SMD pressure and flow sensor for compressed air in LTCC technology with integrated electronics

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Abstract

We propose an SMD (surface mount device) sensor in LTCC (low-temperature co-fired ceramic) technology specially designed for standard industrial compressed air. It combines the measurement of pressure, flow, and temperature, with its integrated signal conditioning electronics. Such a sensor can be mounted on an integrated electro-fluidic platform like a standard component using surface mount technology, obviating the need for both wires and tubes.
Usually, fluidic sensors in LTCC are dedicated to one physical quantity and need external electronics. The device proposed is the fusion of two independent sensors developed previously: one measuring pressure, the other one measuring flow and temperature.

***Keywords**:* LTCC; integrated sensor; pressure; flow; temperature; SMD mounting

1. Introduction

Over the past years, the fields of sensors and microfluidics in LTCC technology have been explored, adding new possibilities to this material initially developed for high-density electronics and packaging. Research has led to the emergence of micro-heaters, flow sensors, pressure sensors, micro-reactors, fluidic mixing channels and bioreactors. However, these devices were mainly developed as stand-alone products without integrated signal amplification and conditioning, and not suited for industrial applications with surface mounting technology (SMT).
Our laboratory had previously developed different kinds of sensors in standard thick-film technology and in LTCC, aimed for the low-cost, mass production industry. For instance, a micro-flow sensor for liquids[1] was integrated in a disposable microreactor driven under LabView. An SMD pressure sensor with integrated electronics was also realized[2], followed by a flow sensor demonstrator to determine the most suitable measurement principle (calorimetric or anemometric)[2].
In this work we propose for the first time a combined SMD sensor in LTCC for measuring compressed air pressure, flow and accessorily temperature, integrating signal conditioning electronics for linearization, adjustment and (for pressure and flow) temperature compensation. The pressure measurement is based on thick-film piezoresistors mounted in Wheatstone bridge on an LTCC membrane (Fig.1 (a) to 1 (c)); the nominal range is 0…6 bars, a repeatability of 0.1%. The air flow measurement is based on the anemometric principle, with a heater resistor placed in the flow; see Fig. 1 (e). The intended range is between 0 and 100 NL/min when using a bypass (only a fraction of the total flow is measured). Finally, two thermistors upstream and downstream give the fluid temperature.
The presence of both discrete SMD components soldered on top of the sensor, and soldering pads at the bottom for the fluidic and electrical connections is made possible by the use of two soldering pastes with different melting points (lead free SnCuAg for the former, and SnPb or SnBi for the latter); cf Fig. 1 (c) and 1 (d).
The design of the currently fabricated integrated SMD sensor is described, as well as the performances and limitations of the individual former prototypes from which it originates.

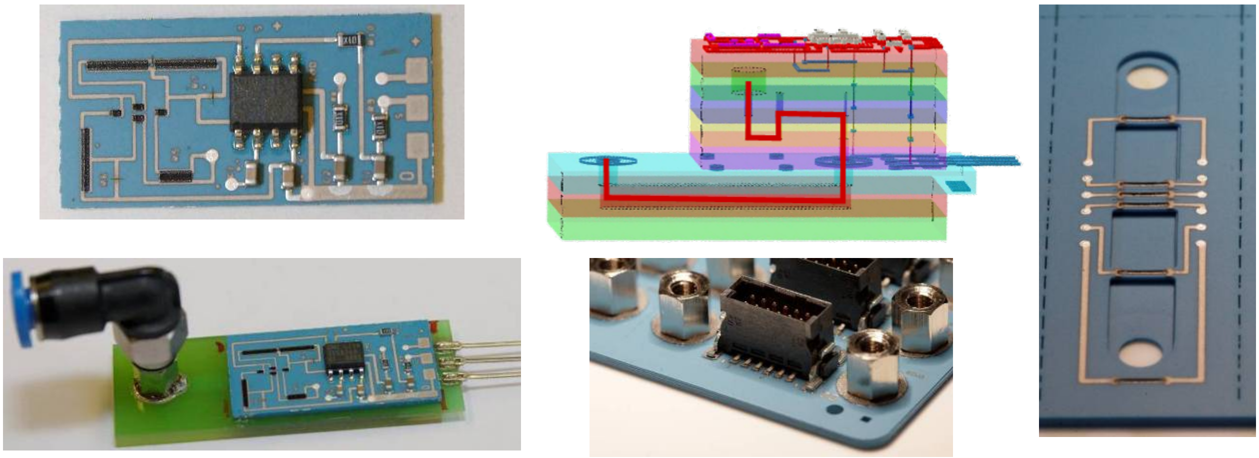

Fig. 1. (a) Left top: demonstrator of pressure sensor with its piezo-resistive bridge and amplification electronics. (b) Left bottom: demonstrator mounted on an electro-fluidic PCB, with M3 inlet. (c) Middle top: semi-transparent 3D view of the pressure sensor mounted on PCB, with the path of the air pressure between the inlet and the membrane. The fluidic channel makes a Z to minimize stress on the membrane. (d) Middle bottom: demonstrators of flow sensors in the final stage of fabrication, with fluidic fittings + electrical connector mounted on fresh paste, ready to be soldered in a reflow oven. (e) Right: flow sensors prototype voluntarily fired without lid, to demonstrate the feasibility of cofiring suspended bridges in different variants of conductor tracks and resistor shapes

2. Integrated sensor: design considerations

The sensor is currently under manufacturing, but the results will be available for the oral presentation. This chapter will then focus onto the design and the layout.

