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ScienceDirect
Procedia Chemistry 1 (2009) 160–163
Procedia Chemistry
www.elsevier.com/locate/procedia

Proceedings of the Eurosensors XXIII conference

A novel SOI Pirani sensor with triple heat sinks

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Abstract

In this paper, we will present a novel MEMS Pirani sensor with triple heat sinks. The sensors are made on SOI (Silicon On Insulator) wafers leading to a very simple process and good mechanical structures as compared to alternative surface micromachining processes. Moreover, the proposed Pirani has three heat sinks. The area of heat loss through the ambient gas is greatly enlarged as compared to Pirani sensors with one or dual heat sinks without increasing the dimension of the sensor. Consequently, the dynamic pressure range of the Pirani sensor will be enlarged.

Keywords: Pirani; SOI; Triple; Heat sink; Pressure; Sensor

1. Introduction

Miniaturized pressure sensors with a broad pressure range are needed for pressure monitoring in different applications ranging, for example, from pumps to microelectronics packages. One type of pressure sensor for very low pressure is the Pirani sensor. In particular, the micro Pirani sensor is capable of monitoring vacuum levels in miniaturized systems and has been the subject of intensive research efforts [1-4]. Compared to traditional filament based Pirani gauges, they have the advantages of small size, low cost, fast response and a large pressure sensing range.

Various micro Pirani sensors have been fabricated using micromachining technology. Most of the existing micro Pirani sensors are fabricated using surface micromachining on a silicon wafer, typical problems like buckling or collapse of the Pirani bridges, causing failure of the structure and low yield [5].

In order to enhance the mechanical structure of the micro Pirani device and simplify the fabrication process, we use a SOI (Silicon On Insulator) wafer. This SOI-based process allows for long and thin structures, necessary for measuring low pressure. Moreover, to further miniaturize the sensor and enlarge the pressure sensing range, we added three heat sinks, which consist of the substrate beneath and two side walls surrounding the heater (Fig 1). In this way, the area of the heat loss is tripled allowing lower pressures to be measured as compared to existing micro Pirani devices. The small gap between the heater and two side walls can be precisely defined by photolithography

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doi:10.1016/j.proche.2009.07.040

for a large dynamic pressure measurement range. The resulting Pirani sensor was easily integrated in a thin film vacuum packaging process to enable testing of the vacuum level inside micro packages.

2. Theory

The operation of the Pirani is based on the pressure dependent heat transfer from a suspended heater wire to a heat sink through a gas [2]. Normally, the heat is generated by the resistive heating of the wire. The electrical heating (Q_{el}) is equal to three thermal loss components. The first one is the thermal conduction between the heater and heat sink through the gas, ($Q_{gas}(P)$), which is pressure P dependent since the thermal conductivity of the gas depends on the pressure when $K_n = \lambda / d$ >>1; where K_n is the Knudsen number, λ is the mean free path of the gas, d is the characteristic dimension of the domain. The second one is the thermal conduction through the contacts (Q_{end}), and the third one is the thermal radiation (Q_{rad}).

$$Q_{el} = Q_{gas}(P) + Q_{end} + Q_{rad} \tag{1}$$

With reasonable approximation, the pressure dependent heat flux from the heater to the gas is modeled as [6]:

$$Q_{gas}(P) \approx Q_{\infty}\left[\frac{P/P_0}{1+(P/P_0)}\right] \tag{2}$$

where Q_{∞} is the heat flux from the heater to the gas at high pressure, which limits to a constant; P_0 is an empirical transition pressure which determines the upper limit of the dynamic range. From the model [6], P_0 is inversely proportional to the gap size between the heater and heat sink. The lower pressure limit is more sensitive to the active area of the sensor [5]. Hence, to enlarge the dynamic range of the micro Pirani sensor, the gap size should be small and its active area should be enlarged.

3. Design and Fabrication

In our design, we propose a SOI Pirani with three heat sinks. The three heat sinks include the substrate beneath and two side walls surrounding the heater (Fig 1). In this way, the area of the heat loss through gas is greatly increased thereby increasing the dynamic range of the sensor without increasing the dimension of the sensor. The gap between the heater and the two side walls can be precisely defined to be very small due to the selected micromachining technology in our process. As a consequence, it will ensure a high upper pressure limit of the sensor.

