

# Membrane Deflection and Stress in Thermal Flow Sensors <sup>†</sup>

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**Abstract:** The effect of membrane deflection has been investigated for thermal flow sensors. Catastrophic membrane breakage is a common occurrence in membrane based thermal flow sensors due to thermal expansion and internal stresses. This work analyses three sensors comprising a tungsten heater embedded in buried oxide membrane with a silicon nitride passivation layer, the use of back etching creates a cavity underneath to reduce the thermal conduction. The investigation is done using interferometry to measure the membrane shape at room and operating temperature for three membranes of different sizes. As expected, the deflection increases with temperature up to 15  $\mu\text{m}$  at operating temperature and with the reduction of membrane size the deflection is reduced to a minimum of 3  $\mu\text{m}$  for the smallest membrane. The lower deflection measured in devices with a smaller cavity can be related to a reduced internal stress, improving the long term stability.

**Keywords:** MEMS; thermal expansion; mechanical stress; flow sensors

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## 1. Introduction

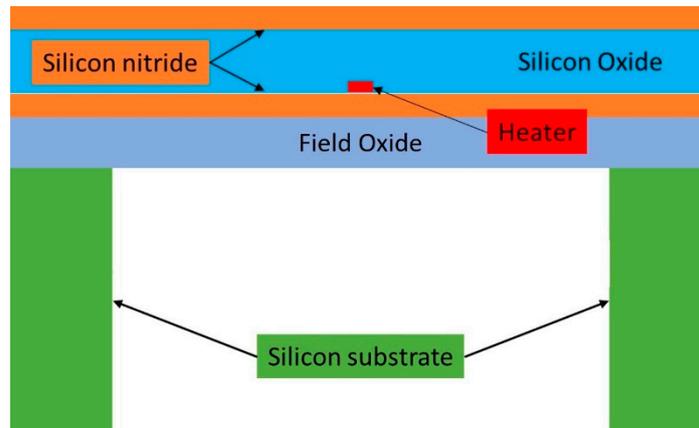
The rise of attention for real-time health monitoring is driving an increasing interest toward highly accurate breathalysers, able to sense low concentration of chemicals in breath to monitor, among the others, diseases [1] or alcohol concentration [2]. Each device needs to include one or more flow sensors, to compensate for the different lungs capability and ensure accurate results. Each sensor has an optimal operating temperature of hundreds of degrees, achieved typically with a power dissipation below 10 mW [3].

The optimal operating temperature depends on the targeted application, with the possibility to detect multiple information by pulsing the signal cycling through different values and post-processing the data [4]. This approach imposes a thermal cycle on the device, that induces a mechanical stress with a negative impact on the reliability [5].

The gravity of this problem increases in membrane-type structures [6], a widely used approach to increase the insulation between active elements and the substrate with a positive effect on power dissipation and sensitivity [5,7].

The devices analysed in this work are built with a commercial CMOS process that includes a stack of layers (schematically reported in Figure 1) with different mechanical properties and thermal

expansion coefficients. The fabrication process is finalised with a deep reactive ion etching step, to precisely remove the silicon from underneath the active area creating a closed membrane structure.



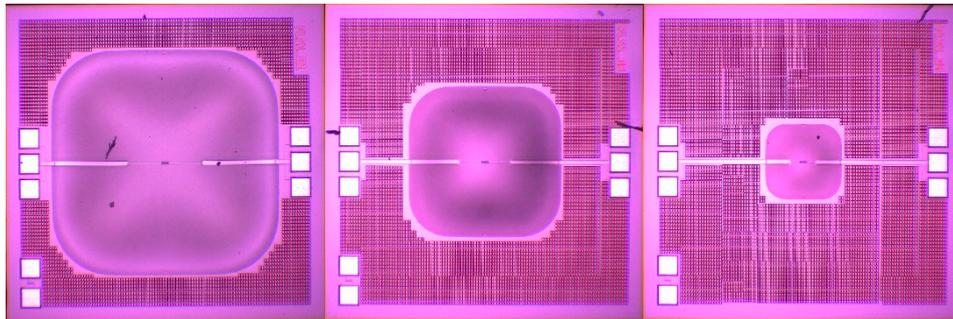
**Figure 1.** Schematic representation of the CMOS technology in this work, with highlighted all the layers (not in scale).

This work analyses three thermal flow sensors consisting of a hot wire with different heater and membrane size (at constant ratio), comparing electro-thermal and thermo-mechanical behaviour in order to find the optimum configuration.

The devices are accurately described in Section 2, while the characterisation processes and their results are reported in Section 3. Finally, Section 4 presents the study conclusions, together with the future work.

## 2. Devices

The three devices analysed in this work are flow sensors with different membrane size (1200 µm, 800 µm and 400 µm respectively) including a single hot-wire in the middle (as shown in Figure 2).



**Figure 2.** Microscope picture of the three devices analysed in this work, with membrane size of (from left to right) 1200 µm, 800 µm and 400 µm.

The hot-wire is a thin strip of metal that, when biased with a constant current, generates heat via joule heating, locally increasing the temperature of active area and surrounding fluid.

