Micro-resonator Parameter Optimization of a QEPAS Spectrophone using a Custom Quartz Tuning Fork with large Prong Spacing

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Abstract: A Quartz-enhanced photoacoustic sensor using a custom quartz tuning fork with large prong spacing was realized and optimized by improving its spectrophone design and performance. The impact of two-tube and single-tube on-beam micro-resonator (mR) geometries on the detected signal and signal-to-noise ratio (SNR) was investigated. Experimental studies demonstrated that a single-tube configuration offers a shorter mR and a higher SNR than two-tube configuration.

OCIS codes: (300.6360) spectroscopy, laser; (280.3420) Laser sensors; (280.4788) optical sensing and sensors.

1. Introduction

Quartz enhanced photoacoustic spectroscopy (QEPAS) is an alternative approach to photoacoustic detection, using a quartz tuning fork (QTF) as a sharply resonant acoustic transducer instead of a microphone [1]. One of the fundamental features of the QEPAS technique, inherited from photoacoustic spectroscopy (PAS), is that it is excitation wavelength independent. Light sources from UV light emitting diodes (LEDs) to the mid-IR quantum cascade lasers (QCLs) have been used in QEPAS sensors for atmospheric monitoring, industrial process control and agricultural biogas detection applications. However, a prong spacing of 300 μm for commercial QTFs limits their applications with lasers having a poor quality beam profile, such as a stripe laser or a THz QCL. The issue was addressed by designing and realizing custom QTFs with prongs spacing of up to 1,000 μm [2]. Recently the first demonstration of THz QEPAS based gas sensor with a bare custom QTF was reported [3]. However, in order to enhance the amplitude of the QEPAS signal, it is advantageous to acoustically couple the QTF with a micro-resonator (mR) system. To-date, we have investigated the mR performance with different geometric parameters and configurations for a QTF with prongs spacing of 800 μm [4,5].

2. Optimization of geometric parameters for a two-tube on-beam mR geometry

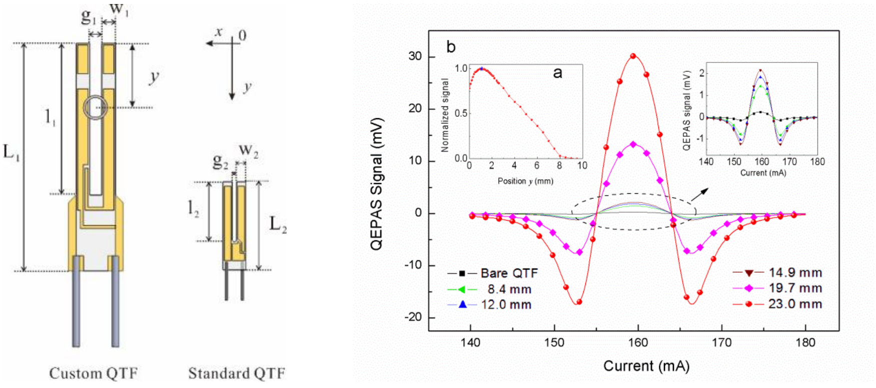

Fig. 1. Left: custom QTF with an on-beam mR configuration and standard bare QTF with respective notation of their dimensions. Right: (a) The normalized signal amplitude as a function of the mR (the inner diameter of 1.3 mm, the length of 12 mm) vertical axial position. (b) Second-harmonic QEPAS signal for the sensor with five different mRs. The signal of the fiber-amplifier-enhanced QEPAS sensor with a bare custom QTF was also shown. All spectra were acquired at atmospheric pressure (P_0= 760 Torr) and room temperature (T= 297.2 K).

The custom QTF and standard QTF are schematically shown in Fig. 1 (left). The custom QTF has a similar geometry as the standard QTF, but is ~4.6 times larger. A two-tube on-beam QEPAS configuration is used to improve the detection sensitivity with respect to the case of a bare QTF [4]. The second-harmonic QEPAS signals obtained with six different mRs is shown in Fig. 1 (right). These studies revealed that the optimized length of the tube for a custom QTF was 23 mm (the total length of two tubes is 46 mm), and that the use of an optimized mR can improve the signal-to-noise ratio (SNR) by a factor of up to ~40, compared to a bare custom QTF.

