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ICL-QEPAS sensor for the detection and monitoring of respiratory components

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To meet the requirements for multispecies gas analysis in exhaled air, quartz-enhanced photoacoustic spectroscopy is used in combination with an IC-based laser system with an external resonator. The laser system enables coverage of a wavelength range of 280 nm with an output power of several mW. By integrating piezoelectric actuators as tuning elements, high sampling rates can be achieved. In this work, results are presented for the detection of the trace gases methane and ethane by sequential quasi-simultaneous measurements. The requirements of multispecies detection, tuning range, output power and detection rate are met by our work.

I. Introduction

The analysis and measurement of multiple species in a gas mixture are of great importance in many applications. Advanced sensing applications and cutting-edge technology usually require very high sensitivity and accuracy, flexibility, simultaneous and real-time measurements. To achieve the required sensitivity, we rely on one of the latest laser-based gas detection techniques, quartz-enhanced photoacoustic spectroscopy (QEPAS).

QEPAS is a promising approach that can meet the requirements needed for such applications. This technology is a laser-based optical absorption spectroscopy for gas sensing, using compact quartz tuning forks (QTFs) as sound-to-current transducers in a closed gas sample by focusing the beam through the legs of the QTF. In biomedicine, this technology can be used to determine the concentration of a volatile organic compound (VOC) profile in a patient's breath. Via the biomarker profile altered by pathological processes, it allows a disease to be identified unambiguously and non-invasively [1]. Another interesting field of application is environmental monitoring, where such sensors can be used to measure and analyze greenhouse gases. These are of great importance as they have a strong influence on climate change. Therefore, continuous monitoring of concentration limits in critical processes to reduce these levels is imperative [2].

Great potential for improving detection sensitivity is shown here especially in the mid infrared range (MIR) range, since in this range the fundamental rotational vibrational bands are several orders of magnitude more absorbing compared to the near infrared range (NIR) range. With suitable light sources, detection limits in the parts per billion (ppb) range have already been achieved under laboratory conditions [3]. For the high-sensitivity spectroscopy applications in this region, our QEPAS setup uses digital distributed feedback filter (D-DFB) as well as broad tunable interband cascade lasers (ICLs), which, in addition to a compact design, enable CW operation at room temperature with excellent efficiency and low threshold current [4].

II. QEPAS setup

A schematic diagram of the optical and electrical setup used to automatically measure the output of the QTF is shown in Fig. 1. The setup consists of the QTF integrated in a gas cell, transimpedance amplifier (TIA), FPGA, analog-to-digital and digital-to-analog converters (ADCs/DACs). By means of FPGA technology, the function generator and the lock-in amplifier are realized together with the laser and thermoelectric cooler (TEC) control in a compact electronic unit with appropriate control algorithms. This enables the execution of automated measurement series and processing of the acquired signals.

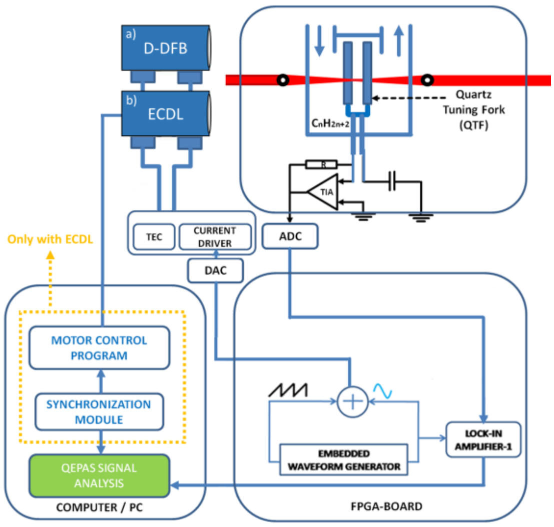

Figure 1: The QEPAS setup consists of the QTF integrated into a gas cell, a transimpedance amplifier (TIA), an FPGA, analog-to-digital and digital-to-analog converters (ADCs/DACs), a function generator, and the laser and TEC control unit.

The QEPAS measurements were performed by focusing the laser light through the gap between the prongs of the QTF and acquiring the 2f signal. Two different types of lasers are used as the light source:

a) D-DFB lasers stand out with an excellent signal-to-noise ratio as well as a low detection limit, but due to their low tunability they are not suitable for the planned detection of multi-species.

b) Our compact and robust IC-ECL with a center wavelength at 3.4 µm. The system has a minimum output power of 1 mW over a wavelength range of 280 nm and enables continuous and mode-hop free scanning of a defined frequency range of several GHz via a piezoelectric actuator.

