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THERMAL BEHAVIOUR OF A SAW TRANSDUCER FOR PRESSURE MEASUREMENTS

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Pirani pressure gauges, Rarefied gas, Surface Acoustic Waves (SAW), Inter-Digital Transducers (IDT).

ABSTRACT

Pirani sensors are widely used to sense pressure in the industry but they still handle very restricted pressure ranges. The vacuum sensor market has expressed its interest in a new combined sensor able to handle the whole sub-atmospheric pressure range down to high vacuum(10^{-4} Pa). The Pirani working principle is based on the heat transfer between a dilute gas and a heated element, the heat exchanged being proportional to the number of gas molecules surrounding the heater and therefore to the gas pressure.

As reported in literature, an interesting way to obtain a miniaturized Pirani sensor is to use Surface Acoustic Waves (SAW) sensors based on Inter-Digitated Transducers (IDT). SAW sensors are widespread sensors able to use any material sensitive to chemicals, force or humidity as a substrate in which a series of alternated electrodes realize the interface between the sensing layer and the electrical signal. These sensors use typically a substrate made of non-linear optical crystals (i.e. Lithium Niobate - $LiNbO_3$) as a waveguide with two separated IDTs at the ends. At one end of the substrate an IDT transmitter is used as an oscillator which converts a supplied electrical potential (or other electromagnetic signal) into an acoustic wave which travels through the free length of the substrate surface between the IDTs. At the opposite end of the substrate, the IDT receiver converts the acoustic wave traveling in the substrate back into an electrical signal.

Jinyoung et al. [1] and Nicolay et al. [2], among others, recently demonstrated that SAW sensors can be used as pressure sensors. The work of Nicolay et. al. [2] has also shown that combining thermal and pressure effects allows to extend the sensing range. However, despite promising results, no SAW devices for pressure measurement based on the Pirani principle have been commercialized so far. These SAW-Pirani sensors use the same operating principle as a conventional Pirani since the heat losses of the substrate are proportional to the gas pressure in contact with the surface, like in a classical Pirani sensor., However, the variation of the surface temperature is transduced in this case into a frequency variation instead of an electrical resistance change. It is noteworthy that with this new operational mode, it becomes possible to consider wireless connections for the sensor.

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A numerical analysis of the heat transfer mechanisms activated in a miniaturized SAW sensor is made with the aim to optimize the thermal behavior of the device for low values of pressure. Starting from the basic model of a SAW IDT presented in the COMSOL library, a similar 2D and then 3D geometry of the device were implemented in COMSOL (see Figures 1 and 2). The heating power is provided at the bottom of the sensor and the top surface of the piezoelectric substrate is assumed to be in thermal contact with a rarefied gas. The heat transfer between the top surface and the gas depends on the value of the gas thermal conductivity which is a function of the gas pressure.

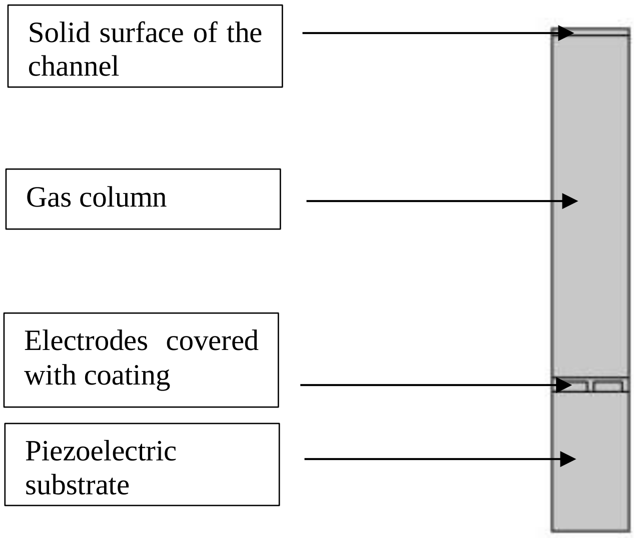

Figure 1: 2D periodic geometry of the SAW Pirani sensor

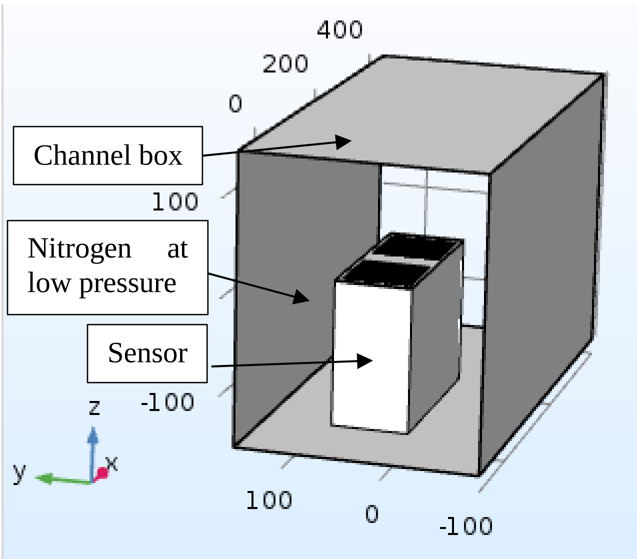

Figure 2: 3D geometry of the SAW Pirani sensor.

If the gas pressure changes, the heat transfer between the substrate surface and the gas changes accordingly, which induces a change in the temperature of the substrate surface. The frequency of the waves propagating along the substrate changes and this variation is recorded by the IDT receiver. In this model, the effect of the gas pressure is taken into account by varying the thermal conductivity of the gas in thermal contact with the sensor. The relationship between the thermal conductivity of the gas and the pressure is considered known within the range from atmospheric pressure down to 0.00001 Pa.

The effect of radiation heat transfer between the top surface and the surround is also taken into account.
Two different simulations are made:
(a) a 2D simulation where the sensor is considered as a periodic sensor supplied with a constant heating power.
(b) a 3D simulation where the sensor is modeled as a 3D sensor with its real dimensions inserted in an external box.

The numerical outputs of both these simulations in terms of thermal response of the sensor will be shown by varying a series of parameters like the dimensions of the sensor, gas pressure, the emissivity of the surfaces and so on. For each case the evolution in time of the temperature of the substrate surface as well as the sensor characteristic response time have been calculated as a function of the gas pressure. The frequency shift corresponding to each substrate temperature obtained for different values of gas pressure is then calculated..

These simulations allow to define the main characteristics of the new SAW-Pirani sensor. Further work will also include an analysis of the behavior of this sensor for gas pressure values close to the atmospheric ones, of manufacturing possibilities and constraints and of wireless interrogation methods.

Acknowledgements

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