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Miniaturized SMD-Reflow-Capable Photoacoustic CO_2-Sensor Using a Dual-Chamber Approach

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Summary:
The increasing interest in monitoring indoor air quality has led to a growing demand for simple and small-scale gas sensors. We present a miniaturized photoacoustic dual chamber sensor module that includes an infrared hotplate emitter and a wafer-level manufactured photoacoustic detector. The sensor module was controlled by a PSoC 4200M microcontroller and is capable of being soldered in a SMD reflow soldering process. The sensor prototype achieves a 3-sigma noise level of 138 ppm CO_2, which is suitable for most consumer applications.

Keywords: photoacoustic, gas sensor, wafer-level, CO_2, MEMS

Introduction

Interest in measuring air quality has increased significantly over the past three years. The publication of studies showing a correlation between bad air quality and viral load spurred the demand for small and simple sensor solutions [1]. The most commonly used marker for bad indoor air quality is an increased concentration of carbon dioxide (CO_2) in the air [2].

The first commercially available optical gas sensors were relatively large and mechanically complex. However, sensor technology has improved over the years, allowing for the manufacturing of smaller, more cost-efficient devices. Recent trends have shown a movement towards reducing the sensor size even further and the introduction of surface mounted device (SMD) reflow capability as an assembly feature. The latest generation of CO_2 sensors uses the photoacoustic effect to determine the CO_2 concentration in air. However, such sensors work with a spectral filter and only one photoacoustic cell [3]. Therefore, this approach has a limited selectivity towards the target gas and is sensitive to acoustic interference.

In another approach, the so called "dual-chamber approach", two sensor cells are used: one exposed to ambient air and a second cell containing the microphone and filled with the target analyte. In this concept, the filling gas acts as a spectral filter and makes the sensor selective only to the target gas [4].

We present a miniaturized sensor based on this dual-chamber approach, measuring only 9 x 13 x 7.8 mm³ (L x W x H). To our knowledge, this is the smallest dual-chamber concept photoacoustic sensor module reported to date.

Methods

The sensor module consists of a micro-electrical-mechanical system (MEMS) microphone membrane, which we encapsulated on both sides using wafer bonding technology. During the encapsulation process, the device was exposed to a 100% CO_2-atmosphere, which effectively trapped the CO_2 in the cavities above and below the microphone membrane. This microphone was placed on a thin substrate circuit board and connected to an application specific integrated circuit (ASIC) which features an integrated temperature sensor and digital signal filter for preprocessing of the acoustic data. The microphone assembly was soldered together with a ceramics-packaged MEMS infrared (IR) emitter module onto a component carrier circuit board. Both components were covered by a gold-plated and reflective metal lid. This lid acted as a protective housing and at the same time as a reflector for the IR radiation. The module was contacted using castellated hole side contacts. A photograph of the sensor module without the attached reflector lid can be seen in Fig. 1. The module was connected to an Infineon PSoC 4200M microcontroller-based motherboard which carried voltage supply circuitry, a MOSFET for driving the IR-emitter as a low side switch and a USB-UART bridge was used for communicating with the microcontroller.

During operation, the IR-emitter is driven in a sequence of 18 square-wave pulses at a frequency of 40 Hz. The acoustic signal of the microphone is recorded by the microcontroller and sent to a host-computer after each pulse sequence for post-processing and evaluation.

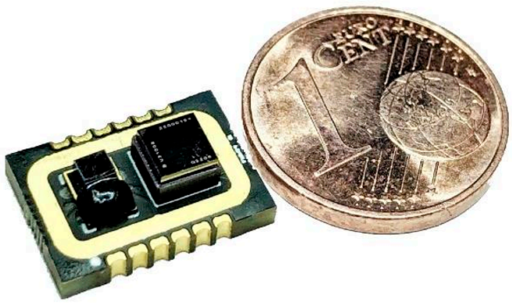

Fig. 1. Developed sensor module with MEMS-detector (left), and IR-emitter (right) (without lid) and a eurocent coin as a size reference.

In post-processing, the microphone signal is bandpass filtered and the RMS value of the signal pulses is determined. The measurement is triggered once every second. To enhance stability, a moving average filter with a window size of 20 seconds is applied. Before each pulse sequence, the integrated temperature sensor is read out. A linear compensation algorithm corrects the slight temperature-dependent influence on the baseline.

Results

In a laboratory gas measurement setup, the sensor module was exposed to a constant gas flow of 500 sccm per minute with varying CO_2 concentrations in the range from 0 to 5000 ppm.

The gas concentration, as well as air temperature, humidity and pressure, were monitored using reference sensors. Fig. 2 depicts the sensor output of our prototype together with the data of the CO_2-reference sensor (GMP343, Vaisala Oyi).

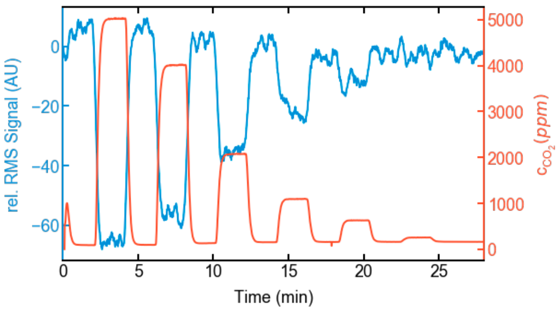

Fig. 2. Averaged RMS signal of our sensor prototype (left) vs. the CO_2 concentration taken from reference sensor (right)

The measurement routine began with a flushing step at zero ppm CO_2 for a duration of two minutes, followed by different concentrations of CO_2 ranging from 5000 ppm to 100 ppm. Each step was held for two minutes and followed by a flushing step with synthetic air for another two minutes.

The sensor sensitivity was determined by evaluating the signal at regions with stable CO_2 concentrations (see Fig. 3).

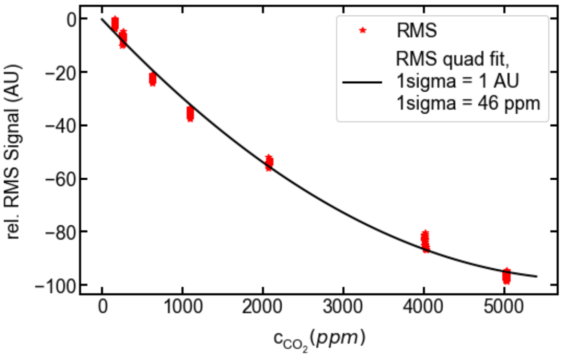

Fig. 3. RMS signal vs. CO_2-concentration for seven different concentrations and quadratic fit curve

Despite the small size of the sensor prototype, we achieve a 3σ-noise level of 138 ppm. The one σ-noise level is 46 ppm. This level of accuracy is appropriate for applications such as the measurement and regulation of indoor air quality.

Acknowledgements

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