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Low temperature co-fired ceramics (LTCC) microsystems

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The paper presents general information on ceramic microsystems. Low temperature co-fired ceramics (LTCC) technology is described in detail. Research and development on the LTCC sensors and microsystems carried out at Wrocław University of Technology (Poland) are presented. Microfluidic system, polymerase chain reaction (PCR) microreactor, acceleration sensor and sol–gel fiber optics for ceramic microsystems are described.

Keywords: low temperature co-fired ceramics (LTCC), microsystem, polymerase chain reaction (PCR), microreactor.

1. Introduction

Ceramic microsystems play very important role at high temperature and high reliability applications. The low temperature co-fired ceramics (LTCC) has been used for almost twenty years to produce a multilayer substrate for packaging integrated circuits. Recently, this technology was also applied for the production of sensors, actuators and microsystems [1, 2]. The LTCC is widely used thanks to its very good electrical and mechanical properties, high reliability and stability as well as possibility of making three dimensional (3D) integrated microstructures. The LTCC technology is well established both for low volume high performance application (military, space) and high volume low cost application (wireless communication, car industry). A great advantage of the LTCC technology is the low temperature of cofiring. It enables to use typical thick film materials as well as various electronic components, sensors, actuators, microsystems, microreactors, cooling and heating systems in one package.

LTCC sensors and microsystems investigated at the Laboratory of Thick Film Microsystems at Wrocław University of Technology are described. Microfluidic system, polymerase chain reaction (PCR) microreactor, acceleration sensor and sol–gel fiber optics for ceramic microsystems are presented.

2. LTCC technology

The starting point in the LTCC technology is a green ceramic tape produced by a tape casting method. Using materials with different electrical and physical properties can modify the properties of the ceramic tape. A typical LTCC module consists of ceramic tapes, connecting vias, external and internal conductors and passive components. The conductor and passive components are deposited by a screen printing method, which is typical of thick film technology. After printing the cavities are made using an automatic punch or laser. Finished sheets are stacked together and laminated. Then the structures are co-fired at 850 °C. Thick or thin film components can be made on both sides of the fired module. Additional active or passive components are added using various assembling methods to the top or bottom part of the fired structure.

New materials and special LTCC techniques are developed for making LTCC microsystems. These techniques include fine line patterning, micromachining of LTCC tapes, special methods of lamination, making cavities, holes and channels and bonding of LTCC tapes to other materials.

3. Microfluidic system

Microfluidic system is a device which has characteristic dimensions in range from single millimetres to hundreds nanometers. Thanks to that, the microfluidic systems are capable to handle liquid and/or gas samples in micro- or nanoliter volume range [3]. In comparison with classical laboratory equipment the microfluidic systems are cheaper, smaller, safer (*e.g.*, in case of work with toxic or poisonous substances). Moreover, they produce less waste and are fully automated and portable. Because of these advantages, the microfluidic systems have found practical application in analytical chemistry, biology, medicine and environment protection. Nowadays microfluidic devices are fabricated using different microengineering techniques. The LTCC and related technologies are almost ideal for manufacturing of various microfluidic systems [1] because of their inherent features: chemical inactivity, chemical resistance, biocompatibility, hermeticity, ease of three-dimensional structur-

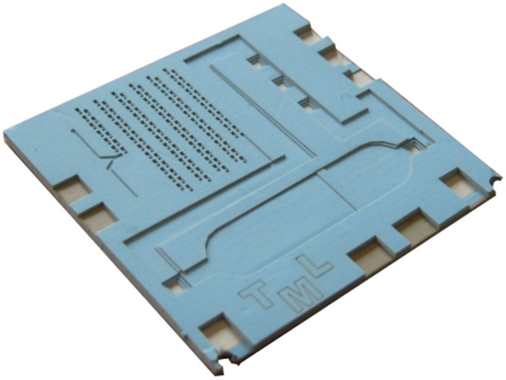

Fig. 1. LTCC-based microfluidic system.

