Near-infrared Quartz Enhanced Photoacoustic Sensor for Sub-ppm Level H_2S Detection based on a Fiber-amplifier Source

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Abstract:
An enhanced near-infrared quartz enhanced photoacoustic spectroscopy (QEPAS) sensor for sub-ppm level H_2S detection by means of a fiber amplified 1582 nm distributed feedback laser was developed. Experimental studies demonstrated that a H_2S detection sensitivity of 142 ppbv can be achieved by the reported power-boosted QEPAS sensor at atmospheric pressure and room temperature.

OCIS codes: (280.3420) Laser sensors; (300.6360) spectroscopy, laser; (110.5125) photoacoustics;

1. Introduction

There is considerable interest in sensor development for in situ measurements of hydrogen sulfide (H_2S) concentration in applications such as atmospheric chemistry, environmental monitoring and in the chemical industry. Quartz enhanced photoacoustic spectroscopy (QEPAS) is one of the reliable technique for H_2S detection, in which a commercially available quartz tuning fork (QTF) acts as an acoustic wave transducer to detect the sound signal generated by the trace gas absorbing an excitation laser beam [1]. A fundamental advantage of QEPAS is that the performance of QEPAS-based sensors can be improved as the excitation laser power is increased. This makes QEPAS based sensor performance benefit from the enhanced excitation laser power. An erbium doped fiber amplifier (EDFA) is an excellent choice for boosting laser power as it can achieve amplification factors of up to 3 orders of magnitude for input signals that occur within the gain bandwidth of the dopant, in a wide range of wavelengths (0.65–2 μm) [2]. In this paper, we describe a QEPAS sensor combined with an EDFA for H_2S detection. The performance of the power-boosted QEPAS sensor was investigated and optimized.

2. Experimental setup

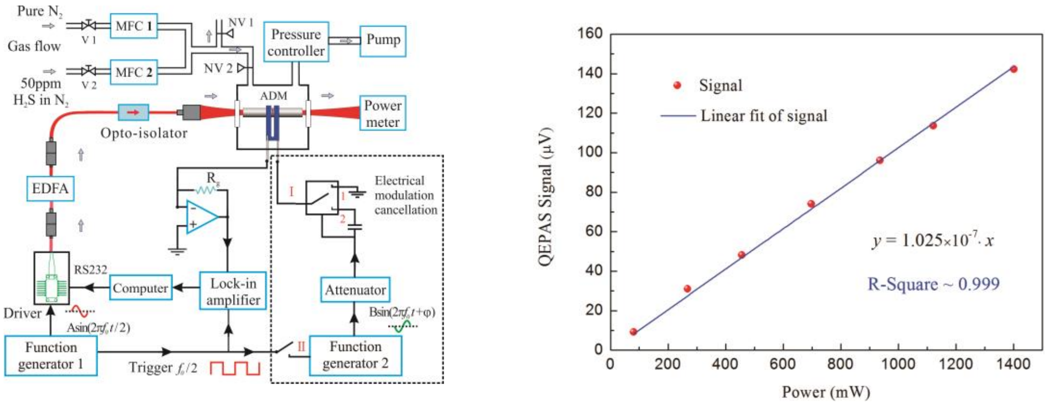

Fig.1. Left: Schematic of the power-boosted QEPAS sensor. MFC: mass flow controllers; NV: needle valve; V: valve; ADM: acoustic detection module. Right: Power-boosted QEPAS signal as a function of the power measured after the ADM.

A schematic of the power-boosted QEPAS sensor for H_2S detection is shown in Fig. 1 (left). The laser beam from a DFB laser operating at 1582.1 nm was coupled to an EDFA which offers an adjustable output power from 30 mW to 1500 mW. The opto-isolator was utilized to protect the DFB laser against back reflections. The laser beam was focused into a 100 μm-diameter light spot by a fiber-coupled focuser before it passed through the acoustic micro-resonator (AMR) which improves the QTF detection sensitivity in an “off-beam” configuration [3]. Electrical modulation cancellation method was adopted to reduce the noise caused by stray light from the EDFA laser output beam [4]. The acoustic detection module (ADM), incorporating a QTF and an AMR, was enclosed inside a gas enclosure. Two mass flow controllers (MFCs) and two gas cylinders constituted the gas mixing and sampling system. A pressure controller and a vacuum pump were used to control the sensor system pressure. A 2*f* wavelength-modulation spectroscopy (2*f*-WMS) approach was implemented by applying a sine wave to the laser to modulate the laser wavelength. An experiment to check the saturation level was carried out, at a concentration level of 50 ppmv H_2S and an optimal modulation depth of 20 mA, to avoid a nonlinear sensor response from the saturation effect [5]. The measured QEPAS peak values for different power levels are reported in Fig. 1 (right). The obtained R^2 value of 0.999 proves the linear response of the sensor to laser power and confirms that the sensor had not reached its saturation condition. In this case, further evaluation tests were performed at an incident laser power of 1402 mW.

