Development of Laser based Spectroscopic Trace-Gas Sensors for Environmental Sensor Networks and Medical Exposure Monitors

Stephen G. So, Daniel Chang, Omar Al'Rifai, Gerard Wysocki, Anatoliy A. Kosterev, Frank K. Tittel
Electrical and Computer Engineering Department, Rice University
6100 Main St. MS 366, Houston, Texas, USA
steveso@rice.edu

Abstract: We report wavelength modulated TDLAS/QEPAS trace gas sensors with reduced size, efficiency, and cost for use in environmental sensor networks and medical exposure monitors. CO_2 measurements with a 2µm diode laser dissipate <1W.

OCIS codes: (300.6360) Spectroscopy, laser; (120.6200) Spectrometers and spectroscopic instrumentation

1. Introduction

Infrared laser absorption spectroscopy is an established technique for trace-gas sensing, but laser based chemical sensors typically require >100W of power, are implemented in a tabletop form factor and typically cost ~$35,000 USD,. Any one of these factors precludes these sensors to be used as dense, large area, distributed environmental trace-gas sensor networks [1], wearable industrial gas or carcinogen exposure monitors and portable medical biomarker breath analyzers [2],

In order to achieve low cost, high efficiency, and an ultra compact footprint, we optimized the sensor characteristics and control for a miniaturized sensor platform. Due to the similarity of the control, signal measurement, and data analysis required for Tunable Diode Laser Absorption Spectroscopy (TDLAS) [3], Photoacoustic Spectroscopy (PAS) [4], and Quartz-Enhanced Photoacoustic Spectroscopy (QEPAS) [5], a single platform can be implemented for a sensor which can be based on these sensor architectures. A complete trace gas sensor consists of a laser source, absorbance detection unit (optical multipass cell and detector, photoacoustic cell and microphone, quartz tuning fork), dedicated control and data acquisition electronics, and an energy source (e.g. batteries).

2. Sensor System Platform

The platform [6] depicted in Fig. 1 provides: 1) high efficiency laser driver and pulse width modulation (PWM) thermoelectric cooler controller (TEC), 2) 2*f* and 3*f* lock-in amplifiers with a reference frequency resolution of ~0.01Hz, and 3) onboard signal processing.

Figure 1: Photograph of sensor board, US Quarter, and quartz tuning fork. This platform was used to measure CO_2 at 2µm using both TDLAS and QEPAS

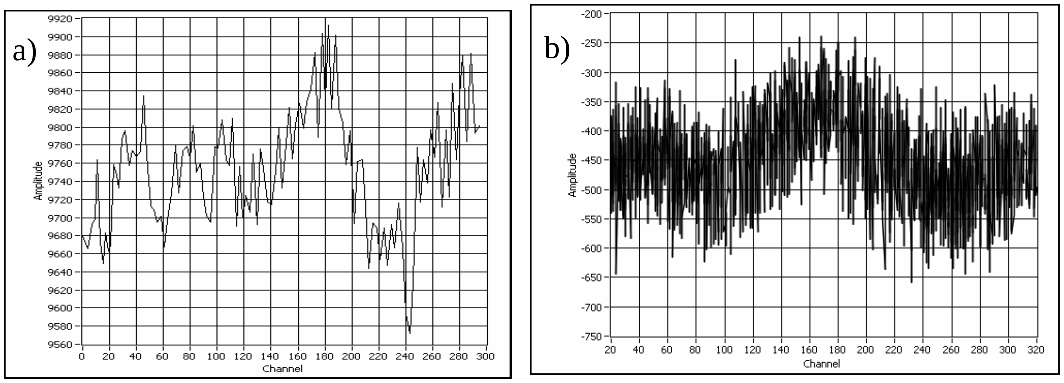

Figure 2: Example (a) TDLAS and (b) QEPAS 2*f* spectrum of ambient CO_2 using a 2μm diode laser with a 4mW output power.

3. Results

In this paper a prototype instrument using a distributed feedback (DFB) diode laser with ~4mW output power targeting a CO_2 absorption line at λ=2.0056 μm in $2\nu_1 + \nu_3$ combination band will be reported for both QEPAS and TDLAS. For both types of sensor architectures, the actual current of the control and acquisition systems measured with an ammeter at the power entry terminals was 56mA (measured with TEC driver and laser driver off), resulting in an electronic power dissipation of 0.201 W at the 3.6V nominal Li-Ion battery voltage. With TEC driver and laser driver on, total power consumption of ~ 0.75 W was required to detect ambient CO_2 using: 1) QEPAS without acoustic micro-resonator with a CO_2 detection limit of ~300-400 ppm in 1 second (similar to [7]) and 2) TDLAS with 30cm path length and extended InGaAs detector with a CO_2 detection limit of ~100ppm in 1 second (see Fig. 2). This was accomplished with a bill of materials cost of < $250 for the developed system electronics. A significant improvement of the CO_2 detection limit can be achieved at wavelengths longer than 2μm (~50 times at 2.7μm and ~2000 times at 4.2μm). Further results obtained with a TDLAS configuration based on a 2.7μm DFB diode laser (Nanoplus 506-2703-2) using a 10cm optical pathlength will be reported, with projected minimum detection limits when using a 4.2μm quantum cascade laser.

4. Conclusion

With these sensor characteristics, wireless sensor networks of low cost, battery powered sensors can now be deployed to measure gas fluxes, localize atmospheric, geological and industrial sources and sinks, and create concentration maps in real time. The ultra-compact size can also be used to monitor exposures to trace chemicals in real time, suitable to provide environmental risk factor data (i.e. carcinogens) in diseases. Our platform can be modified to operate with robust TDLAS, PAS, or QEPAS based detection, providing flexibility for various trace-gas sensor applications and deployments.

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