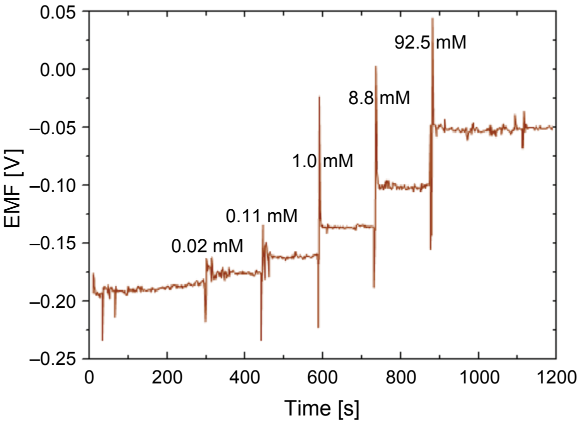

Fig. 2. Dynamic response of the LTCC-based microfluidic system.

ation and matching of coefficient of thermal expansion with silicon. The exemplary LTCC-based microfluidic system developed at the Faculty of Microsystem Electronics and Photonics of Wrocław University of Technology is presented in Fig. 1.

It consists of a high-efficiency serpentine micromixer [4], enzymatic microreactor [5] and array of ISE (ion selective electrode). Presented device is applied for determination of urea in biological fluids. The batch in a form of porous glass beads with immobilized enzyme (urease) is placed in a larger compartment of the microreactor. Urea hydrolyzes in the presence of urease. One of the reaction products is an ammonium ion. Hence, concentration of the ammonium ions can be an indirect measure of the urea in the sample. ISE electrodes using a potentiometric method measure the concentration. The dynamic response of the microfluidic system is presented in Fig. 2.

4. PCR microreactor

The PCR (polymerase chain reaction) technique is a basic tool for molecular biology scientists. A fragment of DNA (deoxyribonucleic acid) can by selected and amplified in the process. A PCR mixture is a complex solution of chemical ingredients. Thus the material of microstructure for PCR should be chosen with respect to biochemical compatibility. The LTCC is high resistant to chemicals. It enables miniaturization of the system by integration of a temperature sensor and heater with miniature structure. Many examples of microsystems for PCR made of wide range of materials were described in literature [6]. PCR compatibility tests of LTCC material were made [7]. The tests revealed that not all commercially available LTCC products were PCR--friendly. A DP951 ceramic tape was chosen [7, 8] for construction of the microreactor. Moreover, a glass optical waveguide was integrated with the structure. The microreactor enabled laser beam excitation and optical monitoring of reaction mixture. The fluorescent measurements of the PCR product inside the ceramic reactor were made [7].

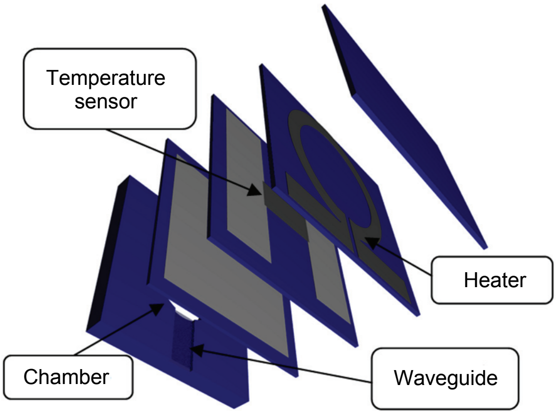

Fig. 3. Construction of LTCC PCR chamber with integrate temperature and optic elements – scheme.

A Peltier module base external temperature control system was used first [7]. Afterwards SMD (surface mount device) heater and sensor was soldered to the structure [8]. In the future buried temperature elements will be used (Fig. 3). The LTCC microreactor was successfully used for PCR process.

