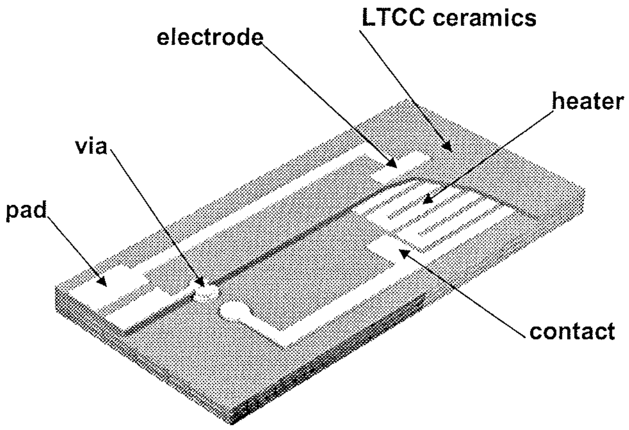

Figure 10: *Basic construction of the gas sensor /41/*

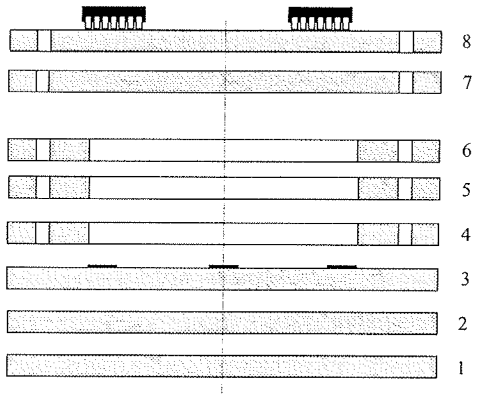

Figure 11: *Cross-section of 3D LTCC pressure sensor*

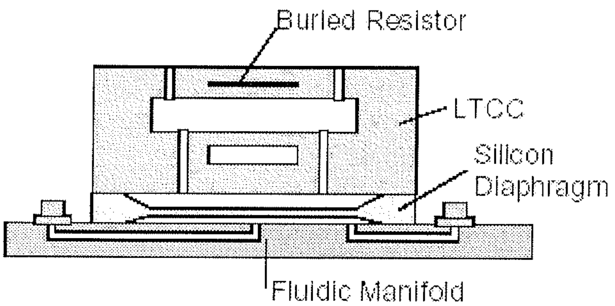

Figure 12: *Microvalve principle setup /38/*

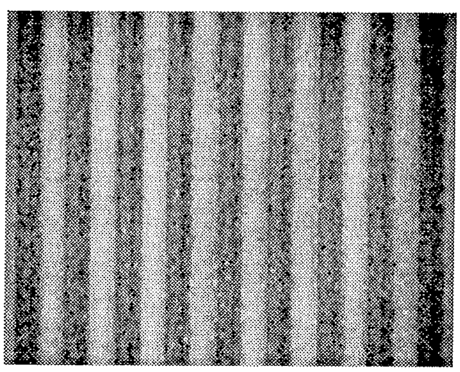

Figure 13: *Heater pattern cut by laser (line width 100 μm)*

4. HEATING AND COOLING SYSTEMS

Heating and cooling systems are very important parts of LTCC microsystems /39,44-52/. The heaters are made of typical thick film resistors or Pt-based conductors printed in the meander pattern. The second kind of heater can be used additionally for measuring the temperature. The example of LTCC platinum heater cut by laser is presented in Figure 13. Heat pipe /46/ and liquid cooling /21,48,50-52/ systems are most frequently used in LTCC cooling devices. Basic construction of LTCC liquid cooling system is shown in Figure 14. The power needed to be supplied to obtain maximum of the structure temperature equal to 80°C is given in Figure 15. The various types of cooling methods are compared in this Figure.

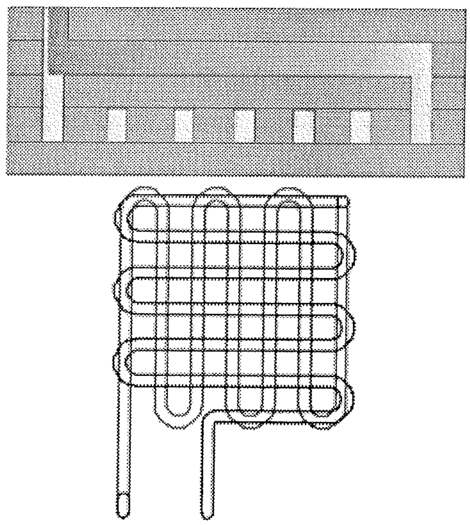

Figure 14: *Basic construction of cooling system (top - cross-section, bottom - top view of channel meander) /21/*

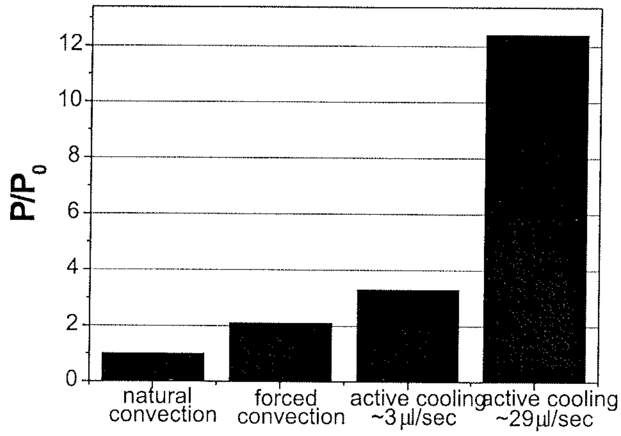

Figure 15: *Comparison of power applied to heat source (normalised to P_0) for different types of cooling methods /21/*

5. OTHER APPLICATIONS

Other important applications of LTCC are miniature fuel cell energy conversion systems, Micro Total Analysis Systems (μTAS), Fluid Injection Analysis (FIA) structures, photonic devices and MEMS packaging /5-7/.

