Ceramic packaging of PiezoMEMS devices

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***Abstract* — In the contribution the design and the fabrication of two different types of ceramic packaging for PiezoMEMS devices is presented. The first ceramic packaging is designed for housing the piezoelectric energy harvester. This packaging is made using LTCC technology and in the final application will integrate piezoelectric device, electronic circuit, storage capacitor and other components into the complex microsystem. The second packaging is developed for piezoelectric vibrating device as a part of water-purification system. In this case, the thick-film technology is used for electrical interconnection of piezoelectric actuators and for the hermetic watertight insulation of the system.**

Keywords* — *ceramic packaging; MEMS; piezoelectric; LTCC; thick film

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I. Introduction

PiezoMEMS device are important segment of the micro-electro-mechanical systems (MEMS) 'family'. This segment includes a number of piezoelectric vibration devices, such as resonators, energy harvesters, ultrasonic generators and detectors, microbalances, tuneable elements, pump, valves and different sensors, which are used in electronics and in different other sectors, including microsystems. In comparison to the packaging of integrated circuits (IC) the packaging of MEMS, sensors and actuators becomes more and more important. Those packaging are more complex than most standard IC packages because they require 'System-in-Package' type of assembly. The most of MEMS is used plastic, metal or ceramic packaging. Ceramic materials and ceramic technologies, including low-temperature co-fired ceramic (LTCC) and thick-film technologies, are suitable for fabrication of PiezoMEMS packaging because of their chemical inertness and thermal, mechanical and dimensional stability. Moreover, these two technologies allow also the integration of the other components (electronic components, fluidic elements, etc.) into the microsystem [1-9].

In the paper the design and the fabrication of two different types of ceramic packaging for PiezoMEMS devices is reported. The first packaging is designed for housing the piezoelectric energy harvester. This packaging is made using LTCC technology and in the final application must integrate piezoelectric device, integrated circuits, storage capacitor and other components into microsystem. The second packaging is developed for piezoelectric vibrating device as a part of water-purification system. In this case the thick-film technology is used for electrical interconnection of piezoelectric actuators and for the hermetic watertight insulation of the system.

II. LTCC PACKAGING OF PIEZOELECTRIC DEVICE FOR ENERGY HARVESTING

Packaging has high impact on PiezoMEMS device especially on mechanical parameters, which are followed by electrical, ambient, thermal and electromagnetic parameters. Therefore, the quality and stability of packaging characteristic is very important [6-9]. From this point of view the packaging of piezoelectric device for energy harvesting was designed and fabricated by LTCC technology.

PiezoMEMS device is a silicon die with 20 cantilevers. Each cantilever has a proof mass on the bottom side and piezoelectric structure on the top side. Electrodes of each piezoelectric structure are electrically interconnected with the wire-bonding pads. The total area of PiezoMEMS device is 12.2 mm × 8.2 mm, while cantilevers are 2500 μm long and 300 μm wide. PiezoMEMS device and cantilevers are schematically presented in Figure 1.

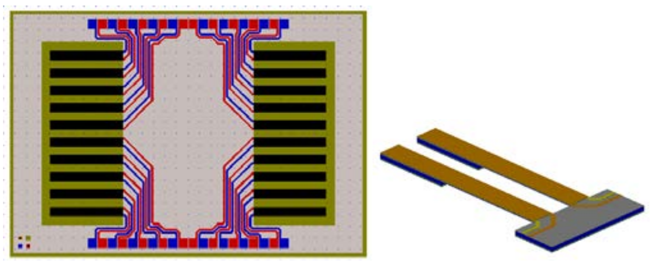

Fig. 1. Top view of the PiezoMEMS device on the left and detail of two cantilevers on the right.

The LTCC packaging of PiezoMEMS device for energy harvesting is designed as three-dimensional LTCC structure with integrated wire-bonding pads, external contact pads and electrical interconnections. In the central part the PiezoMEMS device is located. Under and above the device are cavities, which enables free vibration of the cantilevers. On the top of the LTCC structure is a flat ceramic lid made by LTCC technology. The layout of the LTCC packaging is presented in Figure 2 and schematic cross-sections A-A and B-B are shown in Figure 3.

