Ultra-compact, high efficiency, quartz-enhanced photoacoustic spectroscopy based trace gas sensor platform

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Abstract: An ultra-compact trace gas sensor platform based on photoacoustic spectroscopy using a quartz tuning fork (QTF) and components-off-the-shelf has been developed for sensor networks. Sensitivity limited by the intrinsic QTF thermal noise has been demonstrated.

Quartz-enhanced photoacoustic spectroscopy (QEPAS) [1] provides a sensor solution which is significantly less in cost and size than most sensors capable of real time optical trace gas detection while preserving the high detection sensitivity and selectivity. Reduction of size (and weight) of optical trace gas sensors is important for many real-world applications, such as in-situ medical breath analysis and in monitoring of manned spacecraft environments. Low-cost sensors with low power consumption are particularly needed in applications of trace gas sensor networks, such as wide-area environmental air quality monitoring, semiconductor fabrication, process gas contamination, and source localization for security applications.

This presentation will report a robust, handheld, battery (and/or solar) powered sensor using a fiber coupled near-infrared (NIR) telecom components-off-the-shelf capable of reaching part-per-million (ppm) detection limits in real-time with minimal parts cost. The first prototype trace gas sensor footprint is 7.62 cm x 12.7 cm x 3.81 cm and has a maximum power draw of less than 4W including laser excitation and cooling (see Fig. 1). The complete sensor has a mass of less than 1 kg (consisting of 2 circuit boards 100 g each; copper heat sink 100 g; diode laser, fiber components , reference cell and tuning fork module 300 g) without batteries.

A fiber-coupled NIR distributed feedback (DFB) telecom diode laser with an integrated thermoelectric cooler (TEC) and thermistor is mounted in a butterfly socket on a circuit board (see Fig 1 LHS). A fiber beam splitter sends a fraction of the optical power to a reference cell with a known target gas concentration for line-locking and power normalization. The remainder of the optical power is collimated with a fiber collimator, and is sent through to a micro-resonator enhanced quartz tuning fork (QTF) assembly [2]. A trans-impedance pre-amplifier converts the QTF piezo-current into a voltage for an embedded lock-in amplifier system based on an ultra-low power microcontroller. The lock-in output is processed and saved into embedded flash memory and subsequently sent via USB to a host computer, or broadcast by means of an embedded IEEE 802.15.4 radio for sensor networking.

The implementation of the high efficiency hardware and software for QEPAS has been developed using the experience acquired from experiments with fixed point digital signal processing in semiconductor laser based trace gas sensors [3]. The laser power supply requirements dominate, with 3W maximum available for the TEC and 0.5W maximum for the diode laser driver. The remainder of the electronics draws less than 0.5W for all control and processing functions which include real-time direct digital synthesis and filtering to produce low distortion, tunable modulation and demodulation waveforms, ambient temperature and pressure measurement, and line locking via laser current control and laser temperature proportional-integral-derivative (PID) control. The sensor exhibits close to QTF thermal noise limited behavior (Fig. 2) and demonstrates simultaneous temperature control and current tuning of a telecommunications diode laser at 1.5 microns.

1. A.A. Kosterev, Yu.A. Bakhirkin, R.F. Curl, and F.K. Tittel, "Quartz-enhanced photoacoustic spectroscopy," Optics Letters 27 1902-1904 (2002).
2. A. A. Kosterev, F. K. Tittel, D. Serebryakov, A. Malinovsky and I. Morozov, "Applications of Quartz Tuning Forks in Spectroscopic Gas Sensing", Rev. Sci. Instr. 76, 043105 (2005).
3. S. G. So, G. Wysocki, J. P. Frantz, F. K. Tittel, "Development of Digital Signal Processor controlled Quantum Cascade Laser based Trace Gas Sensor Technology", to appear in IEEE Sensors Journal, October 2006.

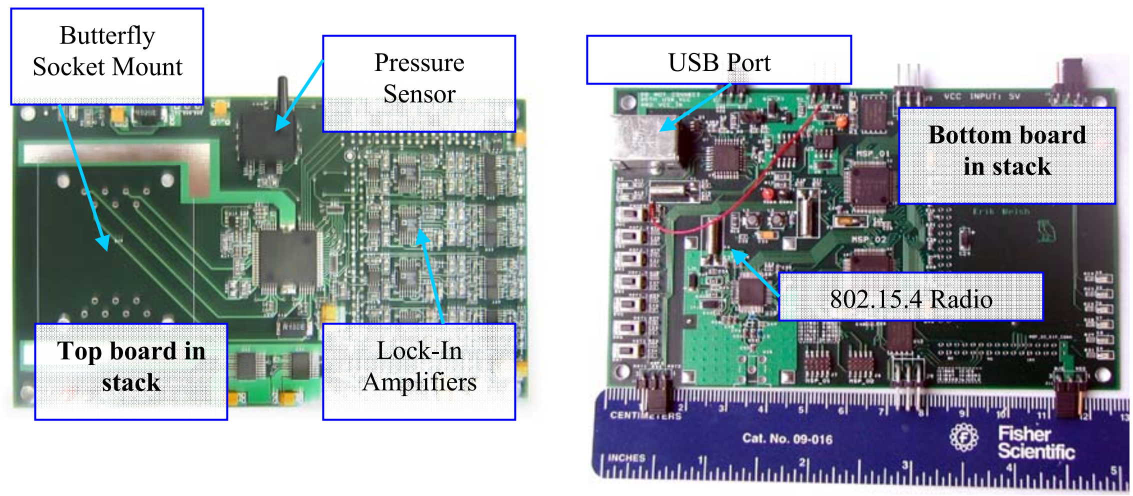

Figure 1: Photograph of circuit boards developed for a miniature QEPAS trace gas sensor system.

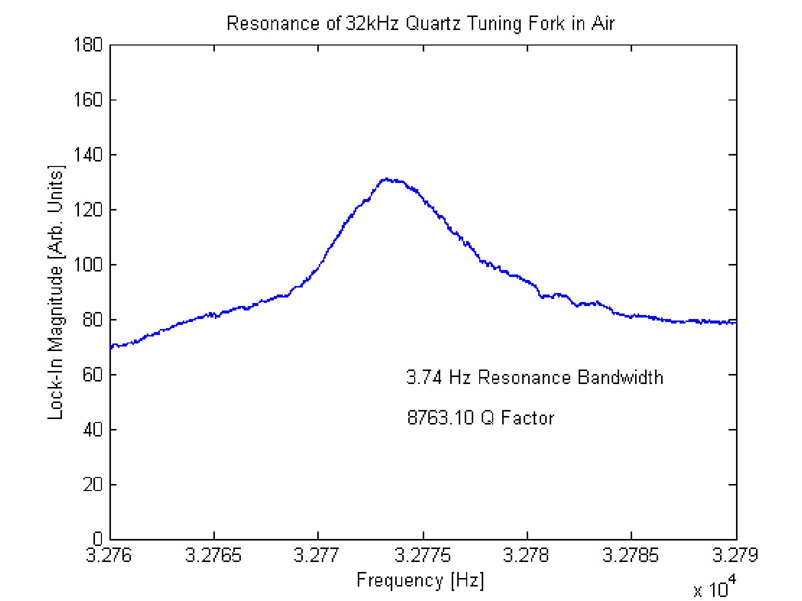

Figure 2: Thermal noise of a 32.7 kHz quartz tuning fork measured by an embedded lock-in amplifier. Q-factor is measured independently.