There are two approaches for producing of the miniature methanol based fuel cell systems: direct methanol conversion (DMFC) and a micro reformer H_2 based system /6/. Development of a chemical microreactor is a key element for fuel cell microsystems.

LTCC technology can be applied to built microsystems for drug delivery, biological parameter monitoring, gas or liquid chromatographs, cooling and heat exchangers, particle separators, polymerase chain reaction (PCR) devices and micro combustion chambers /7,53/. LTCC PCR device was used for DNA amplification using an external peristaltic pump for genotyping experiments /54/.

A three stage LTCC microdischarge device, having an active length of about 0.27 mm and a cylindrical discharge channel 140-150 μm in diameter has been developed and operated in Ne gas /55/. It can be used as UV source in biomolecule assay operations where the targed molecule is fluoresced in the UV light. LTCC grid was used as a focusing electrode in field emitter arrays to obtain high brightness and small electron beam size /56/.

LTCC materials will be applied for the next generation packaging for fiber optic and electro-optic /5/. Opto-electronic systems require direct input/output of optical, RF and other sensitive signals through the package using fiber-optic, coaxial and/or other interconnection approaches. Precise optical alignment is critical to achieve performance capabilities. The opto-electronic MEMS packaging and laser alignment based on a LTCC structure are described in /57,58/.

MEMS packaging is an another very wide field of LTCC application /59-63/. The LTCC package for MEMS Si katharometer cross-section is shown in Figure 16. The package protects the katharometer against mechanical damages and allows on an easy connection of electrical signals. Moreover, the heater and temperature sensors stabilise the temperature of the element.

6. CONCLUSION

The LTCC technology meets the requirements for next generations of microsystems application due to a very good electrical and mechanical properties, high reliability and stability as well as possibility of making three dimensional (3D) microstructures. The new LTCC techniques were developed for making microsystems. A short overview of these techniques and various LTCC sensors, actuators, heating and cooling devices was given in the paper. The newest applications of LTCC technology (fuel cell, microreactors, photonics and MOEMS packaging) are very promissing.

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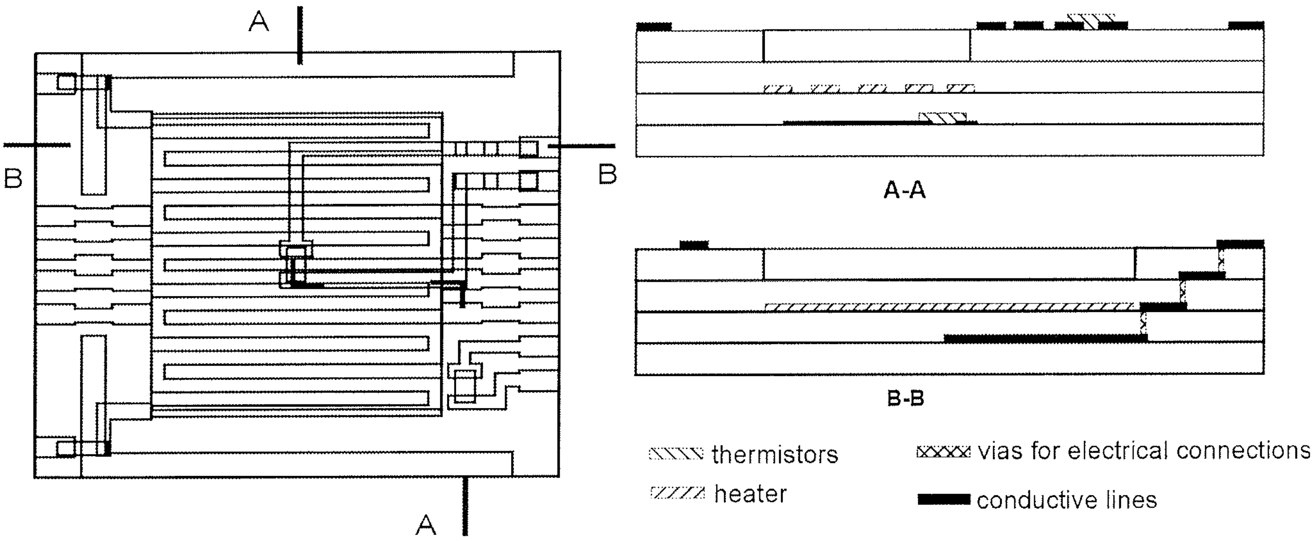

Top view of the structure

Figure 16: The LTCC package crossection

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Prispelo (Arrived): 09.10.2002 *Sprejeto (Accepted): 20.11.2002*