5. Acceleration sensor

Acceleration sensors are widely used in various fields of industry (*e.g.*, automotive, medicine, automatics) [9]. Modern miniaturized accelerometers are fabricated with microelectronic techniques. The accelerometer consists of a seismic mass fixed with a thin membrane. A membrane is clamped to a frame. Piezoelectric accelerometers enable wider measurement bandwidth in comparison with capacitor or piezoresistor ones.

The main difficulty in designing of accelerometers is compromise between a sensitivity and working band. A sensor with a round membrane is recommended to uniaxial measurements. Numerical modeling follows an accelerometer design procedure. The LTCC accelerometer consists of a thin membrane and large seismic mass fixed to the middle of the seismic mass. The lamination with sacrificial materials is necessary to ensure good lamination quality and non-deformed 3D structures.

6. Sol–gel fiber optics

One of the important parts of the LTCC microsystems are integrated optical circuits based on planar optical waveguides. It is very difficult to find a technique to produce inexpensive structures stable in time at a wide temperature range. SU8 is the most popular for planar waveguides in microelectronics devices. It is an organic material and therefore can be used only at temperatures below 150 °C. Moreover, it is not stable in time. The sol–gel method can produce planar waveguides without these disadvantages [10]. The sol–gel processing is a chemical method of production glass and ceramic materials from liquid phase. Hydrolysis and alcoholic or water

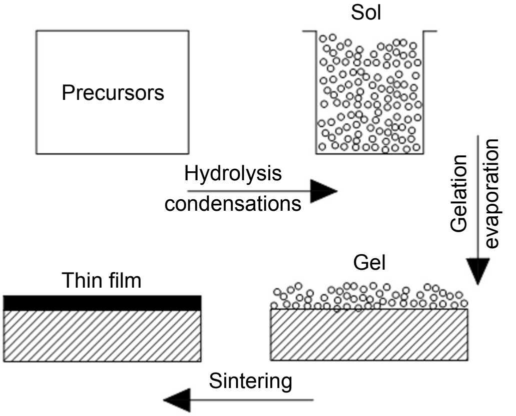

Fig. 4. Fabrication methods of sol–gel films.

condensations of metal alkoxides are main reactions proceeded in sol–gel process. Precursors of silica tetraethoxysilane (TEOS) and tetramethoxysilane (TMOS) are usually used. Dip-coating and spin-coating are most popular for thin films preparation (Fig. 4). In the process of solvent evaporation sol becomes gel. However, after gelling process the films remain porous. The last step of sol–gel technology is thermal sintering treatment of coated films. After this process pores closure is received and transparent thin films of glass with good quality are obtained.

The selection of precursors defines the properties of final structure. Thanks to doping with active elements (erbium *etc*.), it is possible to get optical amplifier. Moreover, some chemical markers could give sensor properties (*e.g.*, red phenol change attenuation versus pH value). All these features make sol–gel technique very promising as a method to produce planar optical waveguides on LTCC substrates for wide range of applications.

Planar waveguides made in sol–gel technique contain two layers of glass. First of them is clear silica material, with refractive index about 1.4. Moreover, the glass smooths the LTCC surface. The second one is made of material with higher refractive index by doping silica sol–gel with precursor of titanium or zirconium.

Apart from optical waveguides made of two layers of different sol–gel materials it also is possible to prepare them as a hybrid structure. In this case only first layer (cladding) is made of sol–gel material, while the core is produced from glaze. This solution enables to make thicker core layer that causes easier light coupling to the optic waveguide. Sol–gel planar optical waveguides on LTCC are very perspective for integrated optoelectronics devices. They allow to make many types of elements from passive to active (*e.g.*, amplifiers and sensors).

7. Conclusions

The microsystem applications of LTCC technology are very interesting. The following advantages of the LTCC ceramic are responsible for a success: high reliability and stability, possibility of making 3D microstructures with cavities and channels, high level of integration (sensors, actuators, heating, cooling, microfluidic, electronic and photonic systems in one LTCC module). The LTCC market is growing very fast because of low cost of investment, short development time, interesting properties of the ceramics and flexibility of the technology.

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