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ScienceDirect
Procedia Engineering 120 (2015) 225 – 228
Procedia Engineering
www.elsevier.com/locate/procedia

EUROSENSORS 2015

Elaboration of a novel design Pirani pressure sensor for high dynamic range operation and fast response time

M. Moutaouekkil[1,5], A. Talbi[1], R. Viard[1,6], J-C Gerbedoen[1], E. Okada[1], O. Elmazria[4], V.Preobrazhensky[1], A. Merlen[1, 3], P. Pernod[1]

Joint International Laboratory LIA LICS/LEMAC [1,2] :
1- IEMN UMR CNRS 8520, Univ. Lille, Centrale Lille, Cité Scientifique, 59651 Villeneuve d'Ascq, France.
2- Wave Research Center of A. Prokhorov General Physics Institute RAS, Russian 119991, Moscow, Russia.
3- ONERA, Chemin de la hunière 91123, Palaiseau, France.
4- Institut Jean Lamour, UMR 7198, Université de Lorraine - CNRS, Vandoeuvre les Nancy, France.
5- LDOM, Departement de physique, Faculte des Sciences, Univ. Mohamed I, Oujda, Maroc.
6- Fluiditech, Thurmelec, 68840 Pulversheim France

Abstract

We report a novel design for realizing Pirani sensor with a working range from a 1kPa up to pressure over than atmospheric one. The sensor is specifically designed to achieve high sensitivity, fast response time and high robustness. The proof of concept is composed of four metallic resistors interconnected to form a Wheatstone bridge. Two of them act simultaneously as the heating and sensing elements and the two others are used as a temperature reference. The heating element consists of a metallic wire of platinum Pt (3µm width, 1 mm length) maintained on each lateral side by periodic silicon oxide SiO_2 micro-bridges. The sensor design, fabrication technologies, electrical characterizations and voltage-pressure responses are described and shown. A future perspective is given, which describe the extension of this concept to elastic wave transduction of pressure using a combination of heater element and thin plate elastic waveguide.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: Pirani, MEMS sensors, acoustic wave

Corresponding authors: abdelkrim.talbi@iemn.univ-lille1.fr, romain.viard@thurmelec.fr

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.578

1. Introduction

The Pirani pressure sensors are suspended resistors in which the heat loss is due to the gaseous conduction heat transfer where the gas is in molecular flow regime [1-6]. The lower limit pressure of the dynamic range is determined by the solid conduction heat transfer between the heater and the supporting structure. The high pressure limit is related to gap between heater and the substrate. To have the largest possible dynamic range of operation, the combination of larger surface area and the smallest possible gap between substrate and heater is needed. To elaborate Pirani gauges sensors a variety of design concepts and processes were used [1-7, 9]. These are based generally on a resistor deposited on an insulating membrane, or on a resistor simply suspended by a bridge or platform. Nano-Pirani based pressure sensors are relatively easy to elaborate can be extremely miniaturized and are a potential alternative for diaphragm based pressure sensors near atmospheric pressures. It was previously demonstrated for conventional Pirani sensors, operating in high vacuum, that it is possible to improve their sensitivity and to enable wireless measurements using surface acoustic waves instead of a resistor as a transduction mechanism [7]. This is also possible for the nano-gap Pirani gauge sensor by using acoustic wave resonators including surface waves and thin plate acoustic waveguides combined with the heater element.

The aim of this work is to propose an alternative design of Pirani sensor which takes advantages from the two designs described above (membrane and simply supported wire) in term of sensitivity, accuracy and mechanical toughness. The design consists of a successively supported wire using transversal periodic silicon oxide bridges. The same design was applied successfully in our previous work to elaborate robust thermal flow sensor [8]. For Pirani gauge, the design will enable us to elaborate a longer heater without causing buckling or damage provided that the bridges are stress free, and consequently this will permit to reach the targeted performances. The design also enables us to achieve a co-integration with thin film plate elastic wave resonator in order: to increase the measurement accuracy by measuring frequency variation instead of resistance one, and to make the sensor compatible with wireless measurements.

2. Sensor design, fabrication and characterizations

2.1 Sensor design and fabrication

As shown in figure 1(a), the device is composed of four resistance wires 1mm long. Two of them, used as heater and sensitive elements, are suspended between silicon oxide SiO_2 bridges (fig. 1(b) and fig. 1(c)). The nano-gap is estimated to be around 400nm. The two others are positioned directly on the substrate and are considered as a temperature reference (fig. 1(a) and fig. 1(c)). Figure 1 (c) shows an example of an infrared image of a heating element captured with an effective heating power of 8mW (infrared camera reference: MIWIR-512, objective magnification: 12 which corresponds to 2µm pixel). The thermal insulation of the heater is very good as predicted by the simulations (not shown here) and the electrical measurements.

