Modeling the dependence of fork geometry on the performance of quartz enhanced photoacoustic spectroscopic sensors

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Abstract: A finite element model for Quartz Enhanced Photoacoustic Spectroscopy (QEPAS) was developed and applied to a study of the dependence of system performance on quartz tuning fork dimensional parameters. In particular, the model was used to determine the optimal position for four different tuning forks. This model can be used as a design tool for optimizing tuning fork dimensions.

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

1. Introduction

Quartz Enhanced Photoacoustic Spectroscopy (QEPAS) is a technique for trace gas detection and measurement that has been applied to a wide range of applications [1]. It is an optical absorption-based spectroscopy method that takes advantage of the localized heating that occurs with absorption This launches an acoustic wave that can be detected with a resonant quartz tuning fork (QTF). Such sensors are compact in size and relatively noise intolerant.

There are a number of trade-offs to be considered in the selection of fork dimensions. Larger forks bend more and have a larger charge surface, but they also have a lower resonance frequency which reduces the overall signal, and a larger surface area which increases energy losses. Modeling is needed for optimizing system parameters. QEPAS systems have been modeled analytically [2] and using finite element modeling [3]. In this work the finite element model method described previously [3] is applied to an examination of fork geometry.

2. Model Details

The equations that govern QEPAS response are described in detail elsewhere [1,2]. This model uses the Acoustic-Solid and Acoustic-Piezoelectric Interaction Modules of COMSOL Multiphysics, version 4.3a. Absorption is incorporated as an acoustic flow line source. Viscous damping is incorporated in the model through the use of an external force applied to the tines based on the oscillating sphere model [4] with the effective radius term chosen to set the spherical surface area of the approximation equal to the tine surface area of the QTF.

Figure 1 shows a generic fork with the key dimensions labeled. A variety of geometries were modeled in this study, set to match four forks for which experimental data was available. The model used a fixed boundary condition for the bottom surface of the base, and coupled fluid-solid interaction boundaries for the other surfaces.
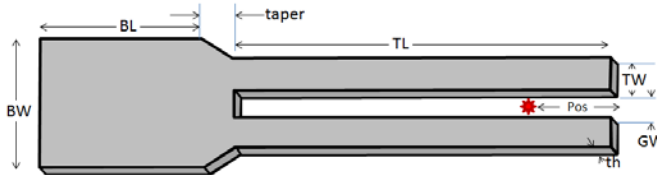

Fig. 1. Illustration of generic tuning fork illustrating the dimensions varied in this study.

Table 1. Key dimensions for the QTFs in this study. All of the forks in this study were 250 μm thick.

Name	BW (mm)	BL (mm)	taper (mm)	TL (mm)	TW (mm)	GW (mm)
QTF-S-C	1.2	2.3	0.2	3.5	0.2	0.4
QTF-M-C	3.4	4.6	0.4	10.0	0.9	0.8
QTF-C-C2	2.4	4.1	0.4	11.0	0.5	0.6
QTF-B-C	3.7	9.4	0.6	17.0	1.0	0.7

3. Results

The results of the simulation of the dependence of resonance frequency and quality factor on pressure for the four forks are shown in Fig. 2 below. For these simulations it was assumed that the distance between the beam position and fork tip was one quarter of the total tine length. The model results show reasonable agreement with experimental data, although the resonant frequencies are consistently higher for the simulation than for the experimental data.
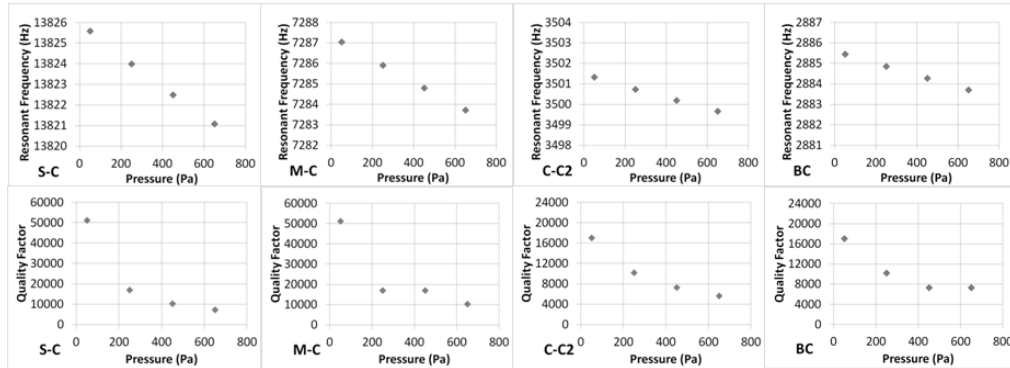

Fig. 2. Resonant frequency and quality factor as a function of pressure for the four QTF geometries.

The mechanical model was also used to investigate the effect of beam position relative to the tip of the fork (the "Pos" variable in Fig. 1). The results are shown in Fig. 3 below. The optimum position was found to be generally greater for longer forks. In order to model this more accurately in the future, the light source in the model should be modified to have a finite radius, rather than being modeled as a delta line function.
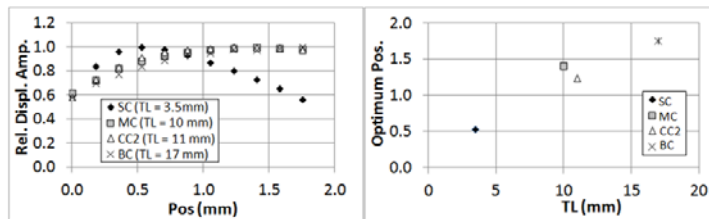
Comment [F1]: Of what ?

Fig. 3. (Left) Relative tip displacement amplitude at resonance versus laser position relative to the tine tip ("Pos" in Fig. 1). (Right) The dependence of the optimum position on tine length. For longer forks the optimum position is further away from the tip.

In order to compare performance among different fork designs, the transduction from mechanical displacement to current was then included in the model. The relative performance for the four forks about their resonance peak for an arbitrary laser power level and absorbance are shown in Fig. 4. This model assumed that each of the four forks was positioned at the optimum displacement point as shown in Fig. 3. Table 2 lists the relative signal to noise ratio for the four fork designs, which is calculated as the signal divided by the square root of the quality factor.

Fig. 4. Relative tip displacement versus beam position

Table 2. Comparison of simulation results for the four forks.

Name	Resonant Freq (Hz)	Q	Peak Amp. (xA)	SNR
QTF-S-C				
QTF-M-C				
QTF-C-C2				
QTF-B-C				

4. Conclusions

5. References

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