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# Optimization of Microresonator Parameters for a Quartz-Enhanced Photoacoustic Spectroscopy Sensor

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**Abstract:** A Quartz-Enhanced Photoacoustic Spectroscopy based gas sensor was optimized to improve its compact spectrophone design and performance. The impact of a 2-tube microresonator geometry on the detected signal and signal to noise ratio (SNR) was investigated. Experimental studies demonstrate that the *l*=4.4mm long tubes (ID=0.5mm) result in a significantly enhanced SNR.

**OCIS codes:** (300.6360) Spectroscopy, laser; (280.3420) Laser sensors; (280.4788) Optical sensing and sensors

## 1. Introduction

Quartz-enhanced photoacoustic spectroscopy (QEPAS) sensor technology is based on a new approach to photoacoustic detection which employs a quartz tuning fork (TF) (see Fig. 1 a) as a resonant acoustic transducer [1,2]. A QEPAS sensor detects the weak acoustic pressure wave that is generated when optical radiation interacts with a trace gas. The weak pressure wave excites a resonant vibration of a TF which is then converted into an electric signal by the piezoelectric effect. Subsequently, the electric signal, which is proportional to the concentration of the gas, is measured by a transimpedance amplifier. Merits of QEPAS compared to conventional resonant photoacoustic spectroscopy include QEPAS sensor immunity to environmental acoustic noise, a simple absorption detection module design, and its capability to analyze trace gas samples of ~1 $mm^3$ in volume.

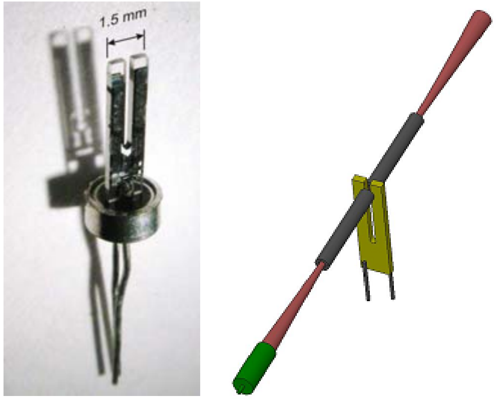

Fig.1 a): A photograph of a typical TF with top part of the TF can is removed. b): A TF with 2-tubes microresonator.

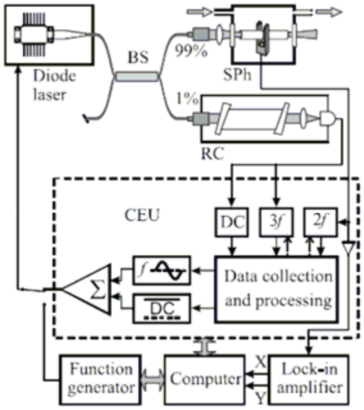

Fig.2 The experimental setup for optimization of microresonator parameters

In order to enhance the amplitude of the photoacoustic signal, it is advantageous to place a TF within a microcresonator composed of two thin tubes (see Fig. 1 b), so that the microresonator yields a signal gain from 10 to 20. To-date, we have investigated the sensor performance with *l*=4mm, 4.4mm and 5mm long metal tubes with ID=0.4 mm, 0.5 mm, 0.58 mm, 0.6 mm, 0.76 mm and 0.084 mm.

## 2. Experimental description

The experimental setup for the optimization of the microresonator parameters is shown in Fig. 2. A near-infrared fiber-coupled distributed feedback (DFB) diode laser (JDS Uniphase model CQF935⁄908-19600) was used as the