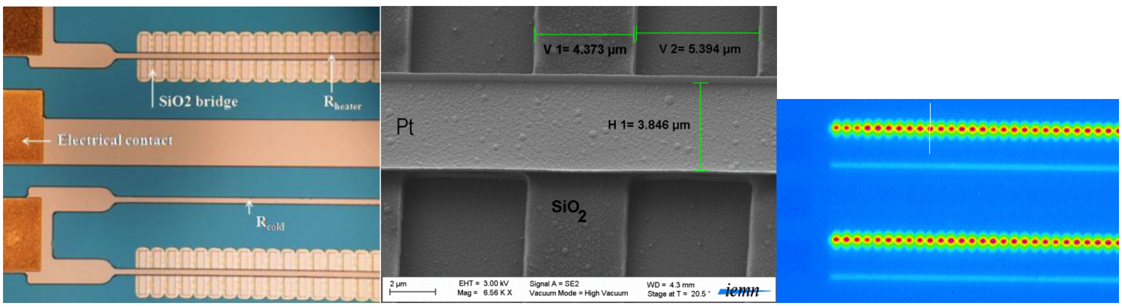

Figure 1: (a) Photomicrograph of the Pirani resistive sensor. (b) SEM image of the unit cell showing the nano-gap. (c) Infrared micrograph showing the temperature distribution on the chip surface of the sensor.

2.2 Sensor characterizations: electrical characterization

The sensor characterizations were devoted to both electrical and thermal characterizations (not analyzed in this paper) of the structure at atmospheric pressure. The current-voltage characteristic of the heater element was measured using a Keithley 2400 sourcemeter. The characteristic of the Wheatstone bridge is presented in the upper half of figure 2 (a), while the resistance variation versus bias power is shown in the lower half of Figure 2 (a). We can notice clearly the linear behavior of the resistance variation with power (and temperature) which confirms the high thermal stability of the metallic thin film.

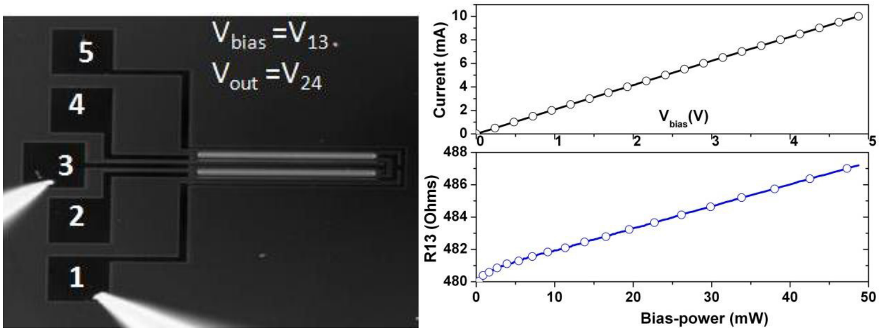

Fig. 2: I-V characteristic of the Wheatstone bridge structure (converted to R13 versus bias power)

2.2 Sensor characterizations: Wheatstone bridge voltage-pressure response

The experimental setup (not shown here) is composed of chamber, and a vacuum pump which brings the pressure down to 100Pa. The pressure, P, is set up by regulating the gas flow into the chamber by a control unit. The signal voltage, Vout (P), measured at the Wheatstone bridge output is displayed on figure 4 for three voltages bias. The sensor characteristics show clearly an extension of operation range to pressure over the atmospheric one resulting from the nano-gap. We observe also a second transition resulting as we expect from a new length characteristic introduced by silicon oxide bridges. This enables us to expand the sensor response to low vacuum and to introduce new geometrical parameters in the design of Pirani pressure sensors.

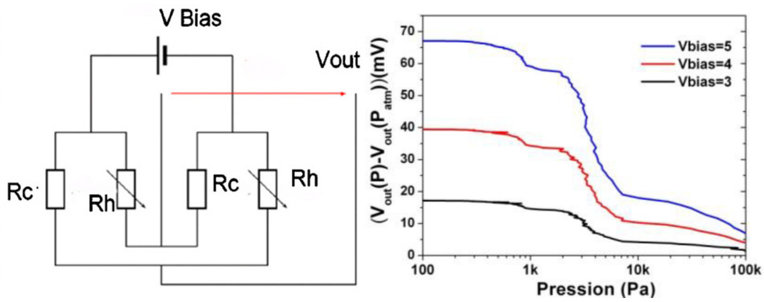

Fig.3: Pirani sensor curves characteristics obtained for three voltages bias.