2.1. Design guidelines

The integrated sensor was designed with the following guidelines:

1. Pressure sensor principle: piezoresistors in full Wheatstone bridge on a membrane. LTCC must be able to sustain an air pressure of at least 10 bars (nominally 6), in a non-aggressive fluid.
2. Flow sensor principle: anemometric, with 1 heating thermistor suspended on a bridge in the airflow. Aimed range is between 0 and 100 NL/min with a bypass. The reaction time must not exceed 3 seconds.
3. Temperature sensor: amplification of a resistive bridge comprising thermoresistors placed toward inlets. The intended range is 0…100°C.
4. Mounting-induced stresses should not affect the sensor measurements (mainly for the pressure).
5. Device must be compatible with surface mount technology (flip chip). No external wires and no tube for connections; all connections must be at the bottom, except for test pins.
6. Electronics for processing the signals must be integrated; maximum of five electrical connections: power, the three signals (one for each physical quantity), and ground.
7. Laser trimming should be avoided, or limited to coarse pre-trimming operations.
8. The heat generated by the power transistor and the residual heat from the heating thermistor must have a minimum impact on the flow and temperature measurement -> drain heat to a bottom thermal plate.

2.2. Mechanical arrangement

Based on previous attempts[2], the tape system chosen is the *DuPont (DP) 951 GreenTape™ PX* (254 µm unfired thickness). Thinner tapes (114, 165 µm) are a possible choice for the membrane (at the expense of reliability) or for the tape supporting the resistors, but this would require more testing. The retained pastes are Ag *DP 6141* for vias, Ag:Pd *DP 6146* for tracks and pads, Ag *DP 6145* for inner ground plane, *DP 2041* (10 kΩ/□) for the piezoresistors, and *DP 5092D* for the thermistors; all will be cofired. For post-firing there will be an overglaze (organic or *ESL G-481*) on both faces, and finally lead-free 96.5Sn-3Ag-0.5Cu solder paste on top for the SMD components.

Due to the rather contradictory aspects of the fluidic functions involved, the placement of the sensing elements and the overall shape of the circuit are of capital importance. While the pressure sensor has to avoid heat and mechanical stresses, the thermal flow sensor must be at the same time insulated from external influences, and evacuate parasitic heat efficiently to the outside. Furthermore, the temperature sensor should measure the actual fluid temperature, and not the result of the flow measurement.

These considerations rapidly led to the selection of an elongated shape for the device, as depicted on Fig 2. The fluidic inlet and outlet form the outmost parts of the bottom footprint of the circuit, which isolates the pressure sensor from mounting stresses: in order to ensure the mechanical stability, all the weight and electrical connections must be concentrated between these two "feet".

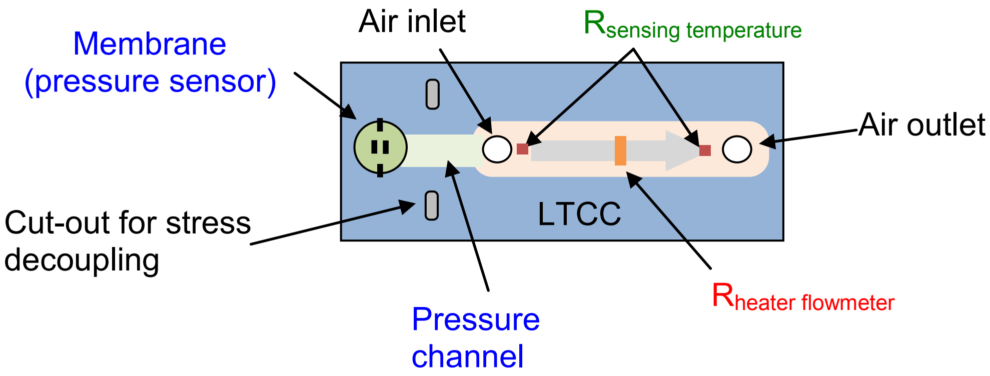

Fig. 2. Schematic top view of the integrated sensor, showing the placement of the fluidic functions and the elongated shape of the circuit.

3. Air flow sensor

On the former prototype[2], two thermal mass flow measuring principles were tested: *calorimetric* (heat diffuses faster than air flows), useful for small flows, and *anemometric* (flow goes faster than heat diffuses), better suited for high flows. In both cases, the regulation is made by maintaining the central heating resistor at constant temperature, approximately 100°C above the ambient (in practice, this is done by keeping a 30% higher resistance value, due to the TCE of 3000 ppm/K of the *DP 2041* paste). The Fig. 3 depicts the bypass and mounting on fluidic PCB.