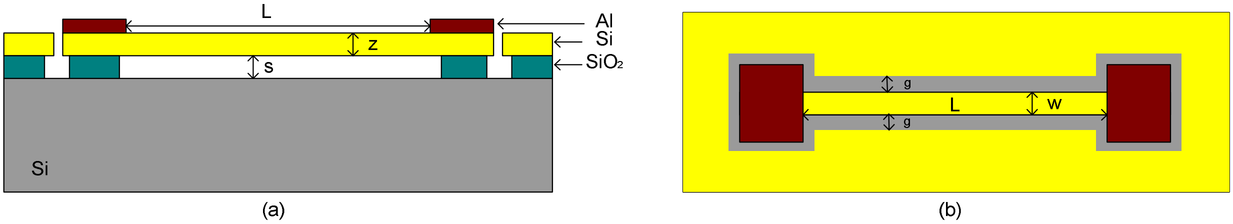


Fig. 1. Schematic drawing of a micro Pirani sensor with three heat sinks: (a). Cross-section; (b).Top-view.

The SOI wafer used has a top silicon with a thickness of 1.4µm and a buried silicon dioxide of 1µm. Our designs vary from 100 to 336µm in length and 2 or 3µm in width. The silicon substrate is one heat sink for the gas. To enlarge the heat absorption surface, two side walls with gaps of only 800nm wide were designed as two extra heat sinks. Some Pirani devices were designed to have 4 bond pads and some had 2 big bond pads to compare the heat loss through the contacts. Fig.2 shows the applied process flow for the micro Pirani devices with the three heat sinks.

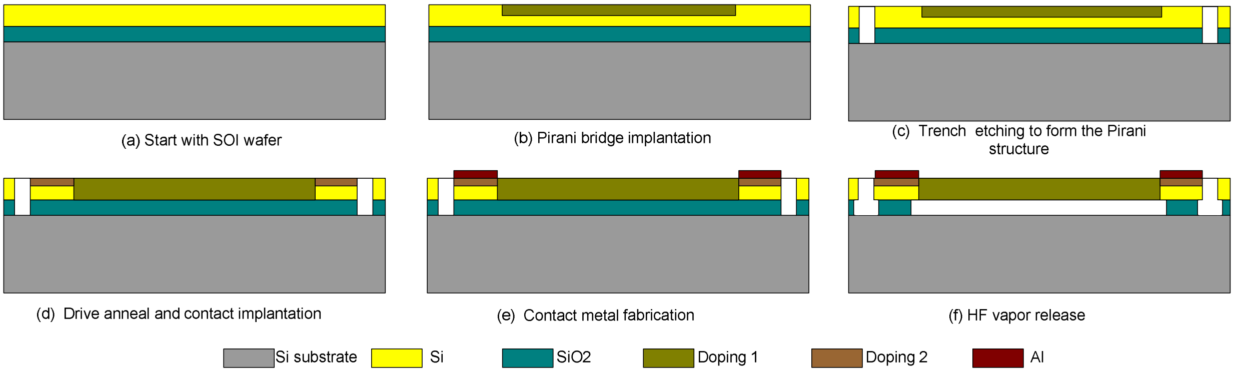
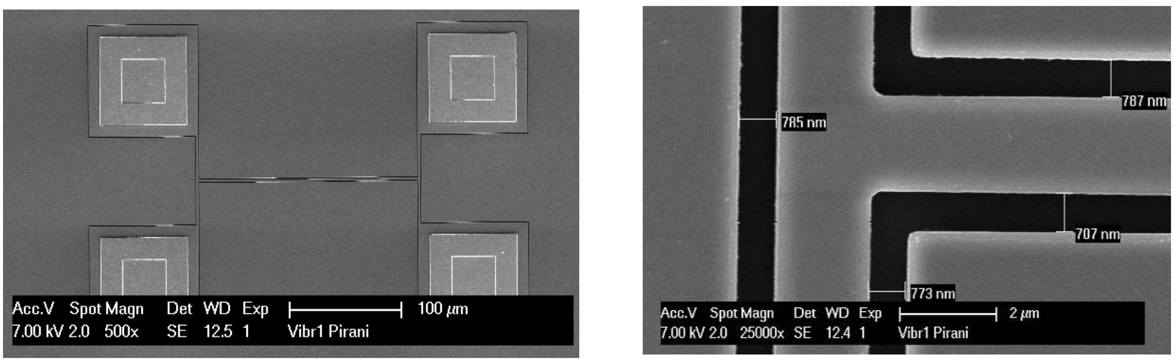


Fig. 2. Process flow of the Pirani devices with three heat sinks.



