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Flexible PCB-MEMS flow sensor

Anastasios Petropoulos[a], Dimitris N. Pagonis[b], Grigoris Kaltsas[a,*]

[a]*Department of Electronics, TEI of Athens, Athens, Greece*
[b]*Department of Naval Architecture, TEI of Athens, Athens, Greece*

Abstract

A flexible gas flow sensor was developed and characterized. The sensor was fabricated on a flexible PCB substrate and is able to quantify flow rate based on the thermal transfer principle. Direct electrical communication to the macroworld is achieved, while the effective thermal isolation enhances sensor performance. Characterization in the range of 1-10 SLPM is presented.

Keywords: Flexible substrate; flow sensor

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1. Introduction

For the past decades, the academy and industry standard regarding MEMS sensors involves the use of a rigid Si wafer as the substrate material on which various structures are formed based on standard micromechanics processes [1]. A relatively recent development in the sensors/actuators field concerns the adoption of printed circuit boards (PCBs) as the substrate material on which structures are formed [2-6]. The resulting devices are often termed “PCB-MEMS” and present advantages stemming from the implementation of organic polymers as the substrate materials related to the thermal and dielectric properties they exhibit. A further advantage is the possibility for direct electrical communication to the macrowrold, as the sensor elements can be directly integrated to the metal tracks of the PCB. A current trend in the PCB industry concerns the constantly increasing use of flexible electronics. Although this is not still a totally mature field, a number of novel processes, materials and products have been presented [7-9].

In this paper we present a flexible gas flow sensor. The sensor is fabricated on a flexible PCB substrate and is able to quantify flow rate based on the thermal transfer principle. In general, the use of flexible flow sensors allows for field measurements in environments whereby a rigid sensing device

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would yield either non-accurate results, or could even perturb the measured quantity. In this context, flexible flow sensors have been used in the measuring of the flow field [10 -14].

2. Fabrication Technology

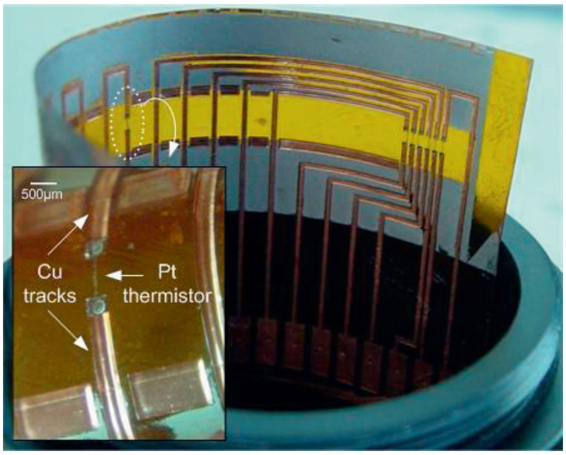

Fig. 1: Photograph of the fabricated device. It can be observed that the structure can be curved with respect to two axes of curvature. In the inset, a Pt resistor which acts both as the heater and sensing element is shown.

The fabrication technology of the presented thermal sensor is described in detail elsewhere [15], and it essentially presents a targeted advance of a well-established technology by our group which allows the direct integration of thermal sensors on rigid PCBs [16]. When using the Kapton foil instead of the common rigid FR4 substrate significant performance enhancement arises. As previously stated, Kapton exhibits a lower thermal conductivity value compared to FR4 (0.15 instead of 0.2 mW/K) and also is significantly thinner (100μm compared to at least 1mm). The reduced heat dissipation to the substrate in static conditions was experimentally verified in [15], whereby it was found that the temperature increase of a resistor fabricated on the flexible substrate was 77% higher than that of a corresponding resistor fabricated on a regular PCB, referring to the same applied power values.

3. Device Operation – Measurement Setup

The sensor operation is based on the hot-wire principle, whereby the cooling of a heater resistor is monitored as a function of the flow within the tube. A cylindrical flow tube itself (CT) was formulated by implementing the very same Kapton sheet that constitutes the substrate material on which the sensor has been integrated. As shown in Fig 2, the Kapton sheet is folded so that the surface incorporating the sensor remains in the inner side of the formed cylinder. The sensor was evaluated under nitrogen flow rate. Within the formatted tube, the flowing gas comes in contact with the sensor, which has been adapted to the CT curvature. The CT ends are accurately adjusted at two rigid pipes, the inner radius of which defines the radius of the flow field circular crossection. The electrical connection of the device to the measuring setup is made at the terminal ends of the copper lines, which remain free standing as

