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MID-IR LED-based, photoacoustic CO_2 sensor

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Abstract

The technology used to implement CO_2 sensors depends on the requirements in terms of sensitivity, price and robustness. The most common technology for highly sensitive tasks are based on tunable diode laser spectroscopy, while so-called non-dispersive infrared (NDIR) photometers [2] are used in less demanding scenarios such as control air conditioning systems. Most NDIR systems use thermal emitters as light source which are readily available at low cost but require compensation for cross-sensitivities toward other gas species. The detector technology employed in these systems ranges from photodiodes to thermopiles and pyroelectric detectors, all of which require the use of spectral filters to avoid cross sensitivities. Here we present a low-cost photoacoustic-based detector comprised of a microphone in a hermetically sealed chamber filled with CO_2. To excite sound waves a MID-IR LED emitting radiation in the strong CO_2 absorption region around 4.2 µm is used for the first time.

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Keywords:

1. Introduction

The measurement of CO_2 is indispensable in many fields including industrial control systems as well as environmental monitoring applications. Many optical sensor devices offer high resolution, but at the same time can be very expensive depending on the quality of the light source, optical system and the detector used. Despite the costs, tunable diode laser absorption spectroscopy (TDLAS) using IR diode lasers [1] as light source are often applied to

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avoid cross sensitivities with other gas species and achieve high accuracy. The infrared spectral region is eminently suitable to detect gas molecules such as CO_2 because of the strong absorption bands in this wavelength range. A further established approach is the employment of broadband light sources such as thermal emitters. Yet this attempt often requires the introduction of spectral filters and sometimes of a reference path to correct for cross sensitivities and component drifts.

On low-cost spectrum of devices, thermopiles or detectors based on the pyroelectric effect are often used which convert temperature variations into an electrical signal. To compensate for signal drifts due to the ambient temperature, they rely on stable cooling mechanisms. Likewise, IR photodiodes or photoresistors show a strong dependency on temperature. Due to their intrinsically small bandwidth, the influence of temperature leads to a high level of thermal noise reducing the signal to noise ratio (SNR). Photodiodes are also susceptible to the impact of stray light. Here we present an alternative detection technology, namely a photoacoustic approach employing a hermetically sealed chamber filled with CO_2.

2. Sensor design

Although the application of IR LEDs leads to poorer optical properties in comparison to diode lasers, LEDs enable CO_2 measurements in the 4.2 µm region almost without cross sensitivities while they can greatly reduce the overall costs. The spectral bandwidth of the LEDs covers the CO_2 absorption line but is still narrow enough to avoid noticeable interactions with other gas species constituting a CO_2 selective measuring principle. Figure 1 depicts the both, the LED emitter spectrum and the CO_2 absorption spectrum.

The sensor devise thus is composed of a MID-IR LED and a detector unit that consists of a hermetically sealed small chamber containing CO_2 molecules at a high concentration and a MEMS microphone. Utilizing the photoacoustic effect, the excitation energy of a modulated light wave is converted into an acoustic signal that can be easily measured using the microphone. The resulting sound wave is amplified and recorded. Since the detector signal relies on a modulated signal, the influence of stray light is also negligible. In our case, the modulation frequency was set to 1 kHz as can be seen in Figure 2.

Further gas molecules in the space between LED and detector reduce the intensity of the light entering the detector leading to a signal decrease. Hence, the signal strength is an indicator for the concentration of the target gas.

The distance between the LED and the detector crucially determines the concentration resolution range of the sensor. An optical waveguide with a certain optical length that accumulates and focuses the light can be used to adjust the resolution dependent on the application.

