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CHARACTERIZATION OF A SAW CHIP AND WIRELESS APPLICATION OF THE PIRANI PRINCIPLE IN VACUUM

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KEY WORDS

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ABSTRACT

A Surface Acoustic Wave sensing chip has been characterized for wireless temperature and pressure measurements in vacuum. The chip is interrogated at 2,45GHz by means of a Network Analyzer and two coupled antennas. Measurements are based on the temperature induced resonance frequency shift of the chip. Pressure measurements are enabled by applying the Pirani principle on the chip. For this purpose wireless heating of the chip was implemented using inductively coupled coils.

Overview

Vacuum sensors with a broad range are required for a number of industrial applications, among which the food and the semi-conductor industries. Many types of vacuum sensors already exist relying on various operating principles. One of their biggest drawback is their limited sensing range. Among vacuum sensors, thermal vacuum sensors rely on the pressure dependent thermal conductivity of gases below atmospheric pressure [1,2].

Since the advent of silicon micromachining, significant progress has been achieved in the miniaturization of thermal vacuum sensors. Indeed, smaller sensors mean smaller invasion of the media sensed and less distortion of the ongoing processes. Likewise, wireless sensor networks/nodes represent a rapidly emerging technology based on the paradigm of wireless power supply and signal transmission to compact autonomous platforms. Thanks to the recent development of micromachining and microelectronics, it is therefore possible to combine lot of functions and devices in a very confined space.

A new wireless vacuum sensor

In light of the recent technology and of the industry requirements, a new sensor aiming to sense a broader vacuum range extending from atmospheric pressure down to high vacuum has been

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developed. It uses state of the art microelectronics enabling efficient wireless power and signal transfer, resistant and stable materials that prevent outgassing and micromachining that allows a compact stable packaging in vacuum.

The sensor operates based on the Pirani principle and Surface Acoustic Waves (SAW-Pirani principle [3]). A piezoelectric chip located inside a channel inserted in a vacuum environment is heated. The heat loss of the chip to its ambient through gas conduction is proportional to the number of molecules in the vacuum system. Temperature variations of the chip due to pressure changes in the vacuum chamber are detected by the change in frequency values of a crossing surface acoustic wave propagating on the surface of the chip via an interdigitated transducer. An interrogation signal is sent to the Interdigitated Transducer (IDT) and the frequency shift due to the pressure is recorded by the reflected signal. The vacuum pressure can therefore be calculated from the temperature of the heated body.

The core of this device consists of a 1 cm^3 polymer cube crossed in its center by a 500 µm diameter cylindrical microchannel. The sensing element is a Surface Acoustic Wave Interdigital Transducer created on a piezoelectric substrate and is based on the SAW-Pirani principle. The sensing element is located inside the crossing channel. The aim of the sensor is to reach a sensitivity of 0.0001 Pa at high vacuum and 100 Pa near atmospheric pressure.

Surface Acoustic Waves propagate on piezoelectric crystals and their oscillating frequency is sensitive to the temperature. A wireless interrogation signal allows to measure the frequency of those waves. Figure 1 shows the structure of the new sensor with all its components.

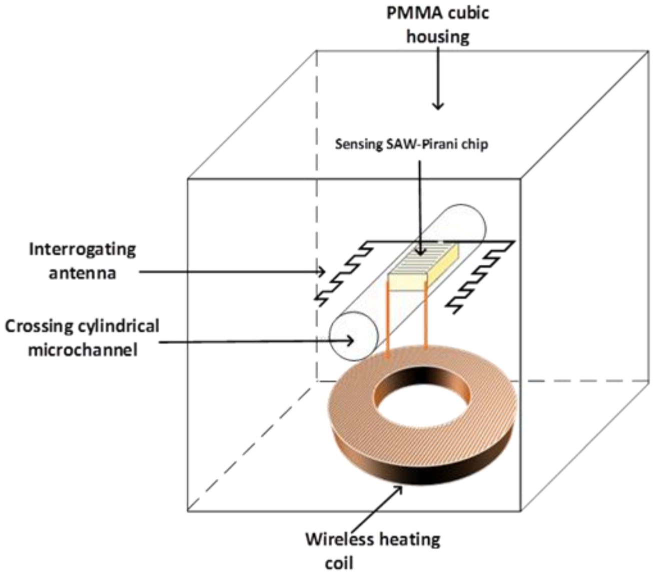
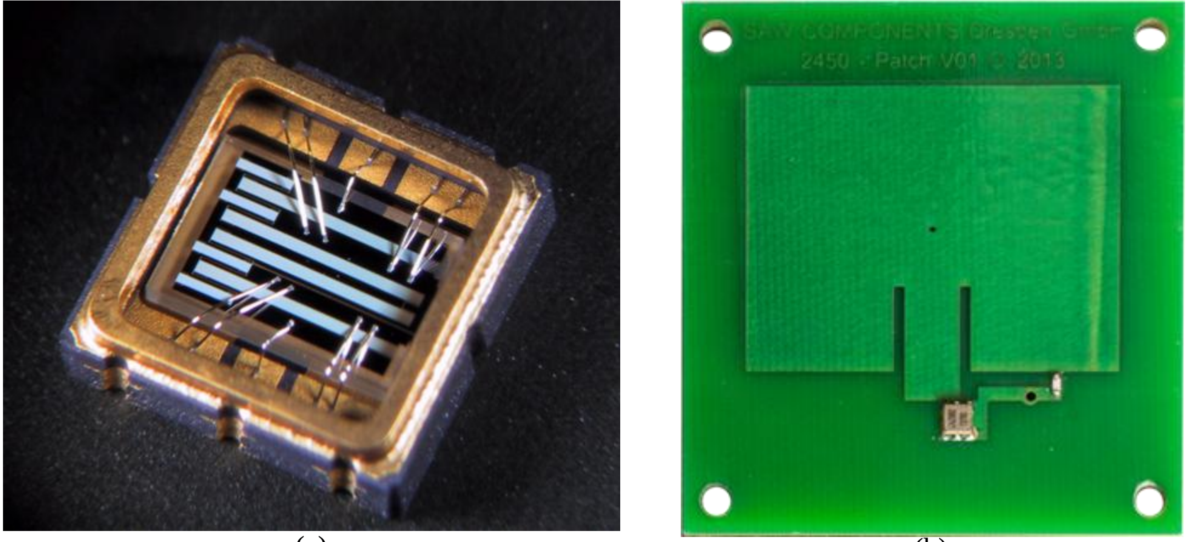