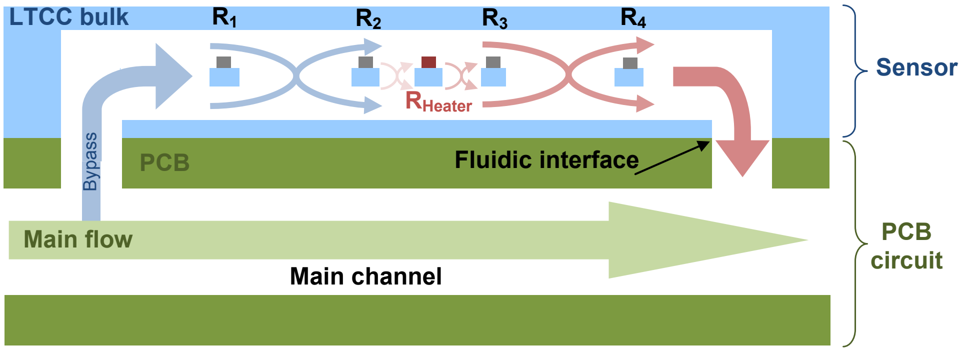

Fig. 3. Schematic view of the flow sensor demonstrator[2] mounted on a fluidic PCB, depicting the bypass and thermistors.

4. Pressure sensor

To decouple the pressure membrane from the mechanical and thermal stresses (due to soldering during assembly, heat dissipation, etc.), it is advantageous to position it in a cantilever fashion at one end of the circuit, and to place oblong cuts to create "hinges" between the pressure measuring area and the main part of the sensor.

Measurement of the demonstrator[2] of Fig. 1 (b), fitted with the *ZMD31010* signal conditioner, gave outstanding results: the repeatability of the sensor was better than 0.1%. Depending on the voltage reference employed, more testing is required to determine its absolute precision, but it is expected to be between 1 and 2% of full scale.

5. Temperature sensor

For the temperature measurement, it was decided to put two thermistors, one close to each fluidic connection to get an averaging and to be insensitive to flow inversions. This was preferred to placing one thermistor in a dead end channel, where the response time would have been greater. The second half of the *LM358* amplifier is employed for signal conditioning, with the help of SMD resistors for adjusting the gain.

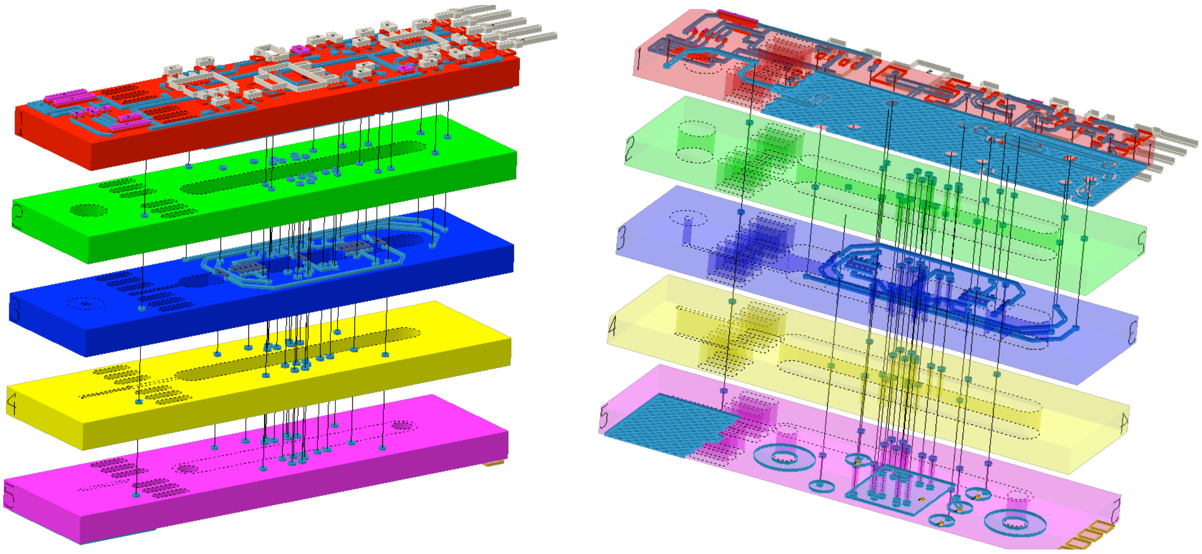

Fig. 4. (a) 3D exploded top view of the integrated sensor, showing the five LTCC tapes. (b) 3D exploded bottom view, semi-transparent.

6. Conclusion

The design of a combined LTCC fluidic sensor allowing measurement of standard industrial compressed air pressure, flow and temperature with integrated electronics and which can be mounted with standard surface mount technologies was discussed, and an elegant solution is proposed on Fig 4. The individual functions having been tested with demonstrators in previous works, we are confident that this new design will be successful. The nominal ranges of measurement are 0...6 bars, 0…100 NL/min, and 0…100°C.

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References

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