III. Results

To verify the broad tunable IC-QEPAS sensor for its use in the detection of trace gases present in the breath, we created a gas mixture of methane (30 % CH_4) and ethane (70% C_2H_6). Ethane in particular is an indicator of excessive free radical damage in the organism (oxidative stress). This is a concomitant of many diseases such as diabetes mellitus or chronic obstructive pulmonary disease. To improve the detection limit, the molecular spectroscopic database HITRAN was used to analyze the absorption bands in the wavelength range to be investigated so that the strong absorption lines could be identified (see Fig. 2).

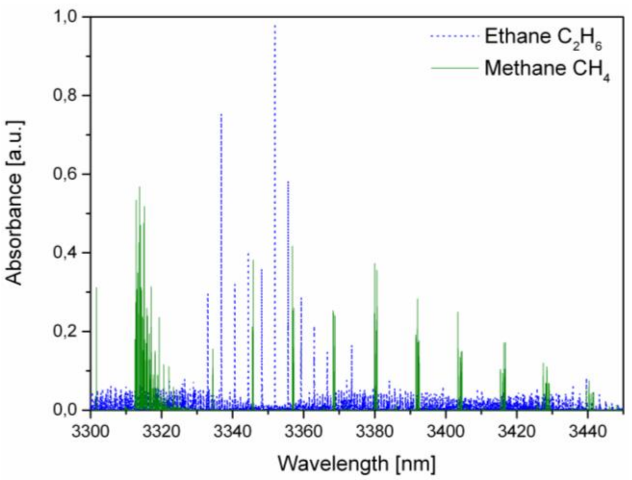

Figure 2: Simulated data of methane and Ethane for the wavelength range from 3.3 µm up to 3.45 µm from HITRAN, which can be covered by the IC-ECL system [5].

The IC-ECL was tuned to the wavelength of interest by driving the motor. To achieve a wide tuning range without mode hops, the operating current was modulated simultaneously while scanning the wavelength range with the piezoelectric actuator. The detected signals were evaluated and compared with the simulated data from HITRAN, as shown in Fig. 3 and 4. The measured values agree well with the simulated values. The proposed configuration makes it easy to measure several species quasi simultaneously. Indeed, the measurements are performed with the same IC-ECL. Therefore, in a single complete scan of the IC-ECL area, all target species absorbing in this area can be analyzed.

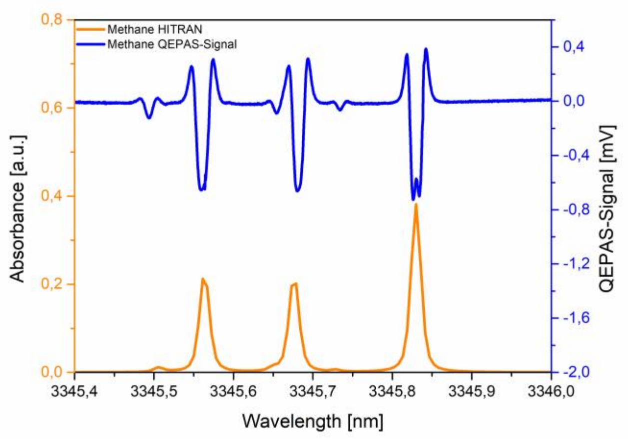

Figure 3: Measurement of the 2f signal of methane. 3 absorption lines of methane could be clearly identified and agree well with the simulated data of HITRAN [5].

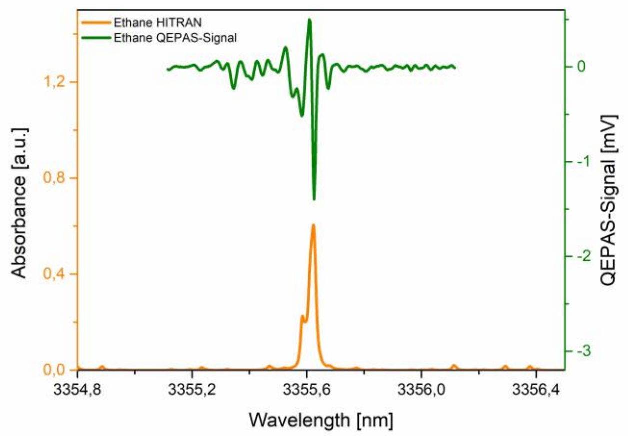

Figure 4: Measurement of the 2f signal of ethane. The measured signal shows deformation due to superposition. Not shown is the influence of methane. Nevertheless, the measurement agrees well with the simulated data of HITRAN [5].

IV. Conclusions

In this paper, a compact and low-cost multispecies detector system consisting of quartz tuning forks with IC-ECL is proposed. The proposed QEPAS method enables real-time quasi-simultaneous monitoring of multiple gases with a simple setup. To meet the requirements of mobile sensing applications, optical and electronic devices were made compact by reducing their size.

Acknowledgments

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