Sensor platform for gas composition measurement

G. de Graaf a, F. Bakker b, R.F. Wolffenbuttel a

a Delft University of Technology, Fac. EEMCS, Dept. ME, Mekelweg 4, 2628 CD Delft, The Netherlands
b Energy research Center Netherlands (ECN), Westerduinweg 3, 1755 LE, Petten, The Netherlands

Abstract

The gas sensor research presented here has a focus on the measurement of the composition of natural gas and gases from sustainable resources, such as biogas. For efficient and safe combustion, new sensor systems need to be developed to measure the composition of these new gases. In general about 6 gas components need to be measured to determine the calorific value and the combustion properties of these gas mixtures. The concentration levels of the relevant components are relatively high, and the emphasis of this research work is therefore on selectivity and avoidance of cross contamination. For this reason and because of their limited stability, chemical sensors are not considered. The sensors in this work are based on physical interaction with the gas. One single sensing principle is insufficient for identification of all components in the natural gas and a microsystem for measuring three different physical properties of the gas components are proposed in this work: thermal conductivity, optical and photo-acoustic infrared absorption.

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1. Introduction

At present the gas distributed to households and industrial users is of constant composition. In the future, there will be a need to change this gas composition [1]. This is caused by the emerging use of imported gases such as LNG and the introduction of locally produced gases from sustainable energy resources, such as biogas and synthetic gases produced by biomass. Since the gas distribution network is widely branched and cross-linked the gas quality needs to be monitored at many local distribution points.
in the network and also at the end-user. Low cost sensor systems are needed to determine the composition of the gas to determine its energy content and to assure safe and efficient combustion.

2. Gas composition

Biogas, produced by fermentation, and synthetic gases such as CO and hydrogen, produced by gasification of biomass and coal have a totally different composition, properties and quality as compared to natural gas. Table 1 shows the typical components of natural gas in The Netherlands (‘Groningen’-gas) and the main types of these “New or Green” gases. Trace gases are not mentioned in this table, since they are not relevant for combustion, however they can be important for contamination of the pipelines, burner and the sensors.

Table 1. Overview of the main combustible gas resources and typical composition.

<table>
<thead>
<tr>
<th>GAS SOURCE</th>
<th>CH$_4$ (%)</th>
<th>C$_2$H$_6$ (%)</th>
<th>C$_3$H$_8$ (%)</th>
<th>CO$_2$ (%)</th>
<th>CO (%)</th>
<th>H$_2$ (%)</th>
<th>N$_2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas (Netherlands)</td>
<td>81</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>LNG (Qatar)</td>
<td>89,6</td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gasification of coal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>4</td>
<td>81</td>
<td>9</td>
</tr>
<tr>
<td>Gasification of Biomass</td>
<td>12</td>
<td>2</td>
<td>-</td>
<td>23</td>
<td>32</td>
<td>29</td>
<td>2</td>
</tr>
<tr>
<td>Fermentation gases</td>
<td>75</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

3. State-of-the-art in microsystem based physical gas sensing

Mid-Infrared absorption techniques can be used to detect most of the gases considered in this project. There are many different techniques for measuring infrared absorption in gases. Optical techniques such as Non Dispersive InfraRed (NDIR), Cavity Ring-down Spectroscopy (CRDS), Fourier Transform InfraRed (FTIR) spectroscopy and the Photo-Acoustic (PA) method are the most common techniques. FTIR is a powerful method for gas composition sensing, however, rather a complex technique to implement in a micro-system. Results of research on MEMS-fabricated components for FTIR have been reported in literature [2], however no devices operating in the infrared spectral range are available at present. Photo-acoustic gas sensors in MEMS bulk micro-machining technology have been already published for trace gases [3]. Cavity Ring-down Spectroscopy (CRDS) is a very sensitive technique, however it requires an expensive Mid-infrared laser. Mass spectroscopy and gas chromatography are also relatively complex techniques. Although gas chromatographs have been realized in micro-systems [4], they have not been commercialized and they are not well-suited in the low-cost consumer application pursued here. NDIR (Non-Dispersive Infra-Red) gas sensing is the most straightforward implementation of the absorption technique both in terms of simplicity and robustness as well as micro-system compatibility.

Other commonly used physical techniques are thermal conductivity, gravimetric and paramagnetic effects. Gravimetric sensors measure changes in mass due to the selective chemical absorption in a layer. Resonant MEMS micro beams have been investigated as gravimetric gas sensors, however these feature low stability and very large cross-sensitivity [5]. The paramagnetic effect can be used for O$_2$ and NO$_x$. 

only [6]. Thermal conductivity is a gas sensing principle that can be conveniently implemented in micro-system technology [7]. A multi-sensor gas sensing micro-system based on thermal conduction and chemical absorption has been published in [8].

4. Proposed gas sensing principles

The sensors in this work are based on physical interaction with the gas and all sensors are fabricated using surface micro-machining technology in a common silicon sensor die. Hydrogen (H$_2$) and carbon dioxide (CO$_2$) can be measured by the thermal conductance principle and this can be conveniently implemented in micro-system technology [7]. The infrared absorption spectra of CH$_4$, CO and CO$_2$, shown in Figure 2, are well separated and can be resolved with medium resolution, infrared spectrometry in the wavelength range in between 3.4 and 4.3 μm. For improved spectral resolution an NDIR array technique has been chosen as the main optical sensor principle in the proposed sensor platform. Photo-acoustic sensing is also under investigation as a complementary technique. The challenges in the design are the IC-compatible fabrication and the short optical path in the micro-system. As a result the following three principles are considered as the best candidates for low-cost reliable gas sensing and for integration on a single chip as an additional constraint:

1. NDIR infrared absorption techniques
2. Thermal conductivity measurements
3. Photo-acoustic sensing.

5. Sensor platform for combustible gas analysis

The proposed gas multi-sensor system is illustrated in Figure 2. The figure shows a two-chip solution consisting of a bottom sensor chip and an optical filter chip on top. For the three gas sensing principles the following components need to be integrated in the bottom chip:

- A thermal conductivity gas detector (TCD)
- Thermal infrared sources for NDIR and photo-acoustic
- Thermal infrared detectors for the NDIR
- MEMS microphones for the photo-acoustic gas sensing
- Temperature and pressure sensors for compensation

Thermopiles have been used as thermal detectors because of their excellent stability and their IC-compatibility.

5.1. Thermal conductivity detector (TCD)

The technology for the fabrication of the thermal conductivity detectors (TCD) has been presented before [6]. Figure 3 shows the chip photo of a typical device. The center part is heated using a thin-film polysilicon resistor. The sample gas or liquid is in the thin cavity between the membrane and the
substrate. The short thermal path via the gas to the substrate results in a very high sensitivity of around \(35 \times 10^{-3} \text{ V/(Wm}^{-1}\text{K}^{-1})\).

5.2. Infrared absorption spectrometer

Traditional NDIR gas sensors have only one detector. In our approach we use an array of thermopiles as detectors and many optical resonators for filtering, as shown in Figure 4. Such an infrared microspectrometer provides more spectral information and can provide the high selectivity required for multi-component gas analysis.

6. Conclusions and future work

A sensor platform for natural gas composition measurement has been presented. The sensors are based on different principles of physical interaction with the sample gas to provide high selectivity. All sensors can be fabricated on common silicon die. High-sensitivity TCD’s have been already fabricated and tested. First prototypes of the LVOF spectrometer have been fabricated in a thin-film surface micromachining process from DIMES Technology Centre of Delft University of Technology.

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7. References:


