DOI 10.5162/SMSI2023/B4.2

Multi-Parameter Gas Monitoring System for Natural Gas with Hydrogen

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Summary:

We demonstrate the use of a newly developed multi-parameter gas property MEMS chip, that is designed to measure density, dynamic viscosity and thermal conductivity of gases, for the characterisation of hydrogen-containing combustion gas mixtures. The sensor is able to measure combustion gas with hydrogen directly in the process line independent of the process conditions (pressure, temperature and flow) and without complex gas conditioning. The chip design is aimed at ensuring that cost-sensitive mass applications can also be served with this sensor in the future.

Keywords: micro cantilever, gas thermophysical properties, natural gas, hydrogen, calorific value

Background and Motivation

Monitoring gas compositions in realtime at low costs directly in the process becomes more and more important in different fields of applications. Using MEMS sensors is an adequate way to solve this demand. By means of correlative methods, various desired quality properties of gas mixtures can be derived from thermophysical properties like density, viscosity and thermal conductivity of gases in an application-specific manner. For example, the composition of multi-component process gas mixtures such as welding shield gases or gases in food packaging (MAP) can be characterised and monitored online. Another important application for such a measuring system are combustion gases such as natural gas or biogas, which can also contain large quantities of hydrogen. The properties that are relevant here are calorific value, Wobbe index, methane number, hydrogen concentration, inert gas content, molar mass and reference density [1,2].

Description of the System

Our silicon chip contains two micro cantilevers, piezoelectrically activated (see Fig. 1). As shown in previous publications, this chip can be used to measure thermophysical properties of gases. On the one hand, the 1st cantilever is vibronically excited to its resonance frequency. The density and viscosity can be derived from the determined oscillation properties frequency, f, and quality factor, Q [2,3,4]. What is new about this chip version is that by heating the second cantilever with a constant heating power and simultaneously measuring the temperature difference that arises between the two cantilevers, the thermal conductivity of the gas can also be determined. This measurement can be carried out simultaneously or alternately with the density and viscosity measurement. With the help of the different temperature sensors on the chip, the gas temperatures associated with the measured variables density, dynamic viscosity and thermal conductivity can also be precisely tracked at any time. In conjunction with a pressure measurement the measured gas can be completely characterised independently of the process conditions.

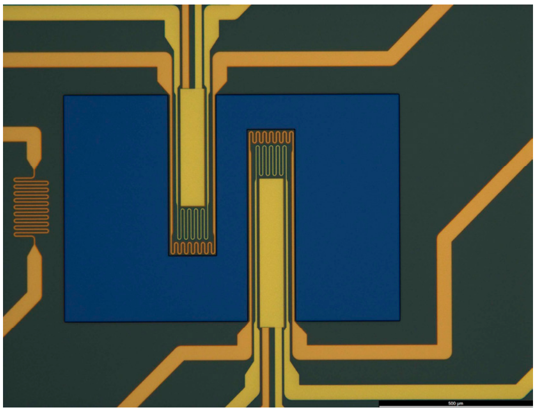

Fig. 1. Picture of the MEMS chip containing two micro cantilevers of slightly different lengths (500 and 600 µm), which can be piezo electrically driven and read out. The two cantilevers are each equipped with a temperature sensor and a heating element. In addition, there is another temperature sensor on the frame of the chip (left side).

With our chip it is possible to measure in a temperature range from approx. -40 to 80°C and in a pressure range from approx. 0.5 to 10 bar. No complex gas conditioning and branching is necessary, which makes the installation simple and inexpensive.

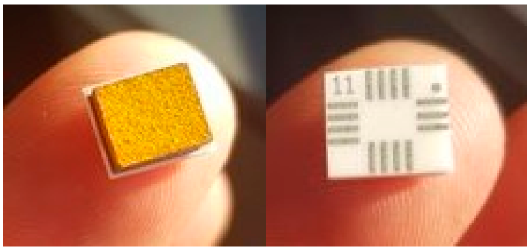

Fig. 2. Pictures of the packed chip from top and bottom. The MEMS chip is flip chip bonded to a ceramic PCB (right) and covered with a porous filter cap (left).

To protect the sensing cantilevers and to be able to measure reliably in the process under changing conditions and with possibly contaminated gases, the MEMS chip was covered with a filter cap (see Fig. 2). The cap consists of a porous structure made of sintered bronze with pore sizes in the range of a few micrometers. The filter cap also prevents gas convection at the chip, which would interfere with the measurement of thermal conductivity. Nevertheless, due to the small chip dimension, the filter cap allows a very fast diffusive gas exchange in the range of < 2 sec and thus measurements almost in realtime.

Results

The following shows the achievable measurement performance of such a measurement system for methane and natural gas mixtures with hydrogen contents up to 20% mol in a wide temperature and pressure range. For the experiments, the sensor was mounted together with a pressure sensor in a pressure tight measuring cylinder. The complete system was placed in a climate chamber and various gas mixtures (see Tab. 1) were measured at pressures between 2 and 6 bar and temperatures between 0 and 50°C. The results can be seen in Figs. 3 and 4. The calorific value and the Wobbe Index of the gases could be determined with an accuracy of 1 to 1.5% over the entire measuring range.

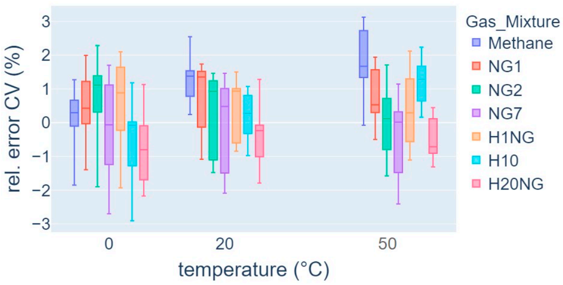

Fig. 3. Relative error of the calorific value determination of 7 different gas mixtures at different temperatures. Each box plot includes measurements performed at three pressures (2, 4 and 6 bar).

The hydrogen content was determined to <0.5% mol and the total inert gas content to approx. 1% mol.

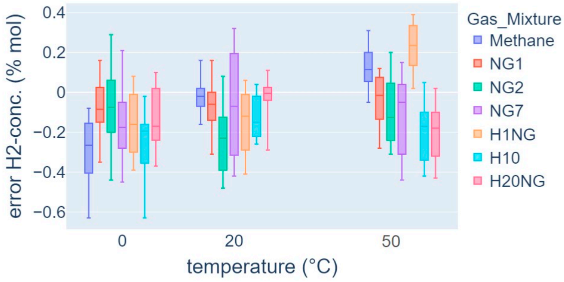

Fig. 4. Error of the hydrogen concentration determination of 7 different gas mixtures, containing up to 20% mol hydrogen, at different temperatures. Each box plot includes measurements performed at three pressures (2, 4 and 6 bar).

Tab. 1. Composition of the measured gases.

gas	NG1	NG2	NG7	H1 NG	H20 NG	H10
CH_4	93	85	84	91.8	74.1	90
C_2H_6	4.2	9	5	4.1	3.4	0
C_3H_8	0.8	1.5	2	0.8	0.7	0
C_4H_{10}	0.3	0.5	0.5	0.3	0.3	0
N_2	1.3	2.5	4	1.3	1	0
CO_2	0.7	1.4	4	0.6	0.5	0
H_2	0	0	0	1	20	10

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