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Frequency Multiplexing Method for Implementing a Reference Channel in resonator-enhanced direct photoacoustic setups

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Summary:

Direct photoacoustic setups offer means for selective and sensitive detection of trace gases, particularly when using light sources with emission profiles smaller that the absorption features of target molecules and acoustic resonators to enhance the acoustic signal. However, those setups still require the measurement of the exciting light source's intensity, which to date is achieved using photodiodes. Here a method relying on the position-dependent excitation of acoustic modes is proposed to determine light intensity and number density independently, which may be used to calibrate the signal's dependence on light intensity without using additional components.

Keywords: photoacoustics, acoustic resonator, frequency multiplexing

Introduction

Optical gas sensors enable the selective detection of trace gases and the miniaturization of setups is crucial to enable scalable, widespread use at low cost. Photoacoustic approaches are particularly suited to achieve this. In direct photoacoustic spectroscopy setups, the signal strength depends on the light intensity as well as the particle density [1]. Consequently, sensor setups based on this principle will suffer from signal changes if the light source intensity changes [2], e.g. by aging or staining. This causes distorted gas measurement result and therefore this effect must be compensated for. At the same time, acoustic resonators feature a rich mode spectrum [3], where different resonance frequencies correspond to spatially varying pressure changes inside the resonator. In turn, the different spatial mode distributions result in coupling efficiencies that depend on the position of the sound source. Hence different resonance frequencies may be used to couple in photoacoustic signals from different position in the vicinity of the acoustic resonator. This may be used to establish a reference channel for direct photoacoustic setups.

Typically, the resonance frequencies for different resonant modes are different, as is the spatial distribution of the associated vibrations coupled into the resonator. To this end, an acoustic resonator may be designed such that, in addition to longitudinal modes, at least one azimuthal or radial mode can be excited. To establish means to udetermine the light intensity, the coupling of the photoacoustic signal generated by a metallic reflector may be adjusted so that the associated signal is coupled into an azimuthal mode, while photoacoustic signals resulting from gas absorption is coupled into a second mode.

In this contribution a moveable light emitting diode (LED) exciting nitrogen dioxide (NO_2) at 400 nm is employed in an acoustic resonator enhanced setup to test the viability of the approach and probe the influence of the coupling efficiency on the sound source position. Simultaneously, the influence of the microphone position inside the resonator is determined.

Experimental

An ultraviolet LED (UV-LED LHUV-0415-A070, Lumileds Holding B.V.) emitting light at 415 nm is modulated at frequencies in the range between 500 Hz – 30 kHz and two microphones (ICS-40619, InvenSense) inside a cylindrial acoustic resonator with inner diameter and length of 11.4 mm and 54.5 mm, respectively, determine the sound wave amplitudes resulting from exciting photoacoustic signals at different positions. One microphone is placed on the symmetry axis of the resonator, while the second microphone is placed at the wall. After amplification of the microphone signals a Lockin amplifier (204, Anfatec Instruments AG) is used to analyze their signals. The resonator may be rotated such that the standing wave distribution may be probed. The setup is depicted in Figure 1.

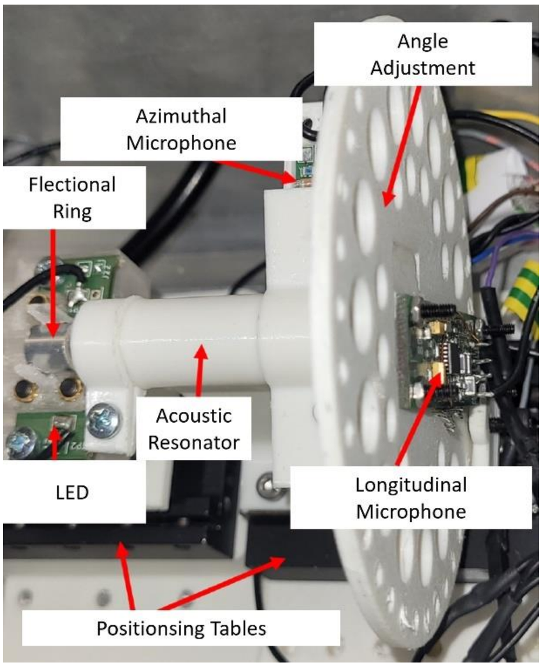

Figure 1: The experimental setup to probe coupling efficiency in the vicinity of the acoustic resonator opening as well as the spatial distribution of the standing wave inside the resonator.

Results

The influence of the position of the photoacoustic source has been determined for various resonator modes and an exemplary result is shown in Figure 2. This highlights the possibility of adjustable the coupling efficiency for different resonance modes. In particular, the most efficient coupling position for the azimuthal mode differs considerably from that for longitudinal modes.

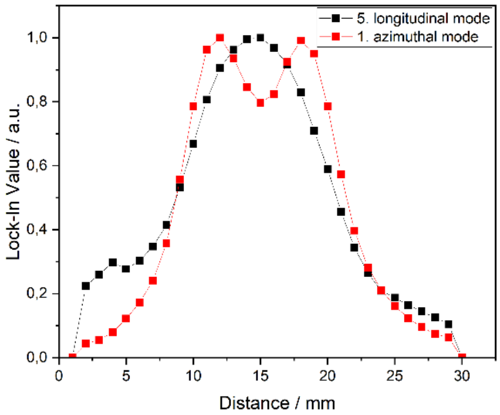

Figure 2: Normalized lock-in values of the radial microphone for two types of modes. The ideal coupling position for longitudinal modes is on the symmetry axis of the resonator, while azimuthal modes show an offset.

The relevance of the placing of microphones for detecting the azimuthal mode is highlighted by the results shown in Figure 3. While the amplitude of longitudinal modes is independent on the rotation, azimuthal modes may only be efficiently detected if the photoacoustic source and the microphone are at suitable angles with respect to each other.

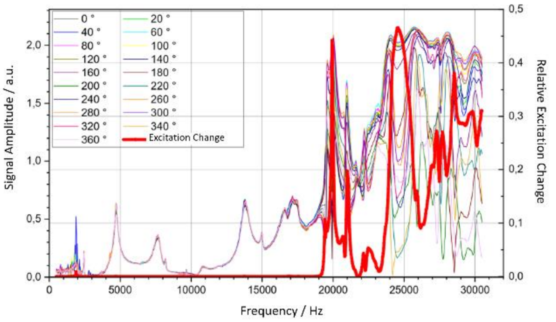

Figure 3: Several resonance frequencies may be excited in the frequency range to 30 kHz. The azimuthal modes spatial distribution makes the positioning the microphone crucial.

Conclusion

The results demonstrate that the relative position of the photoacoustic sound source with respect to the acoustic resonator may be used to tune the coupling efficiency. Since azimuthal and longitudinal modes are also separated in frequency, multiplexing may be used to simultaneously determined photoacoustic signals originating from different locations, which in turn may be used to establish a reference channel.

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