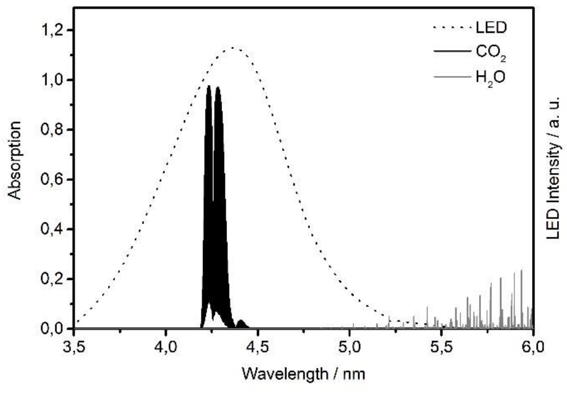

Fig. 1. Relevant spectral distributions of the MID-IR light source, the CO_2 absorption bands and water vapour. Due the negligible overlap between the LED spectrum and H_2O no cross sensitivities with humidity levels emerge.

3. Results

Employing photoacoustic based IR-detectors offers the possibility to increase the selectivity while at the same time maintain the simple setup of standard NDIR systems. Consequently, the CO_2 sensor investigated here uses a MID-IR LED to excite photoacoustic waves in a non-resonant, CO_2 containing, hermetically sealed chamber. To detect the sound waves a MEMS microphone is integrated for the first time in such a setup.

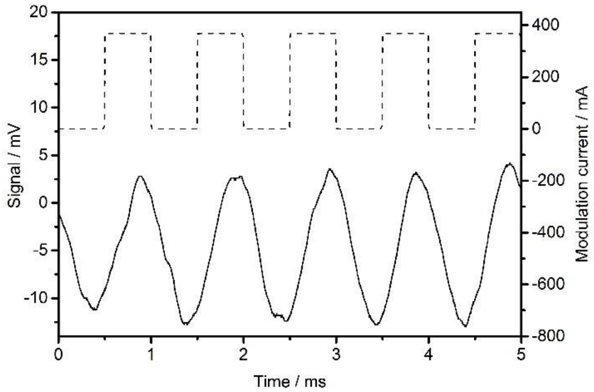

Fig. 2. Photoacoustic sensor signal generated by a LED with a 1 kHz square shaped modulation current. Thermal light sources are not able to excite such high frequency sound waves without the use of mechanical choppers.

Due to the potential for fast modulation of the LED it thus becomes possible to implement new strategies for signal generation in order to reduce the influence of acoustic noise. By tailoring the effective optical path length of the probing light the sensitivity of the gas sensor can easily be adapted to the required concentration range. To this end, we demonstrate the use of low-cost production of mid infrared waveguides that also act as measuring chamber. As opposed to commonly used photoacoustic detecting schemes we use a standard NDIR setup substituting the non-selective detectors currently used with photoacoustic based, highly gas selective IR detectors at low cost.

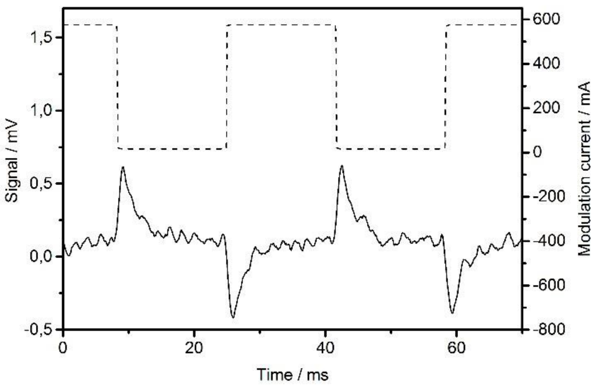

Fig. 3. Slow modulation frequencies allow for monitoring the dispersion of single sound waves in the non-resonant, hermetically sealed detector. Here, the heating and cooling of the gas and the corresponding creation of sound waves are shown.

4. Conclusion

We have presented a gas sensing system for CO2 that can be a serious alternative to conventional measuring techniques providing high sensitivity at low costs. The scheme can be easily adapted for other gases with strong absorption bands in the infrared spectrum. Furthermore, a complete micro-integration of an ultra-low power consuming, mobile sensor device is feasible and can readily be integrated into more complex systems.

Acknowledgements

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