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Feasibility of Wireless Gas Detection with An FMCW RADAR Interrogation of Passive RF Gas Sensor

Hamida Hallil^{*+}, Franck Chebila^{*+}, Philippe Menini^{*+}, Patrick Pons^{*}, Hervé Aubert^{*+}

^{*}CNRS ; LAAS ; 7 Avenue du Colonel Roche, F-31077 Toulouse, France

⁺ Université de Toulouse ; UPS, INP ; LAAS ; F- 31077 Toulouse, France

hhallil@laas.fr

Summary

The feasibility of the remote measurement of gas detection from an RF gas sensor has been experimentally investigated. It consists of a Frequency-Modulated Continuous-Wave (FMCW) RADAR interrogation of an antenna loaded by the passive sensor. The frequency band of the RADAR [28.8-31GHz] allows the detection of the resonant frequencies of Whispering Gallery Modes that are sensitive to gas concentration. Reported experimental results provide the proof-of-concept of remote measurement of gas concentration fluctuation from RADAR interrogation of this new generation of passive gas sensors.

Motivation

Recent results obtained from electromagnetic simulations¹ indicated that a TiO₂ dielectric resonator (DR) can adsorb gas molecules (like CO) and such adsorption induces a frequency shift in resonant frequencies of high-sensitive Whispering Gallery (WG) modes. This transduction is given by the dielectric relaxation effect at high frequency. The experimental validation of the design and electromagnetic simulations was carried out using BaSmTiOxide ceramic as a dielectric material for the DR instead of TiO₂, as it is easier to fabricate by standard Sintering technique than metal oxide DR: the dielectric property of this ceramic presents a relative permittivity (78.6 ± 2 from²) is very close to TiO₂ one.

Results

The fabricated Whispering-Gallery mode resonator with its coplanar waveguide (CPW) feeding lines is shown in Fig.1. The measured transmission coefficient S_{13} in the millimeter-wave frequency range is reported in Fig. 2. As expected, transmission peaks are observed at the resonant frequency of the WGH_{5,0,0}, WGH_{6,0,0} and WGH_{7,0,0} modes. Due to the technological inaccuracies, the three resonators (with the same dimensions) micro-machined on the same wafer do not have identical transmission peak magnitudes and frequencies : for example the WGH_{7,0,0} mode resonates at 29.4 GHz for the resonator 1, at 29.5 GHz for the resonator 2 and at 29.9 GHz for the resonator 3 (see fig.3). These three resonators can be considered as a gas sensor that resonates at three different frequencies, each frequency corresponding to a specific gas concentration. These three resonant frequencies (or gas concentration) can be measured from the FMCW RADAR interrogation of an antenna loaded by the resonator (passive sensor). As shown in Fig.4, the sensor interrogated by this reader, use an identification technique³ which depends on the backscattered signal of the horn antenna (structural mode) and the cables delay line, a length of coaxial cable, connected to the cell (antenna mode). The three WGH_{7,0,0} resonant frequencies can be scanned by the RADAR because they belong to its specific band (28.8GHz to 31GHz). In the FMCW radar output spectrum, the beat frequency that allows measuring the location of the sensor can easily be detected (here the distance between the radar antenna and the sensor horn antenna is 3.4 m and consequently the beat frequency is 30 KHz). Depending on load which is applied to its output, on Fig.5, the presence or absence of the sensor is checked. Table 1 shows the variation of radar amplitude between the three structures with the output open circuit. These first measures validate the feasibility of a radar measurement of gas detection and their quantity by wireless communication between the reader and a totally passive sensor.

¹ H. Hallil, P. Ménini, H. Aubert, "Novel Millimeter-Wave Gas Sensor Using Dielectric Resonator with TiO₂ sensitive layer", IEEE Sensors Conference, New Zealand, 25-28 October, 2009.

² TEMEX CERAMICS (<http://www.temex-ceramics.com>).

³ F. Chebila, M. M. Jatlaoui, P. Pons and H. Aubert, "Pressure Measurement from the RADAR Interrogation of Passive Sensors", accepted in IEEE symposium Antennas and Propagation Society, Canada July 11-17, 2010

Figures

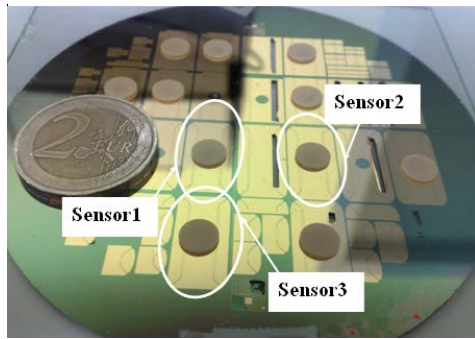


Fig. 1: Fabricated sensors on 4" Silicon wafer: resonator with its CPW excitation lines.

