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# Development of an Indirect Photoacoustic Sensor Concept for Highly Accurate Low-ppm Gas Detection †

**Ananya Srivastava [1,*], Achim Bittner [2] and Alfons Dehé [1,2]**

[1] Hahn-Schickard-Gesellschaft, 78052 Villingen-Schwenningen, Germany; alfons.dehe@hahn-schickard.de
[2] Georg H. Endress Chair for Smart System Integration, Department of Microsystems Engineering–IMTEK, Albert-Ludwigs-University Freiburg, 79110 Freiburg, Germany; achim.bittner@hahn-schickard.de
* Correspondence: ananya.srivastava@hahn-schickard.de; Tel.: +49-7721-943-155
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**Abstract:** Indirect photoacoustic sensing (PAS) offers accurate low-ppm gas measurements, with an inverse relation of the obtained signal to the measured gas concentration. The gas is sealed in transistor outline (TO) housing using a new method. This provides a relatively a very small volume for the reference gas signal. The gas sensing system features a black body source, highly reflective measurement volumes and TO housing sealed with gas and multiple sensors. $CO_2$ is used for testing and characterizing the sensor sealing and working concepts in the measurement range 0–2000 ppm, with other gases, such as CO, methane, etc., planned to be tested. A PAS signal corresponding to a 4 ppm minimum gas concentration is measured. Allan Deviation measurements provide a theoretical limit of detection of 3.14 ppm, with the integration time of $5.2 \times 10^3$ s.

**Keywords:** photoacoustics; indirect PAS; gas sensor; low-ppm gas measurements; transistor outline (TO) housing; infrared absorption

## 1. Introduction

Indirect photoacoustic gas sensors offer the possibility of self-calibrating, ultra-sensitive and miniaturized sensing systems. They are at least two-chamber systems with reference and measurement chambers. To avoid cross sensitivities to a large number of gas species, the target gas itself is used as the filter medium since it features near-identical spectral characteristics [1]. The generated photoacoustic signal for a non-resonance mode of operation for a small volume is inversely proportional to the volume of the chamber [2]. Keeping this in mind, a new method was employed to hermetically seal the gas accurately in a small chamber with a pressure transducer, which offers an improvement to preliminary indirect PAS prototypes [3]. The attenuation of light due to radiation absorption between the optical source and the reference chamber was used to infer the gas concentration. The performance of this device is compared to similar state-of-the art concepts [4,5].

## 2. Methodology

$CO_2$ is sealed in TO housing, along with a MEMS microphone, a photodiode and an NTC. Along with a novel gas sealing strategy, the sensor system features a custom-built lock-in amplifier PCB. The reference signal is provided by 100% $CO_2$ sealed in the reference chamber, and mass flow controllers (MFCs) are used to vary the gas concentration in the measurement chamber from 0 ppm to 2000 ppm. Figure 1a shows a TO housing variant with tubes for gas flushing. While flushing, the ends of the tube are firmly closed by applying mechanical pressure. The ends are subsequently soldered, sealing the 100% gas concentration with all the sensor components inside a TO package.

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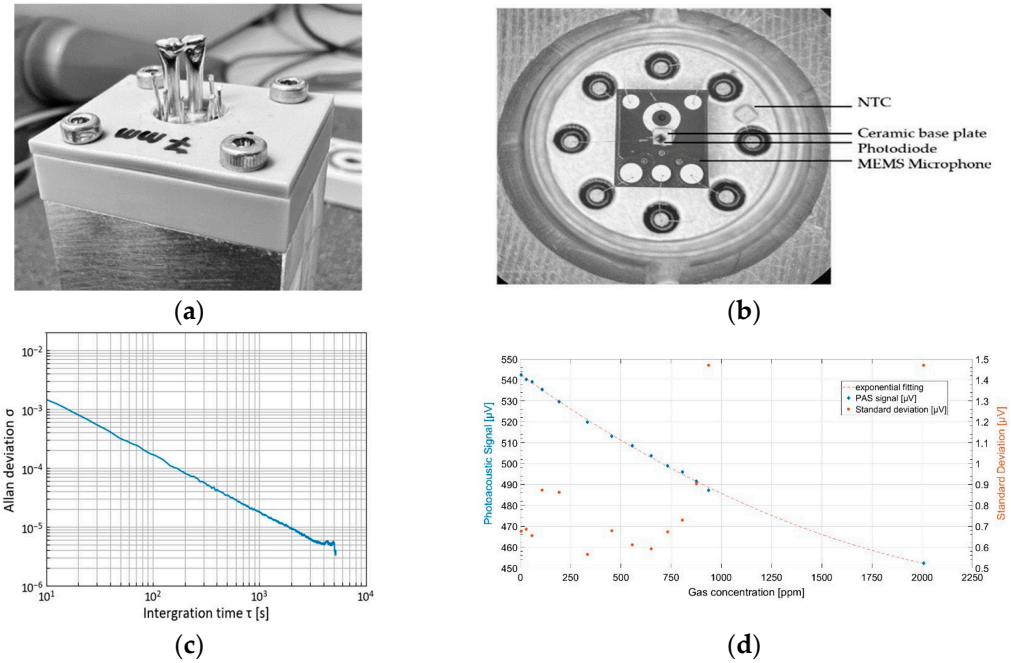


**Figure 1.** (**a**) Sealed TO package in a sensor setup, (**b**) placement of detector elements on a TO housing base, (**c**) Allan Deviation plot with an integration time of $5.2 \times 10^3$ s, and (**d**) PAS signal output between 0 and 2000 ppm fits the negative exponential trend with an R2 score of 0.9992.

## 3. Discussion

Allan Deviation measurements provided a theoretical limit of detection of 3.14 ppm, with an integration time of $5.2 \times 10^3$ s. Gas concentrations of up to 4 ppm were measured. In previous work [4], the resistance welding approach was used to seal the gas in TO housing and long measurement times were used to measure the minimum gas concentration of 250 ppm. In a related work [5], up to 100 ppm $CO_2$ was detected. In this work, the measurement time was limited by the settling time of the lock-in amplifier. It subsequently took nearly 2 min for the standard deviation to decrease <1 µV.

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