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Fully Integrated Bridge-type Anemometer in LTCC-based Microfluidic Systems

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Abstract. A thick film anemometer for in situ control of the flow rate in fluidic systems was designed, manufactured and characterized. The sensor is integrated in a retention modulus consisting of Low Temperature Cofired Ceramics (LTCC). These materials allow the cost-effective realisation of fluidic microsystems with integrated electronics. The challenge of the work is to design an anemometer under the exclusive use of thick film technologies. The necessity to trim resistors causes the external use of relevant pastes. Therefore, the use inside of a closed fluidic system requires the leak of process gases and, at the same time, a maximal heat-insulating of the sensor element from the substrate. Free-standing elements necessitate the control of stress due to shrinking mismatch, TCE mismatch, density gradients and deformation during the lamination. In the presented solution, embossed flue channels prevent blow forming on a free-standing bridge. The anemometer has a linear sensor characteristic for flow rates up to 0.1 ml/min. The layout guarantees that the fluid gets only in contact with the basic ceramic material, which is compatible with a wide range of biological substances. Therefore the sensor is applicable in contact with cell fluids or PCR-reagents.

Introduction

Interest has recently been focused on Low Temperature Cofired Ceramics (LTCC) as a material for microfluidic systems on account of the excellent dielectric and thermal properties offered, and the fact that electrical and fluidic multilayer can be easily produced. The materials are conspicuous for their high chemical and thermal stability. Hybrid fluid systems are still available [1], [2], [3]. A modular fluid system for several fluid handling processes and microreactions was already represented in [4], [5]. This work is focused on the monolithically fit-in of a thick film sensor into this modular fluidic system, focused on the processing of biological reagents. Resistor thick film compositions with high temperature coefficient are commonly in use at the outside of a multilayer substrate and can contain biologically harmful substances. Therefore, the bio-compatibility has to be taken into account besides of functional aspects. The compatibility of functional pastes with the respective reagents was investigated in a previous study and found to be poor. Therefore, it was necessary to encapsulate the whole sensor into the base material, which was found to be well tolerated with the reagents. Typical thermistor compositions with a high temperature coefficient of resistance are designed for the use on outside layers and the

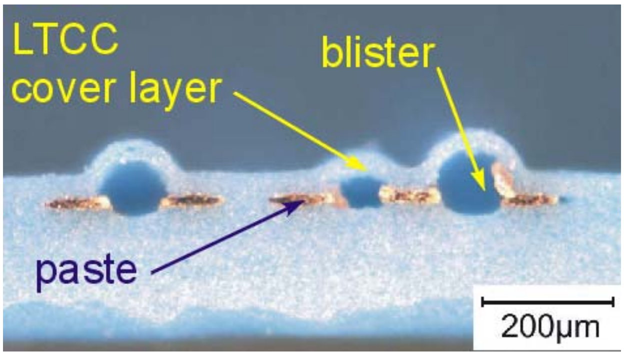


Figure 1. Blistering of cofired heater patterns on the inner layer of a stack.

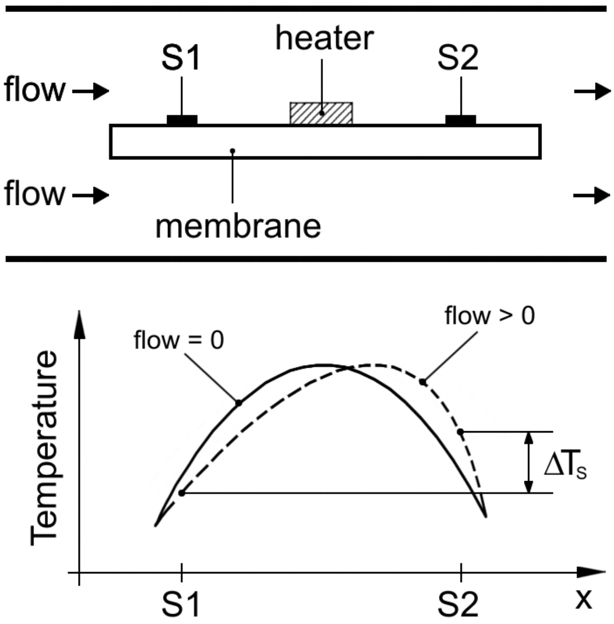


Figure 2. Functional principle of the flow sensor, S1, S2: temperature-sensitive resistances.