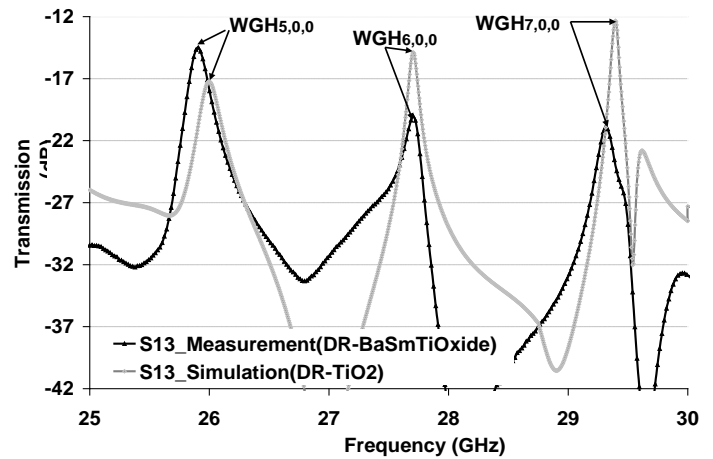


Fig. 2: Measured and simulated transmission coefficients versus frequency for the BaSmTiOxide and TiO₂ dielectric resonator.

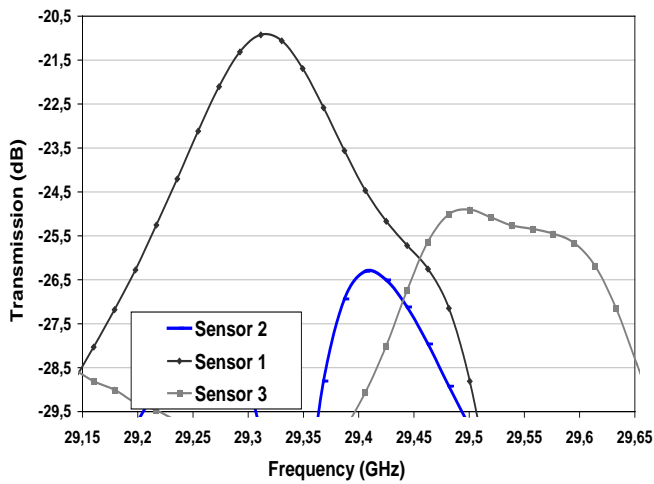


Fig. 3: Measured transmission coefficient versus frequency for three sensors at WGH_{7,0,0}.

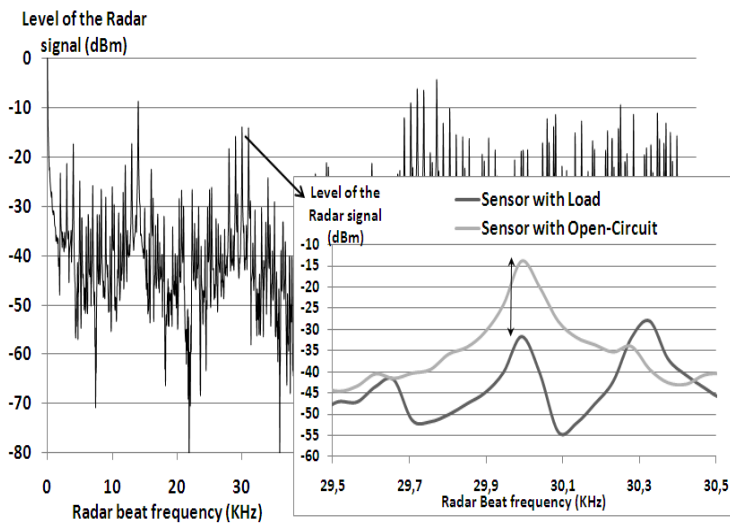


Fig. 5: Spectrum of the radar signal: Identification of the sensor variations (with and with out load)

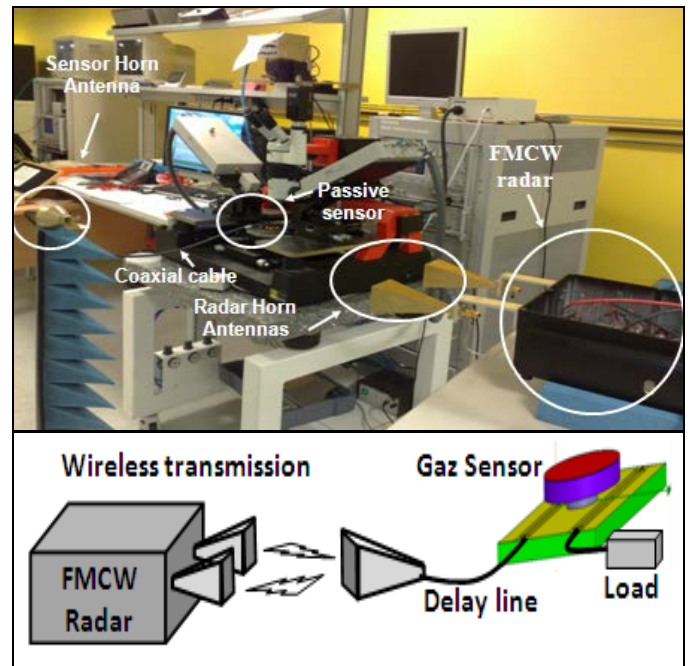


Fig. 4: Experimental assembly between the radar and gas sensor

Level of the Radar signal	Sensor 1	Sensor 2	Sensor 3
Sensor with open-circuit (dBm)	-10,4	-12,7	-13,9
Sensor with Load (dBm)	-43	-18,5	-31,7

Table 1: Level of the beat frequency radar for each sensor (1, 2, and 3)