The metal resistivity strongly depends on the temperature with an empirical quadratic relation (Equation (1)) where  $T_0$  is 25 °C and the fitting parameters, provided by the foundry, are reported in Table 1.

$$\rho(T) = \rho(T_0) \times [1 + \alpha \cdot (T - T_0) + \beta \cdot (T - T_0)^2] \quad (1)$$

**Table 1.** Temperature coefficient of the metal layer.

$\alpha$ [ $K^{-1}$ ]	$\beta$ [ $K^{-2}$ ]
$2.05 \times 10^{-3}$	$3 \times 10^{-7}$

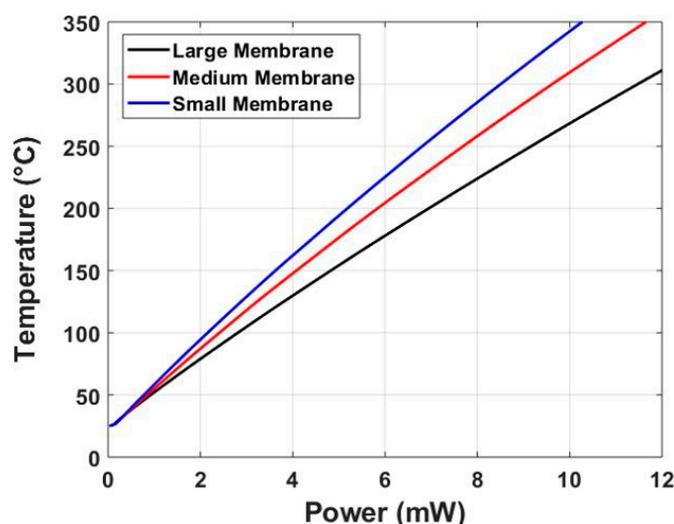
This known relation can be used to extrapolate the device temperature from its resistance. A calibration process then relates the heater temperature with the fluid velocity above the sensor.

### 3. Results

The electro-thermal characterisation used the hot-wire as both heat source and temperature sensor via the change in resistance. To ensure high accuracy in the temperature evaluation, a Kelvin probing approach is used:

- two wide tracks are used to deliver the biasing current with a reduced heat generation;
- two thin tracks, connected at the edges of the hot wire, are used to accurately measure the voltage across it.

A labview script can be used to convert the current and voltage values in power dissipation and temperature. The results for the three devices are plotted in Figure 3 below for a wide range of input power.



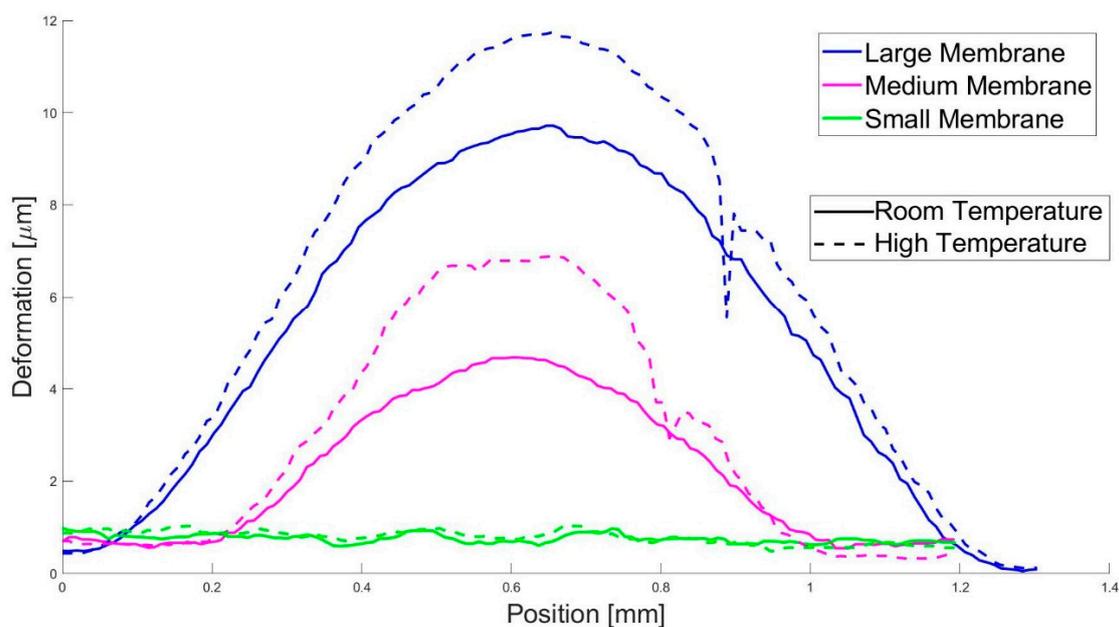
**Figure 3.** Power-temperature relation for the three flow sensors under test. Devices with smaller membrane require less input power to reach the same temperature.

For the thermo-mechanical analysis, the vertical deflection inside the membrane has been recorded in all devices at room temperature and when biased with 10 mA, corresponding to a heater temperature of  $\approx 400$ , 300 and 200 °C respectively. Figure 4 shows a comparison between the profiles on a cut perpendicular to the heater passing through the centre of the membrane.

### 4. Conclusions and Future Work

A complete characterisation of three flow sensors has been performed, looking at the electro-thermal behaviour as well as the mechanical deformation for different membrane size to minimise the internal stress and improve the device reliability.

The findings show that smaller membranes require less power to reach the same operating temperature and, below a threshold membrane size, have a perfectly flat profile, proof of negligible internal stress regardless of the operating temperature.



**Figure 4.** Comparison between the vertical profile in the three flow sensors at room temperature and when biased with 10 mA current. The deformation reduces with the size of the membrane, getting down to effectively zero for the 400  $\mu\text{m}$  one. The temperature gradient due to the current bias increases the deformation.

Future studies are required to evaluate the membrane size effect on the flow response to identify the optimum design.

**Author Contributions:** Conceptualisation: F.U.; Device design: A.D.L.; Investigation and Data curation: C.F. and E.L.W.G.; Resources and data analysis: N.A. and L.A.F.; Writing-Original Draft: C.F.; Writing-Review & Editing, F.U., A.D.L., E.L.W.G., N.A. and L.A.F.

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**Sample Availability:** All the samples used in this analysis are available via Flusso Ltd.



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