QEPAS excitation source. The diode laser output was split into a 1:99 ratio by means of a fiber beam splitter (ThorLabs 10202A-99-APC). A small fraction of the laser light was sent to a commercial fiber-coupled reference gas module (Wavelength References, Mulino, OR) containing a sealed cell filled with a mixture of 5 Torr $C_2H_2$ and 145 Torr $N_2$, a fiber collimator, and a photodiode. The remaining laser power was directed to a spectrophone consisting of the TF and two tubes forming the acoustic microresonator. The spectrophone was placed into a vacuum-tight enclosure (the inner gas volume is $V \sim 1$ cm$^3$ when the spectrophone is installed) equipped with two sapphire windows and gas inlet and outlet. $C_2H_2$ in $N_2$ (10 ppmv) was used as a convenient target gas whose flow was set to 100 ccm. A control electronics unit (CEU) was employed to measure $f_{TF}$ and $Q$-factor of the TF, to modulate the laser current at $f_L = 1/2\, f_{TF}$, to lock the laser wavelength to the targeted absorption line and to measure the current generated by the TF in response to the photoacoustic signal. For a specific length tube configuration, we varied the gas pressures by means of a pressure controller (MKS Type 649) to obtain the signal amplitudes for different gas pressures. Finally a comparison was made to determine the optimal parameters for the microresonator.

## 3. Experimental results

The sensor performance was evaluated based on the SNR with a calibrated $C_2H_2$ gas mixture. In Ref. [3] it was shown that the TF noise is inversely proportional to the square root of the equivalent resistor $R$ of the TF. Therefore, the SNR is proportional to the product of signal amplitude and $\sqrt{R}$ of the TF. Figure 3 displays the SNR comparison for several microresonator configurations (where K is a constant). The two gaps between TF and microresonator tubes are 50μm except for where stated differently in the plot legend. Based on these results we conclude that the $l$=4.4mm tubes yield the highest SNR.

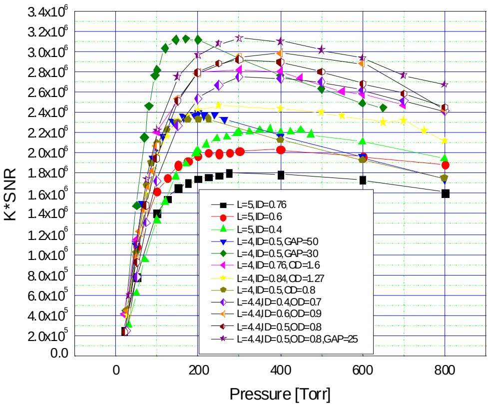

Fig.3 SNR comparison for several microresonator configurations.

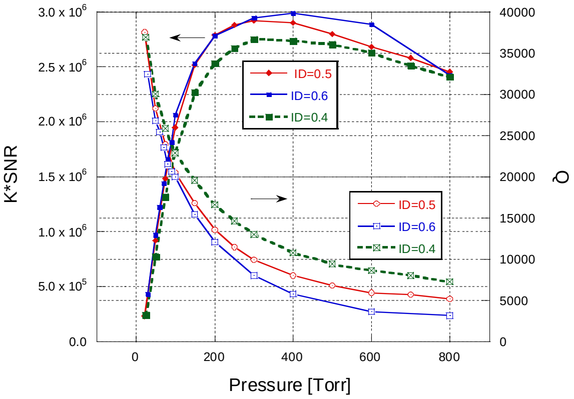

Fig.4 SNR optimization based on Q measurements.

The SNR and $Q$ plots of the 4.4mm-long tubes with 0.4mm, 0.5mm and 0.6mm inner diameters (ID) are shown in Fig. 4. We selected the ID=0.5 for the spectrophone design, although ID=0.4 results in somewhat higher SNR at >300 Torr pressure. The reason for this choice is the higher $Q$-factor for ID=0.5, which ensures higher immunity to environmental acoustic noise. In Fig.3, the two top curves (purple and olive) represent the results when the gaps between the TF and the tubes are set to 25μm and 30μm, respectively. This parameter also affects the SNR; namely, a smaller gap yielded higher SNR.

In conclusion, the optimal microresonator parameters are $l$=4.4mm and ID=0.5mm, with the two gaps between TF and tubes set to between 30μm and 50μm.

## 4. References

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