Recent advances in quartz-enhanced gas-phase photoacoustic spectroscopy

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Abstract: Quartz crystal tuning forks were used as resonant microphones for photoacoustic gas sensing. This results in a novel technique for performing gas analysis of extremely small samples and sensor immunity to external acoustic noise.

OCIS codes: (300.6430) Spectroscopy, optoacoustic and thermo-optic; (280.3420) Laser sensors

Photoacoustic spectroscopy (PAS) is an established method of experimental physics [1]. It is based on detection of sound waves produced in an absorbing medium when the medium is illuminated by modulated radiation. Unlike direct absorption spectroscopy, this technique is background-free, i.e. the detected signal is directly proportional to the absorbed radiation energy. Thus, PAS sensitivity is not limited by fluctuations of the light source power. When applied to chemical sensing in the gas phase, PAS allows the detection of absorption lines with peak absorption coefficients in the $10^{-9} - 10^{-10}$ cm^{-1} range, depending upon the available laser power [1-3]. However, such high sensitivities are difficult to attain in real environments outside the laboratory because of the high PAS sensitivity to background acoustic noise. We propose a modification of PAS that allows to overcome this limitation with an added advantage of using an ultra-small gas sample volume.

A common approach used to detect the acoustic signal generated by modulated laser radiation in a weakly absorbing gas utilizes an acoustic resonator filled with the gas sample. The absorbed laser power is accumulated in the acoustic mode of the resonator for $Q/2\pi$ oscillation periods, where Q is the quality factor of the resonator, usually Q~40-200. In 2002 we proposed and demonstrated a technique to accumulate acoustic energy not in the gas but in a high-Q crystal quartz which serves as a resonant microphone due to its piezoelectric properties [4]. We refer to this approach as Quartz-Enhanced Photoacoustic Spectroscopy, or QEPAS. A quartz crystal tuning fork (TF) which is used as a frequency standard in electronic clocks was selected for this application from a variety of commercially available crystals. At atmospheric pressures the TF Q is up to 13 000 (depending on its dimentions). Its geometry makes it easy to excite the piezoelectrically active symmetric vibration mode by placing the laser beam waist between the TF prongs. On the other hand, such a TF is greatly insensitive to acoustic waves from distant sources because of being an acoustic quadrupole. A standard clock TF has a resonance close to 32 768 (2^{15}) Hz. This frequency is sufficiently low compared to the V-T relaxation rate in most gases, and at the same time it is sufficiently high so that environmental acoustic noise becomes negligible.

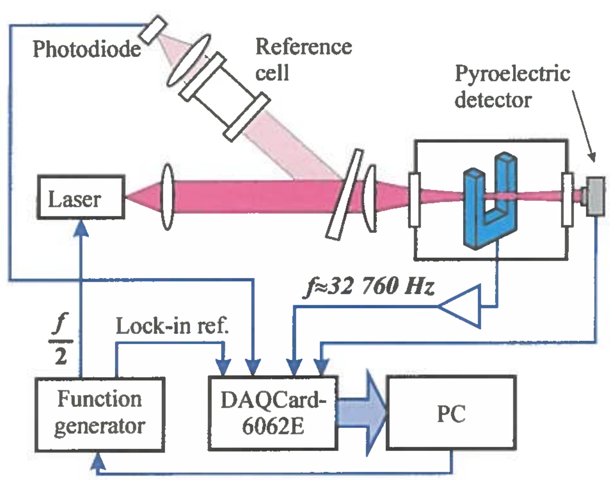

Fig. 1. Simplified schematic of QEPAS laboratory setup. Triangle represents one-chip transimpedance preamplifier with a 10 MΩ feedback resistor followed by a SR560 low-noise amplifier (Stanford Research Systems).