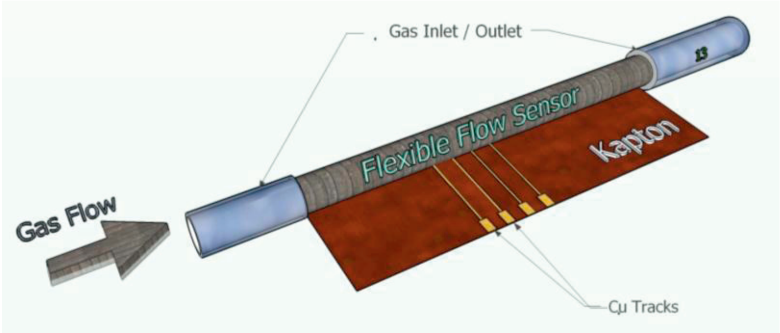

Fig 2: A schematic representation of the measuring method. The flexible sensor is folded in such a way that it forms the tube wherein the gas flows. The Cu pads lie outside the formed tube.

they are detached from the main cylinder body. The terminating edges of the Kapton substrate are hermetically sealed by implementing a special double sided sealing tape. For the purposes of the specific evaluation experiments, the designated tube radius was 6mm yielding a crossection surface of 113mm^2.

4. Results - Discussion

In Fig. 3 the sensor calibration curve in the range of 0-10 SLPM is shown, for the two distinct current values of I_1=40mA and I_2=60mA. The sensor signal in this case is defined as the normalized resistance change $\Delta R/R_o$ where $\Delta R = R - R_0$, R is the resistance value of the heating element and R_o is the resistance value at zero flow. It can be shown that $\Delta R/R_o$ is directly proportional to the element temperature change:

$$\frac{\Delta R}{R_o} = \alpha_T \Delta T \qquad (1)$$

Expressing the sensor signal in terms of the normalized resistance and the corresponding temperature change, offers a more global perspective as it allows the comparison of data coming from different measurements and potentially from different devices.

The results concerning the sensor calibration curve are depicted in this manner. In the left y-axis the normalized resistance change is shown as a function of the flow rate, while the right y-axis depicts the corresponding temperature change. As expected, higher operating current implies a greater amount of thermal energy generated at the heater vicinity, with a subsequent gain on device sensitivity.

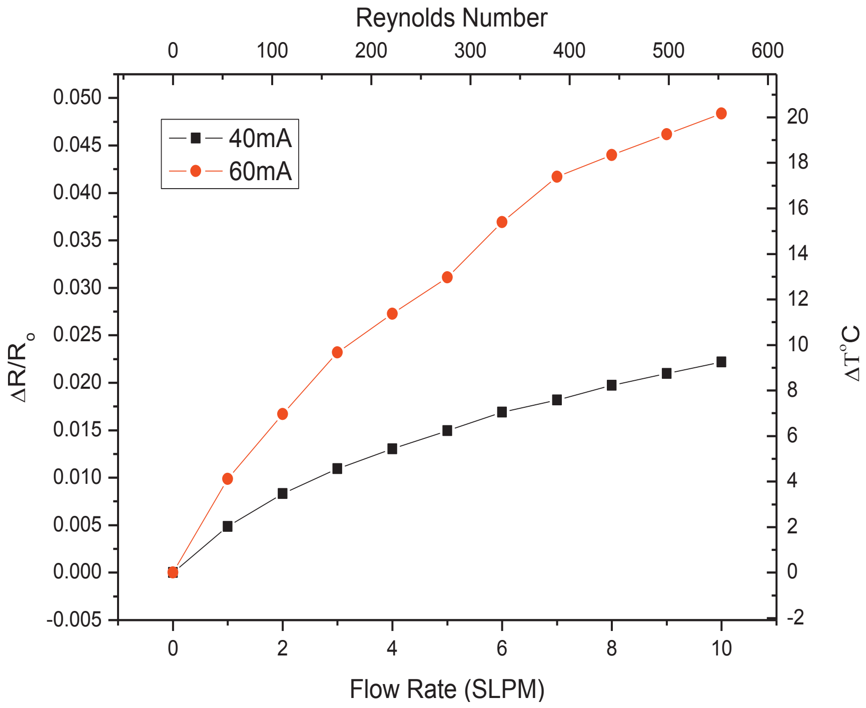

Fig. 3: The sensor signal as a function of the flow rate for heater operating currents of 40mA and 60mA

5. Conclusions

Overall, a flexible thermal sensor for the measuring of gas flow was presented. The device is the advanced prototype of a fabrication technology which allows the direct integration of MEMS sensors on printed circuit boards. The flow sensor is a result of a relatively simple fabrication process, with low equipment needs. The electrical communication of the heating/sensing element to the Cu macropads is obtained in a direct manner, this way eliminating the need for wire bonding. The latter, beyond the process simplification by one stage and the increased device robustness, also allows for an obstacle-free sensor surface to the flow field, this way achieving minimally invasive measurements.