LTCC structure is made in two parts – the ceramic lid and bottom three-dimensional ceramic structure. The lid is made by the lamination of 3 and the bottom part is made by the lamination of 14 tapes. On green LTCC tapes (thickness of 254 μm) are screen-printing Pd/Ag thick-film paste for external contact pads and Au thick-film paste for wire-bonding pads and internal electrical interconnections. After screen-printing and drying LTCC tapes are shaped by laser and then collect into the three-dimensional structure. The LTCC structure was laminated separately in two or more steps at 70°C and at a pressure of 5-20 MPa. After the final lamination, the laminates structure of green LTCC tapes was fired for 90 min at 450°C (organic binder burnout) and 20 minutes at a peak temperature of 875°C. After the assembling of PiezoMEMS device the ceramic lid is bonded onto the bottom part of the packaging using low-temperature sealing glass, which enables hermetisity of the packageing. The dimensions of the final LTCC packaging are 28.2 mm × 24.0 mm × 3.3 mm. Fabricated LTCC packaging is presented in Figure 4.

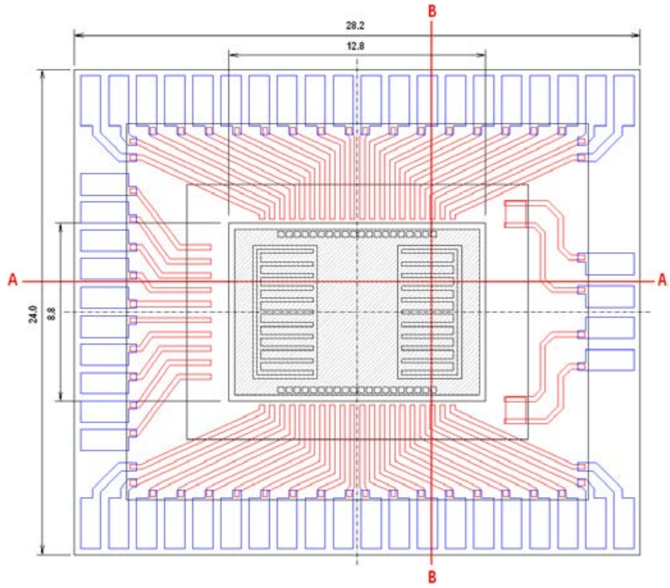

Fig. 2. Layout of LTCC packaging for PiezoMEMS device, which is located in the centre of the structure.

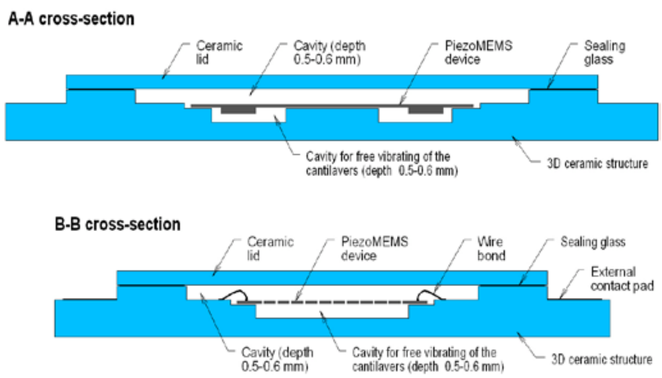

Fig. 3. A-A and B.B cross-sections of LTCC packaging for PiezoMEMS device.