(a) (b)

Fig. 3. (a) SOI Pirani sensors with three heat sinks; (b) Enlarged view of the gaps between the Pirani bridge and side heat sinks.

After fabrication, the micro Pirani devices showed no buckling or collapse. The resulted 800nm small gaps were almost uniform in both horizontal and vertical directions (see Fig. 3).

4. Experimental results

A four-point probe electrical measurement was used to determine the resistance change of the Pirani under pressures ranging from vacuum to atmospheric pressure. The set up is shown in Fig. 4.

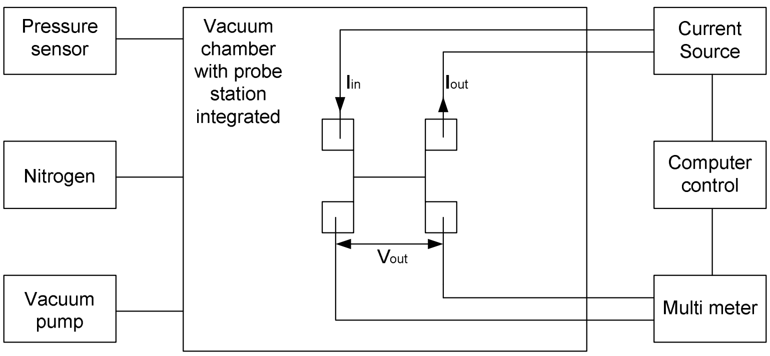


Fig. 4. Schematic of the measurement setup for the micro Pirani sensor.

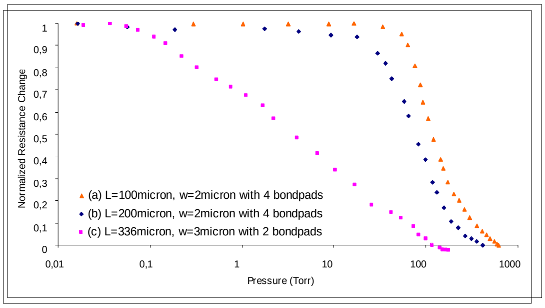


Fig. 5: Normalize resistance change of 3 types of SOI Pirani sensors versus pressure.

Fig. 5 shows 3 types of Pirani sensors, including sensor (a) Pirani device with four bondpads, length 100µm, width 2µm, thickness 1.4µm; (b) Pirani device with four bondpads, length 200µm, width 2µm, thickness 1.4µm; (c) Pirani device with two bondpads, length 336µm, width 3µm, thickness 1.4µm. From the measurement results, we found that sensors (a) and (b), which only differ in length, are able to measure 40torr to 500torr and 10torr to 480torr, respectively. The longer one is capable to detect a smaller pressure and a larger dynamic range due to larger heater area which is compatible with the theory. Sensor (c), with only 336µm in length is capable to measure a very large pressure range, i.e. from 80mtorr to 200torr. It shows a dynamic range that is larger than ever been reported with surface micromachined silicon Pirani devices. The three heat sinks greatly enlarge the dynamic pressure range of the sensor.

5. Conclusions

We proposed a SOI based Pirani sensor with triple heat sinks in this work. The SOI process is simple and the fabricated micro Pirani devices are very well defined. The problems of collapse and buckling, which are often reported by the surface micromachined devices, are eliminated. The proposed Pirani sensors have a large dynamic range, out performing surfaced micromachined silicon Pirani sensors reported so far, with very small dimensions. The simple process makes it highly compatible for integration with other MEMS, thin film packaging processes and electronic read-out circuitry.

Acknowledgements

This work is supported by the Materials innovation institute M2i (The Netherlands) under the project number MC3.05230. The authors would like to thank NXP semiconductors for their work on the fabrication of the devices.

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