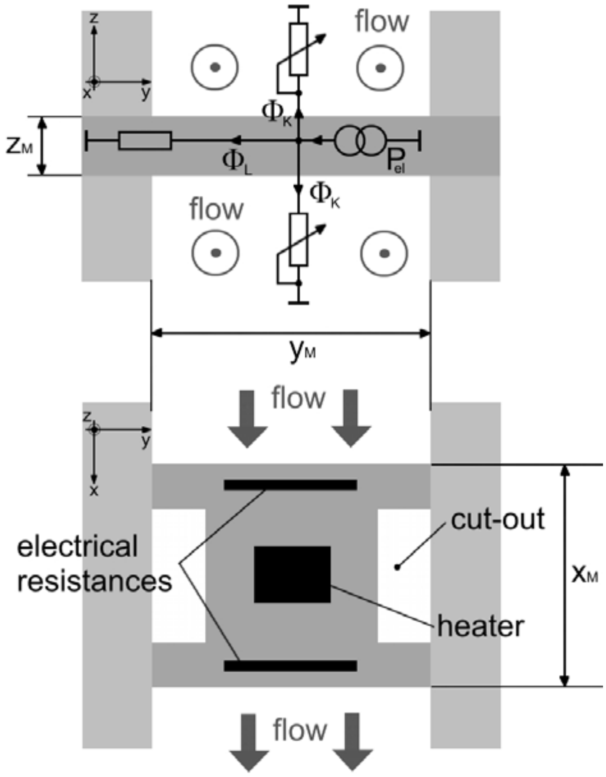


Figure 3. Thermal equivalent circuit of the sensor.

cofiring inside of a multilayer generates gases, which cause blistering, see fig. 1. Therefore it is necessary to create channels, which allow the defined escape of the process gases. The resulting challenge is to design a capsulated thick film sensor inside of a fluidic channel with a good thermal decoupling from the substrate.

Sensor design

The presented flow sensor is based on the boundary layer principle. It consists of one heating resistance between two temperature-sensitive resistances acting as temperature sensors, schematically illustrated in fig. 2. The thermal equivalent circuit diagram is depicted in fig. 3

At passive state, that means without a flow, the heater warms up the membrane and a parabolic temperature profile is formed along its surface. Critical temperatures for the organic media cause the maximum limit for the heater temperature of 80°C. In previous tests an operating voltage of 5V was identified as useful for a heater resistance of 5 Ω.

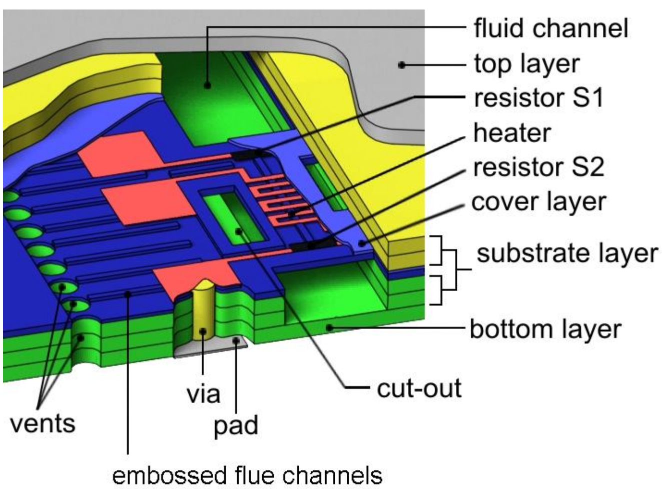


Figure 4. Sensor design with flue channels.

The first thermal resistance (S1) in flow direction measures the temperature in front of the heater and the second thermal resistance (S2) the temperature behind the heater. Because of the symmetric geometry, the temperatures at S1 and S2 are equal in the passive state. An applied flow deforms the parabolic temperature profile, which results in a temperature difference (ΔTS) between S1 and S2 which is proportional to the flow rate.