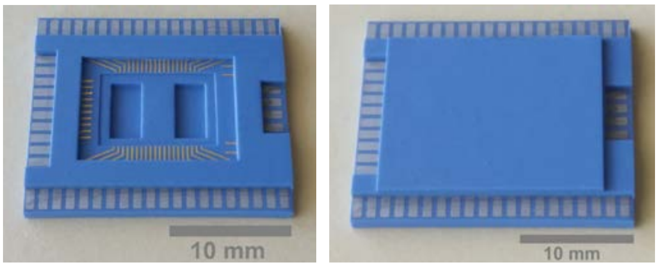

Fig. 4. Open (on the left) and close (on the right) LTCC structure for packaging of PiezoMEMS device.

III. Packaging of Piezoelectric Vibrating Device for Water-Purification

In our case, the 'hart' of the water-purification system is porous membrane [10]. Its function is filtering and in some applications chemical cleaning of the water. An additional function of the system is vibrating, which is use to clean fouled porous alumina membrane periodically and/or to improve chemical reaction in it. The vibration system, which we developed for this purpose, consists of a square 0.8 mm thick porous alumina (Al_2O_3) plate (50 mm × 50 mm) with porosity of 25% and mean pore size of 4 µm. The circularly shaped filtering area, with diameter of 40 mm, is in the middle of the plate and act as filtering membrane. The plate is semi-clamped circularly into a tube with two sealing O-rings on the border of the filtering area. The vibrations of the ceramic plate are driven using four discrete piezoelectric actuators. Those actuators are located outside the filtering area, i.e., in the each corner of the plate, and they are electrically interconnected with thick-film conductors. The system is schematically presented in Figure 5.

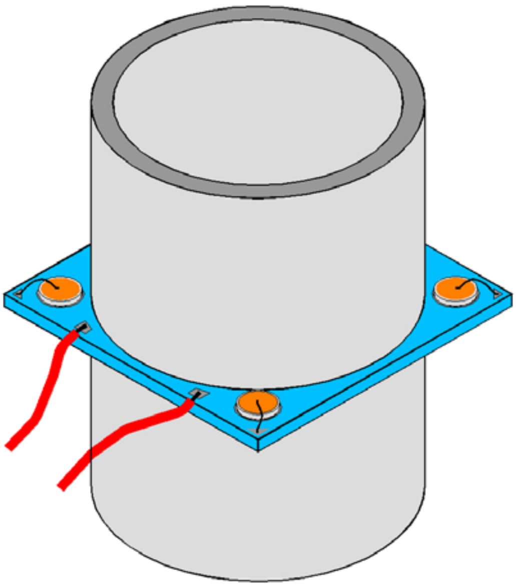

Fig. 5. Schematic presentation of ceramic membrane (with integrated actuators) mounted in the tube.

The piezoelectric actuators with gold electrodes have to be connected to the electric driving voltage. This electrical interconnection includes conductive lines and pads and hermetic isolating protection to avoid its contact with media (water). All these materials were deposited by screen-printing technology on porous flat ceramic plate. For this purpose we used Pd/Ag conductive thick-film material (QM21 Du Pont) for fabrication both conductive lines and pads and dielectric thick-film materials (QM42 Du Pont) as a hermetic layer for watertight protection.

The entire region of the membrane excluding the filtering area was screen-printed by QM 42 thick-film paste, which is a ceramic-glass composite. Three passes were performed and each individual pass was fired in a box furnace at 850 °C for 10 minutes with a heating and a cooling rate of 10 °C/min in air. This protective layer was deposited on top- and bottom-surfaces of the plates. Than the conductor lines for electrical interconnections were screen-printed and fired at 850 °C. Onto this structure, the top protective layer was screen printed and fired. Finally, all four edges of the porous alumina plate are covered with the same thick-film paste QM42 and fired at 850 °C. The scanning-electron microscopy (SEM) image of the cross-section of the structure is shown in Figure 6.