The sensor was evaluated in the 0-10 SLPM flow range under the hot-wire operating principle, for two heater current values. A high sensor sensitivity was revealed by the calibration curves, far higher than the sensitivity exhibited from the PCB-MEMS flow sensor fabricated on a rigid substrate, a fact that is attributed to the more efficient thermal isolation provided by the Kapton substrate as compared to FR4.

References

[1] Bryzek, J., Roundy, S., Bircumshaw, B., Chung, C., Castellino, K., Stetter, J.R., Vestel, M. Marvelous MEMs: Advanced IC sensors and microstructures for high volume applications (2006) IEEE Circuits and Devices Magazine, 22 (2), pp. 8-28

[2] Gassmann, S., Ibendorf, I., Pagel, L., Realization of a flow injection analysis in PCB technology (2007) Sensors and Actuators, A: Physical, 133 (1), pp. 231-235

[3] Gassmann, S., Ibendorf, I., Pagel, L., Realization of a flow injection analysis in PCB technology (2007) Sensors and Actuators, A: Physical, 133 (1), pp. 231-235

[4] Zagnoni, M., Golfarelli, A., Callegari, S., Talamelli, A., Bonora, V., Sangiorgi, E., Tartagni, M., A non-invasive capacitive sensor strip for aerodynamic pressure measurement (2005) Sensors and Actuators, A: Physical, 123-124, pp. 240-248D.

[5] Gazzola, D., Iafelice, B., Jung, E., Scarselli, E.F., Guerrieri, R. An integrated electronic meniscus sensor for measurement of evaporative flow (2008) Sensors and Actuators, A: Physical, 145-146 (1-2), pp. 194-200

[6] C. Aracil, J.M. Quero, A. Luque, J. M. Moreno, F. Perdigones, Pneumatic impulsion device for microfluidic systems, Sens. Actuators A 163 (2010) 247–254

[7] Logothetidis, S., Flexible organic electronic devices: Materials, process and applications (2008) Materials Science and Engineering B: Solid-State Materials for Advanced Technology, 152 (1-3), pp. 96-104

[8] S.Y. Xiao, L.F. Che, X.X. Li, Y.L. Wang, A novel fabrication process of MEMS devices on polyimide flexible substrates, Microelectronic Engineering 85 (2008) 452–457

[9] Su, P.-G., Wang, C.-S., Novel flexible resistive-type humidity sensor (2007) Sensors and Actuators, B: Chemical, 123 (2), pp. 1071-1076

[10] Lichtenwalner, D.J., Hydrick, A.E., Kingon, A.I., Flexible thin film temperature and strain sensor array utilizing a novel sensing concept (2007) Sensors and Actuators, A: Physical, 135 (2), pp. 593-597

[11] Abad, E., Mazzolai, B., Juarros, A., Gómez, D., Mondini, A., Sayhan, I., Krenkow, A., Becker, Th., Investigation of fabrication and encapsulation processes for a flexible tag microlab (2008) Microsystem Technologies, 14 (4-5), pp. 527-534

[12] Buchner, R., Froehner, K., Sosna, C., Benecke, W., Lang, W., Toward flexible thermoelectric flow sensors: A new technological approach (2008) Journal of Microelectromechanical Systems, 17 (5), pp. 1114-1119

[13] Tan, Z., Shikida, M., Hirota, M., Xing, Y., Sato, K., Iwasaki, T., Iriye, Y., Characteristics of on-wall in-tube flexible thermal flow sensor under radially asymmetric flow condition (2007) Sensors and Actuators, A: Physical, 138 (1), pp. 87-96

[14] Buder, U., Petz, R., Kittel, M., Nitsche, W., Obermeier, E., AeroMEMS polyimide based wall double hot-wire sensors for flow separation detection (2008) Sensors and Actuators, A: Physical, 142 (1), pp. 130-137

[15] A. Petropoulos D. Goustouridis, T. Speliotes, G. Kaltsas “Demonstration of a New Technology Which Allows Direct Sensor Integration on Flexible Substrates”, European Physical Journal - Applied Physics, 46, 12507 (2009)

[16] G. Kaltsas, A. Petropoulos, K. Tsougeni, D. N. Pagonis, T. Speliotis, E. Gogolides and A. G. Nassiopoulou, “A novel microfabrication technology on organic substrates - Application to a thermal flow sensor”, Journal of Physics: Conf. Ser. , 92 012046 (2007)