A suitable material for the heater element is the platinum conductor composition 9896. The heater element should have a resistance of 5 Ω to match the thermal requirements. A meander with a conductor width of 100 µm and a length of 5 mm heats an area of 0.77 mm².

PTC thermistor compositions have a high temperature coefficient of the resistance. The coefficient for the composition 5093D amounts to 2750 ± 250 ppm/K. The active sensor surface amounts to 0.2 x 0.2 mm² and has a resistance of 1 kΩ and a temperature resolution of 2.75 Ω/K between 20°C and 80°C. The distance between heater and sensor amounts to 500 µm and determines the temperature profile dependent on the mass flow. A schematic view of the sensor is depicted in fig. 4.

Technological approach

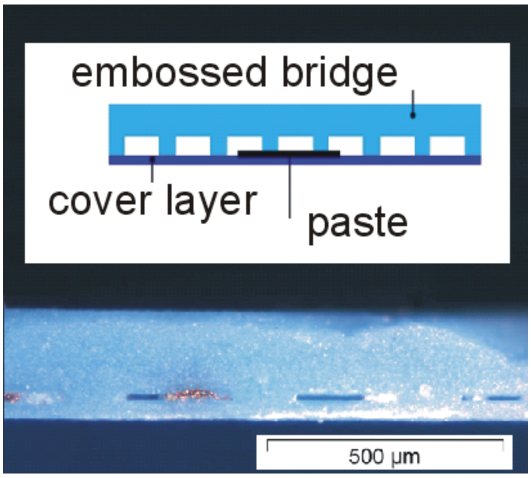


Figure 5. Encapsulated paste patterns with embossed flue channels, no blistering.

In a standard procedure, the bottom and the top part are prepared with electrical wiring, fluidic and vent channels.

The sensitivity of the flow sensor depends on the temperature resolution of the temperature-sensitive electrical resistances (S1 and S2) and the cross section of the thermal bridge to the substrate. Thermal conduction into the substrate and the thermal capacity of the measuring element decisively determine the response time and power consumption of the sensor and must be minimized. Therefore, the thickness of the bridge and the cross section of the hanging should be small as possible. Fine channels can be embossed into LTCC single layers [SSI 07]. In a previous test was proved, that those are useful as flue patterns. Fig. 5 shows the result. No blister formation was observed. Hence the method is suitable to form flue channels inside of the sensor bridge. This channels are embossed with a 50 µm deep silicon tool into one layer of 951 with a thickness of 113 µm. Heater and sensor elements are screen printed on one layer of 951 with a thickness of 50 µm and laminated on the embossed layer with a pressure of 4 MPa. This prepared sensor / heater sheet is laser cut to minimize the cross section of the bridge hanging.

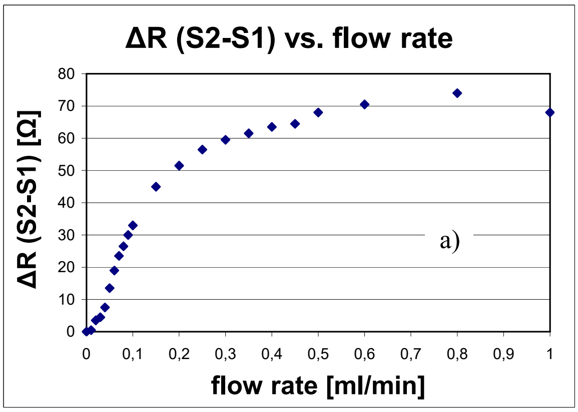
Sequential lamination is required to avoid sagging of the free standing LTCC-bridge. Using this method, the compression state of the prepared parts balances the stress generated because of shrink and TCE mismatch between paste and tape. Bottom and the top sheet are laminated under a lower pressure than the of the bridge sheet. During the sintering in a furnace at a peak temperature of 850°C therefore the bridge sheets shrinks less and deformations due to embossed channels and the printed pattern on it are compensated.

Sensor characterization

The large tolerance range for thick film resistances of 20 % causes the necessity to trim the components. For sensor elements inside of a channel system this is not possible, therefore the temperature characteristic of each measuring elements must be determined and the dependence on the flow rate has to be calibrated.