3. Optimization of geometric parameters for a single-tube on-beam mR geometry

In order to further shorten the mR length, single-tube on-beam QEPAS (SO-QEPAS) employing a single-tube mR between the prongs of the custom QTF was developed, as shown in Fig. 2 (left). The SO-QEPAS spectrophone configuration can be realized due to the large prong spacing of the custom QTF, allowing space of the mR between the prongs, thus avoiding the cutting of the mR into two pieces. In this case, the behavior of the single-tube on-beam mR is similar to that of an ideal one-dimensional acoustic resonator, resulting in a shorter mR length and a further enhancement of the QEPAS signal. Fig. 2 (right) shows the SO-QEPAS signals, obtained by the three different spectrophones in logarithmic-form as a function of the mR lengths. mR #1 has an OD of 0.8 mm and mR #3 has an ID of 0.75 mm, which are equal to or comparable with the prong spacing (g) of the custom QTF. mR #2 has a larger OD value, but a smaller ID value compared to the prong spacing (g) which is a compromise between mR #1 and #3. The data points were fitted by a Lorentz line shape. The SO-QEPAS spectrophone with AmR #2 demonstrated the strongest signal compared to the other two AmRs, as shown in Fig. 2 (right). Its optimal length is 38 mm. Furthermore, the SO-QEPAS improves the detection sensitivity by two orders of magnitude compared to a bare QTF. This approach significantly reduces the spectrophone size with respect to the two-tube on-beam mR geometry [5].

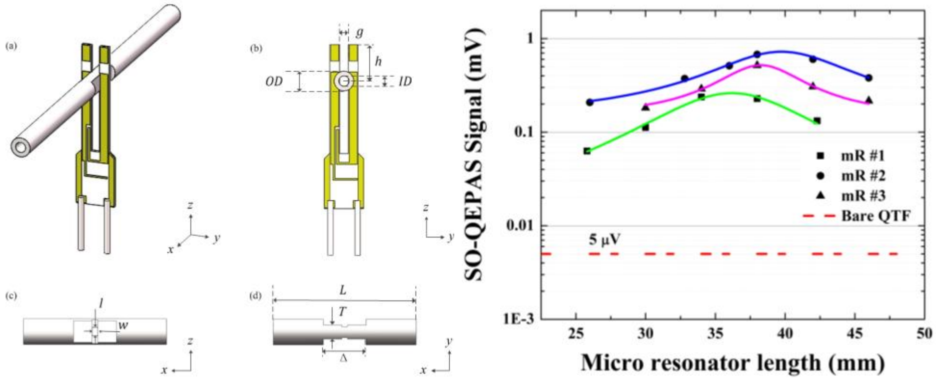

Fig. 2. Left: (a) Schematic of the SO-QEPAS spectrophone; (b), (c), (d) symbols of the geometric parameters of the spectrophone where *g* is the QTF prong spacing, *l* is the slit length, *w* is the slit width, *L* is the acoustic resonator length, *ID* is the inner diameter, *OD* is the outer diameter, *T* is the waist thickness and Δ is the waist length. Right: SO-QEPAS signals obtained by three different spectrophones as a function of AmR.

4. Conclusions

We have demonstrated a novel QEPAS spectrophone configuration using stainless tubes and a custom tuning fork with prongs spacing of 800 µm. Using a two-tube on-beam mR geometry we obtained an improvement of the SNR by a factor of ~40, while using a single-tube on-beam mR configuration a two orders of magnitude improvement of detection sensitivity was archived. The possibility to employ QTF overtone modes [6] with the single-beam mR configuration is expected to further enhance the detection sensitivity and reduce the QEPAS spectrophone size.

5. References

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