3. Optimization of power-boosted QEPAS sensor for H_2S detection

The linearity of this sensor was evaluated by measuring its response to the different H_2S concentrations from 0 ppm to 50 ppm. The data acquisition time was set to1 s and the results of measurements are plotted in Fig. 2 (left). The results confirm the linearity of this sensor response to the H_2S concentration. A 1σ minimum detectable concentration limit of 734 ppb was obtained at 1 s data acquisition time and 1402 mW laser power based on Fig. 2 (left). The time constant of the lock-in amplifier was at 300 ms corresponding to a detection bandwidth of $\Delta f = 0.833$ Hz. Hence the corresponding normalized noise equivalent absorption (NNEA) coefficient for H_2S is 9.8×10^{-9} W $cm^{-1}/\sqrt{Hz}$. To evaluate the long term stability of this sensor an Allen–Werle deviation analysis was performed. The ADM was filled with pure N_2 at atmospheric pressure and room temperature, and the laser frequency was locked to the H_2S absorption line at 6320.6 cm^{-1}. The result of this analysis is shown in Fig. 2 (right). Based on the data, the optimal detection sensitivity can be reduced to 142 ppb for a 67 s integration time [6].

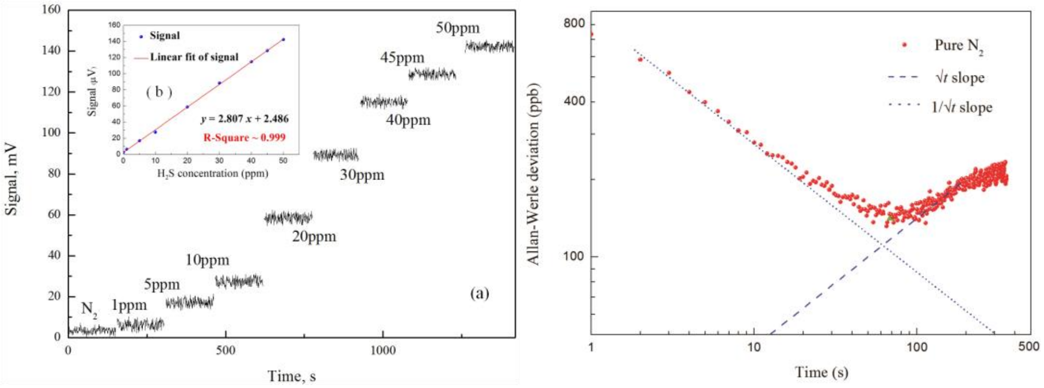

Fig. 2. Left: (a) Power-boosted QEPAS signal repetitively recorded as a function of time for H_2S concentration values ranging from 1 ppm to 50 ppm. (b) Same data averaged and plotted as a function of H_2S concentration. Right: Allan–Werle deviation as a function of the data averaging period. Solid circles trace: laser frequency was locked to a H_2S absorption line at 6320.6 cm^{-1}, data acquisition time 1 s. Dotted line: $1/\sqrt{t}$ slope. Dashed line: $\sqrt{t}$ slope.

4. Conclusions

A power-boosted QEPAS-based H_2S sensor system was developed using an EDFA and a 1582 nm DFB laser. The sensor achieved H_2S detection sensitivity of 142 ppb with an integration time of∼67 s at atmospheric pressure and room temperature with a laser power of 1.4 W. Further improvement of the detection sensitivity should be feasible for an on-beam ADM configuration by improving the beam quality of the high power laser output from the EDFA by means of a more efficient optical beam collimator.

5. References

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