The temperature characteristic for both sensor elements S1 and S2 were measured in a temperature controlled oil bath between 20°C and 80°C.

Afterwards, each sensor has been calibrated under the use of a precision analytical pump with water at room temperature (22°C). A constant heating voltage of 5V was applied to the heater element and the resistances S1 and S2 were measured. Flow rates from 0.02 to 10 ml/min were forced with high accuracy and the respective resistance difference S1 - S2 was monitored. The resulting graph is shown in fig. 5a. Under the use of the data from the temperature calibration, the



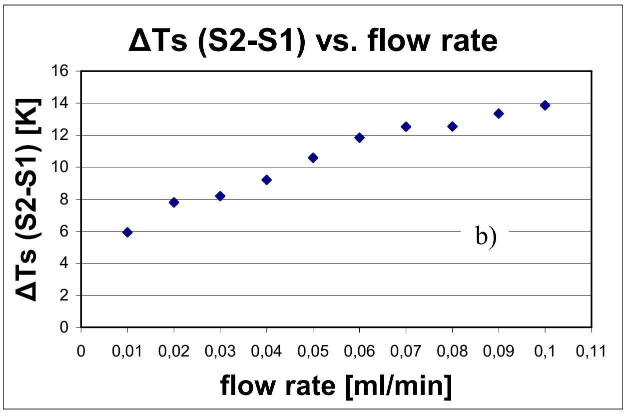


Figure 6. Sensor characteristics as a function of the applied flow for water. a) resistance difference S1 –S2 b) temperature difference

temperature difference was calculated and the characteristic is depicted in fig. 5b. The arrangement shows a linear behaviour for flow rates up to 0.1 ml/min. An adaptation of the measuring ranges is possible through the variation of the distance between the heater and the sensor elements as well as the variation of the channel diameter. The power consumption of the tested sensor amounts to 450 mW in the passive state.

Summary

A thick film sensor is monolithically integrated into a LTCC retention module. Its encapsulated design was enabled through the use of embossed flue channels inside of a free standing bridge and allows the processing of biological substances. The implementation of the bridge into the fluid flow results in a good thermal decoupling, which leads to a small power consumption of 450 mW. A linear sensor characteristic is achieved. Beside of the presented application, the technological approach enables the guidance of two independent flows inside of one monolithic substrate and allows further applications such as heat exchangers, for example.

References

[1] M. R. Gongora-Rubio, M. Bariatto, A. Fontes, E. Wagner Simões, J. Santiago-Avilés: *LTCC Hybrid Technology Applied to Water Quality Meso Analytical System*, XVII SBMICRO 2002, 2002, Porto Alegre. Proceedings of SBMICRO 2002. Porto Alegre: 2002. p. 141-150

[2] L.J. Golonka: *Technology and applications of Low Temperature Cofired Ceramic (LTCC) based sensors and Microsystems*, Bulletin of the Polish Academy of Sciences, Technical Sciences, Vol. 54, No. 2, 2006. pp. 212-231

[3] K. A. Peterson et. al.: *Novel Microsystem Applications with New Techniques in LTCC,* CICMT 2005 - Ceramic Interconnect and Ceramic Microsystems Technology, Proceedings and Exhibitor Presentations, April 10-13, 2005, Baltimore

[4] G.A. Groß et. al.: *Mikroreaction Devices made of LTCC*, IMRET9, Potsdam, Germany, September 6-8, 2006

[5] T. Thelemann et. al.: *LTCC based fluidic components for chemical applications*, Journal of microelectronics and electronic packaging, vol. 4, no. 4, pp. 167-172, 2007

[6] M. R. Gongora-Rubio et. al.: *The Measurement And Control Of Sagging In Meso (Intermediate Scale) Electromechanical Ltcc Structures And Systems*, MRS FALL MEETING, Material Research Society Conference Proceedings. Boston, Mass, USA, 1998

[7] Bartsch et. al.: *Embossing of fluidic channels into ceramic multilayer*, Proceedings of the Smart Systems Integration Conference, Paris, France, 2007