FLOW METER BASED ON MULTILAYER p⁺Si/Au THERMOPILES - PRELIMINARY EXPERIMENTAL RESULTS

D. Randjelovic, G. Kaitzis
1IKHTM - IMTM, Njegoševa 17, 11000 Belgrade, Yugoslavia
2IMEI-NCIS Demokritos, 15310 Aghia Paraskevi, Athens, Greece

Abstract - This paper presents preliminary experimental results obtained by measuring nitrogen flow with a thermal sensor, based on p⁺Si/Au thermocouples designed and fabricated in IKHTM - IMTM, Belgrade. Thermal isolation is assured using back etching of bulk silicon. The tests were performed in IMEL-NCIS "Demokritos", Athens. Comparison of the specific sensor with another gas flow sensor from IMEL using porous silicon as thermal isolation is also given. Obtained experimental results can be considered very promising since the thermal sensor was not optimised for flow measurements.

1. INTRODUCTION

During the last two decades, integrated silicon sensors based on Seebeck effect are constantly in the focus of researchers working in the field of microsensors. Some of the most important advantages compared with other types of detectors are that Seebeck effect is self-generated and there is no 1/f noise. Because of these and many other attractive properties a number of applications has been demonstrated. Some of them are listed below:

- Flowmeters [1] (applications: automobile industry (fuel consumption and injection, control of the exhaust gases), consumer industry (natural gas and water supply), chemical industry, biomedical instrumentation, air conditioning)
- IR detectors [3] (applications: thermovision (military, medicine and industry application), intrusion alarm systems, automobile industry, consumer industry (microwave ovens and toasters))
- Accelerometers [4] (applications: automobile industry (airbags and ABS), remote control systems (computer industry - 3D mouse)).

In this paper we present the design, principle of operation and the preliminary characterization of a thermal micro mechanical sensor under fluid flow.

2. TEST STRUCTURE DESIGN

Test structure was designed and fabricated in the IKHTM-IMTM facilities (see [5] for details regarding fabrication) in order to determine some parameters specific for detectors based on Seebeck effect [6]. Fig. 1 illustrates top view and the cross section of the sensor which can have three possible different applications: a) thermal converter, b) IR detector and c) flow meter.

Thermal isolation is achieved by anisotropically etching of silicon in aqueous solution of KOH (bulk silicon micromachining). Using this technique for fabrication of microelectromechanical systems (MEMS) a membrane was formed in the central part of the chip area. Thermal resistance of the structure is increased in this way and at the same time the sensitivity of the sensor is improved.

Fig. 1. Top view and cross section of the test structure with relevant dimensions (in mm).

The main elements of the test structure are [6]:

- thermopile: 44 p⁺Si/Au thermocouples connected in series
- Ni-Cr heater
- two lateral and one central p⁺Si thermistors for measuring temperatures of hot and cold junctions
- thermally and electrically isolating membrane (sputtered SiO₂, over LP CVO SiO₂)
- heat sink (in Si rim)

Total chip area is (3.6×4.8) mm², and each p⁺Si stripe has the same width equal to 30 µm. The width of gold thermocouple stripes is 20 µm. Central part of the chip is the membrane area (2.1×3.65) mm².
3. TEST STRUCTURE AS A FLOW METER AND BASIC PRINCIPLES OF OPERATION

In order to work as a flow meter, the sensor shown in Fig. 1 should be modified in such a way to obtain one thermopile at each side of the heater. Because all 44 thermocouples are connected in series it was necessary to break the gold interconnection (Fig. 2). As a result two independent thermopiles were formed.

![Diagram of Ni-Cr heater and thermopiles](Image)

**Fig. 2** Test structure adapted for flow measuring and main sensor elements.

Ni-Cr heater is driven by DC current source. Heat dissipated at Ni-Cr heater is inducing temperature gradient across the chip and output voltages of both thermopiles are the same because of symmetry. When the sensor is placed in the gas stream, "upstream" and "downstream" thermopile can be identified depending on the flow direction. The Seebeck voltage of "upstream" thermopile will decrease and that of the "downstream" thermopile will increase. This is due to the conventional heat exchange between the gas and the heater. It has been shown both theoretically and experimentally that the difference of the two thermopile signals for small flows, changes linearly with flow, and for larger flows changes linearly with the square root of the flow velocity [1]. The output signal of the upstream thermopile decreases almost linearly with flow, while that of the downstream thermopile increases at a lower rate.

4. EXPERIMENTAL RESULTS

Using the already existing experimental set-up for gas flow measurement in IMEL-NSR "Demokritos" [1], voltage difference between downstream and upstream thermopile of sensor IHMT 2-1 was measured for different flow velocities of nitrogen. The power supply and measuring instruments were controlled by PC using the software Labview. The heater was connected to a Keithley 220 current source, which provided DC current of 10 mA during all measurements. Thus, the power dissipated at the heater was 150 mW. Voltage difference between the two thermopiles was measured using a Keithley 195A Multimeter. All the flow measurements were performed under laminar flow conditions. The maximum input flow velocity was 4 m/s, which corresponded to a Reynolds number Re=1469 for the specific experimental set-up.

As can be seen from Fig. 3, obtained response is not far from linear when nitrogen flow velocities are low (0-0.4) m/s. Fig. 3 shows the difference between the downstream and upstream thermopile voltage, $V_d$ as a function of the flow velocity, $v$. The slope of the curve corresponds to the sensitivity of the flow meter:

$$S = \frac{\Delta V_d}{\Delta v}$$

The evaluated sensitivity is $S=0.54$ mV/(m/s). Sensitivity normalized with respect to input power is given by:

$$S_n = \frac{S}{P_{in}}$$

and it is $S_n=3.6$ mV/(m/s)/W.

![Graph of Thermopile Difference vs Flow Velocity](Image)

**Fig. 3** Response of the sensor IHMT 2-1 for low velocities of gas flow.

Measurements for higher flow velocities were also performed (Fig. 4).

![Graph of Thermopile Difference vs Flow Velocity](Image)

**Fig. 4** Response of the sensor IHMT 2-1 for high velocities of gas flow. (Note: In the range (1-2) m/s measured signal is higher than expected because of the geometry of the tube)
5. CONCLUSION

The experimental results presented in this paper have confirmed one of three possible applications of the thermal sensor with the described topology. Although, it is only the first fabricated structure, by comparison with the similar optimized detectors it can be concluded that preliminary results are quite satisfactory. Besides flow measurement, it is planned to test this sensor as IR detector and thermal converter.

We would like to stress that for large liquid and gas flows sensors measuring pressure difference are suitable, while thermal sensors based on Seebeck effect are superior for measuring low liquid flow and gas flow in general.

6. ACKNOWLEDGEMENTS

The authors wish to thank A. Nasiopoulou and Z. Djuric for support this experiment which were part of the results of the bilateral Protocol of collaboration between IMEL-NCSR "Demokritos" and IMTM Belgrade.

REFERENCES