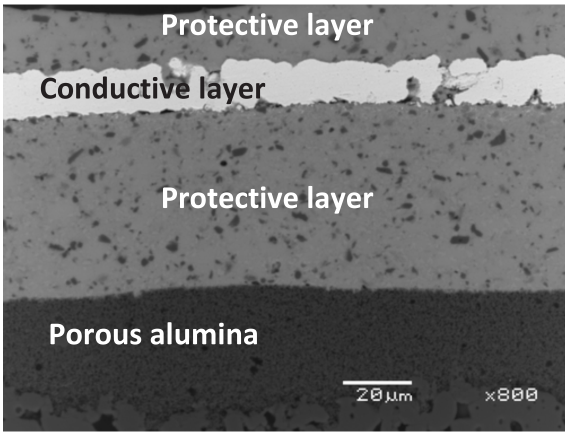

Fig. 6. SEM image (cross-section) of the protective and conductive layers on the porouse alumina plate.

Preliminary testing of protective layer on porous alumina confirmed that the filtering media, i.e., water, can propagate through the porous alumina, but it does not penetrate through the protective layer. This shows that all the conductors and actuators are protected from the filtering media.

Piezoelectric actuators are bulk piezoelectric disks with gold electrodes on both sides. Actuators are attached to the substrate directly on the conductive pad with a conductive adhesive. This bond has two functions. The first is electrical connection to the bottom electrode and the second is mechanical fixation of actuator on the substrate. This fixation must be "strong" enough to transfer vibration from actuators to the substrates and must be stable through the exploitation time (life time of the system). The top electrode of the actuator is electrical connected with conductive pad on the substrate by gluing of the thin wire. The porous membrane with protective layer, electrical interconnection and assembled actuators is shown in Figure 7.

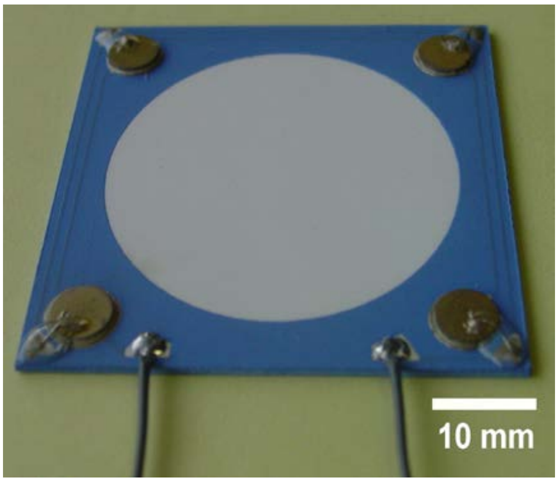

Fig. 7. Porous membrane with protective layer, electrical interconnection and assembled actuators.

The assembling (fixing) of the membrane with actuators into the system (Figure 5) is one of the key procedure for effective vibrating function of the system. The concept of circular semi-clamped fixation with two soft silicone O-rings has following advantages:

- makes possible to locate the actuators outside the filtering area;
- minimal damping of the vibrations because of the fixation;
- circular shape of the membrane allows higher operating pressure comparison to other forms, e.g. square shape;
- hermetic sealing of the filtering area.

IV. Conclusions

In this work, we demonstrated two types of ceramic packaging of piezoelectric MEMS devices. The first is LTCC-based ceramic packaging of piezoelectric MEMS device for energy harvesting application. In this case piezoelectric MEMS device convert mechanical energy (moving and vibrating) into the electrical. Ceramic packaging made by LTCC technology is not only mechanical and environment protection, but also enables effective mechanical, i.e. vibration, transfer because mechanical and dimensional stability of the LTCC-based packaging.

The second demonstrator is thick-film packaging of piezoelectric device, which is a part of water-purification system. In this case, piezoelectric device act as an actuator to generate vibration of porous ceramic plate. Packaging made by thick-film technology enables quality and low-cost watertight protection over the membrane, i.e. porous ceramic plate, for very aggressive media. The system can be used for the purification of wastewater in a wide pH, temperature and concentration ranges.

Moreover, both technologies (LTCC and thick-film) allow also the embedded electrical interconnections and the integration of other components (electronic and fluidic elements, sensors, etc.) to build complex micro or macro systems.

Acknowledgment

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