3. Towards the co-integration with a thin film plate acoustic waveguide

To extend our design for a detection based on elastic waveguide we propose the concept drawn on figure 4-a. The design can be adapted in several topologies [9]. The structure presented in this work consists of an Aluminum Nitride (AlN) bridge that supports the heater and two inter-digitals transducers for emission and detection. The AlN bridge is supported using successive and periodic transversal AlN bridges. A model was developed and implemented in Comsol Multiphysics Software. The model takes into account the thermo-elastic coupling, the thin films elastic constants and air nanogap thermal conductivity dependence on temperature and pressure respectively. Frequency-pressure characteristic of the sensor is displayed on figure 4 (b) (sensitivity is shown in upper half, temperature and corresponding frequency pressure dependence is shown in lower half). The maximum sensitivity reaches 1.5MHz/decade. We also observe from the sensor curve characteristic that the second transition as obtained in experiment for the resistive design doesn't appears in this model. As our geometry design present several gaps, we expect that the thermal conductivity of the surrounding air should be modified to consider these parameters. The model improvement and related experimental results are in progress.

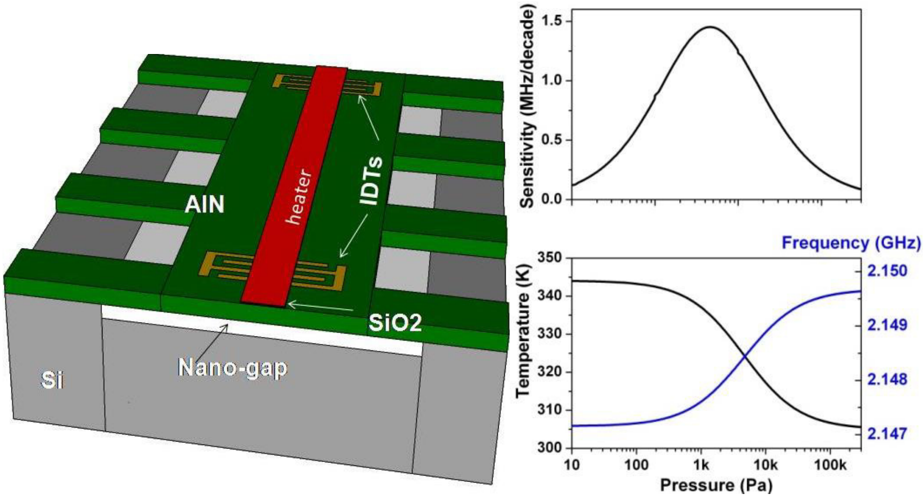

Fig. 4: I-V characteristic of the Wheatstone bridge structure (converted to R13 versus bias power)

4. Conclusion

A surface micromachined nano-gap Pirani gauge is presented. The novel geometry and the simple fabrication process offer sensor that enables us to address measurement from low vacuum to pressure over atmospheric one. Currently, we investigate the co-integration of this design with acoustic wave resonator enabling us to achieve wireless measurements. Furthermore, the sensor will be implemented to perform steady and unsteady pressure measurements for fluid mechanic applications.

Acknowledgements: This work was supported by the French National Research Agency (ANR), in the frame of the CAMELOTT project.

References

[1] A. W. van Herwaarden and P. M. Sarro, "Double-beam integrated thermal vacuum sensor," J. Vacuum Sci. Technol. A, vol. 5, no. 4, pp. 2454–2457, 1987.

[2] M. Doms, A. Bekesch, and J. Mueller, "A microfabricated Pirani pressure sensor operating near atmospheric pressure," J. Micromech. Microeng., vol. 15, no. 8, pp. 1504–1510, 2005.

[3] J. Mitchell, G. R. Lahiji, and K. Najafi, "An improved performance poly-Si Pirani vacuum gauge using heat-distributing structural supports," J. Microelectromech. Syst., vol. 17, no. 1, pp. 93–102, Feb. 2008.

[4] F. Santagata et al, "An analytical model and verification for MEMS Pirani gauges," J. Micromech. Microeng., vol. 21, no. 11, pp. 115007-1–115007-7, 2011.

[5] Kubota, M et al., *MEMS, 2012 IEEE 25th International Conference on* , vol., no., pp.204,207, Jan. 29 2012-Feb. 2 2012.

[6] Völklein et al, Optimized MEMS Pirani sensor with increased pressure measurement sensitivity in the fine and high vacuum regime, Journal of Vacuum Science & Technology A, 31, 061604 (2013).

[7] Nicolay, P.; Elmazria, O.; Sarry, F.; Bouvot, L.; Kambara, H.; Singh, K.J.; Alnot, P., "Wide vacuum pressure range monitoring by pirani SAW sensor," *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on* , vol.57, no.3, pp.684,689, March 2010.

[8] R Viard A Talbi, A Merlen, P Pernod, C Frankiewicz, J-C Gerbedoen and V Preobrazhensky, A robust thermal microstructure for mass flow rate measurement in steady and unsteady flows, *J. Micromech. Microeng.* **23** 065016, 2013.

[9] R Viard A Talbi, A Merlen, P Pernod, and V Preobrazhensk, Miniaturised sensor comprising a heating element, and associated production Method, FR2977886 (A1) 2013-01-18.