Figure 1: Structure of the new sensor

Experimental testing of the chip

Simulation allowed determining the dimensions of the sensor to increase the sensitivity in high vacuum by increasing the Surface to Volume ratio of the chip and maintaining the Knudsen number of the floew between 0.001 and 10 through the whole targeted sensing range. After finalizing the design and the simulation of the behaviour of the new sensor in vacuum, the assembly of a prototype started. Namely, it consists in collecting or manufacturing the components, combining and customizing them in order to send and receive the needed signals. In this context, first characterization tests of a Surface Acoustic Wave sensing chip are presented here. The paper presents the characterization of the chip at different temperature and pressure conditions coupled with the implementation of wireless heating and wireless measurements in vacuum.

First, the chip is characterized at ambient temperature and pressure, then wireless heating is implemented in the chip and finally the chip is introduced in vacuum and wireless heating and interrogation are performed. Figure 2 depicts the SS2467BB3 chip manufactured by SAW Components Dresden bare die on foil on the left side and the chip connected to an interrogation antenna on the right side.



(a) (b)

Figure 2: (a) SS2467BB3 chip (b) SS2467BB3 chip with reader antenna

In order to measure pressure with the chip it needs to be heated, the heat loss to its ambient being proportionnal to the surrounding pressure. Inductive heating enables to operate wirelessly the chip as a pressure sensor in a vacuum environment. In practice, wireless heating is done through two coupled coils manufactured by Würth Elektronik. Figure 3 shows both the transmitting and the receiving coil. The receiving coil can deliver a power of up to 0,11 W to the coil.

(a) (b)

Figure 3: (a) Transmitting coil (b) Receiving coil

In the interest of operating the chip in vacuum, a special setup with a large enough glass window was designed and manufactured to allow wave propagation. This setup allows to have a distance between transmitting antenna and receiving antenna and between transmitting and receiving coil as low as 16 mm. The measurements were made using a mini VNA Tiny Vector Network Analyzer and consisted in calculating the S11 vs frequency for frequencies between 2 GHz and 3 GHz with a variable step. This measurement allows to determine precisely the resonance frequency and see its variation with respect to temperature. Figure 4 shows the S11 of the chip at a temperature of 26°C. S11 is the reflection coefficient of the chip that is minimal at the resonance frequency: it means that at the resonance frequency most of the energy radiated from the interrogating antenna is accepted by the chip and not reflected back

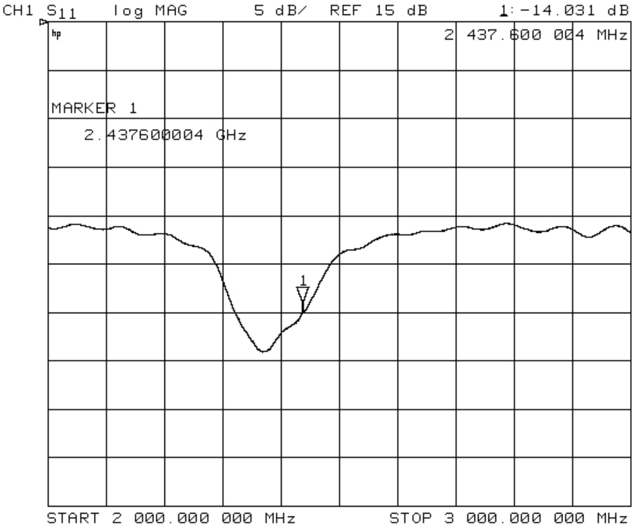


Figure 4: S11 of the chip vs frequency between 2 GHz and 3 GHz at 26°C

The minimum value of the reflection coefficient S11 corresponds to the resonance frequency identified as 2,4376 GHz. The sharp variation close to the resonance frequency allows an easy identification of the resonance frequency.

The first characterization tests presented constitute the first step in the assembly of the prototype. They allow a first characterization of the chip and to couple it with the wireless heating which will help define the best operating mode of the sensor that will grant the highest sensitivity of the measurement through the whole targeted sensing range.

Acknowledgements

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