Modeling for Design Optimization of Quartz Enhanced Photoacoustic Spectroscopy-Based Sensors

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Introduction

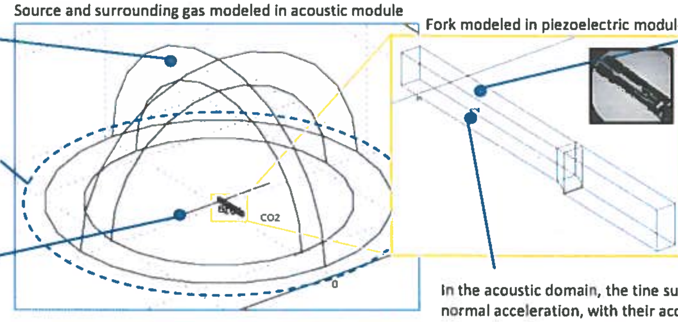
Our goal is to measure the flux of environmentally relevant gases in and out of the ocean. The flux will be determined using the Eddy Correlation method, which requires fast (~10 Hz) and highly sensitive (ppb) measurement of gas concentrations. We are exploring Quartz Enhanced Photoacoustic spectroscopy (QEPAS) as a possible solution.

In photoacoustic spectroscopy, the optical source is modulated at an acoustic frequency. If the optical wavelength corresponds to an absorbance line in the gas, the periodic optical signal will launch an acoustic signal that can be detected with a microphone. In QEPAS, a quartz tuning fork is used instead of a microphone. Compared to other PAS methods, this promises great simplicity and sensitivity.

The Laser Science Group at Rice University has observed that the addition of acoustic resonator tubes about the tuning fork dramatically increases the current output. But determining the optimal tube geometry is analytically difficult. Numerical modeling is essential in order to fully test various design options at an acceptable cost.

Anatomy of a Model

System modeled in COMSOL Multiphysics



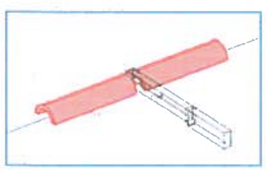
Comparison to Data

	COMSOL Model	Experiment
f_0 and Q in vacuum	32 765 kHz, 96368	32 764 kHz, 93456
f_0 and Q at 760 Torr	32 747 kHz, 13366	32 756 kHz, 13271
Output Signal (1000 ppmv NH_3, N_2 at 430 Torr using 6528.80 cm^{-1} line with 61.7 mW laser)	37.8 pA	72.3pA

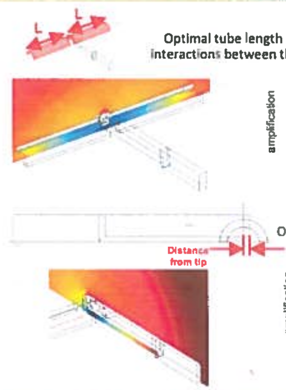
Compared against observations reported in
A. A. Kosterev et al., "Applications of quartz tuning forks in spectroscopic gas sensing", Rev. Sci. Instrum., 76, 043105 (2005)
N. Petra et al., "Theoretical analysis of a quartz enhanced photoacoustic spectroscopy sensor", Appl. Phys. B, 94, pp. 673-680, (2009)

Modeling Resonator Enhancement

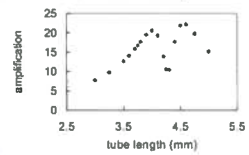
Acoustic resonator tubes have been found to significantly increase the current output. We added them to our model and used the model to predict the optimal length and position.



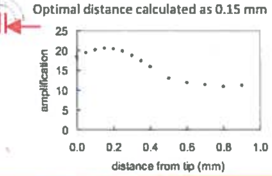
Results



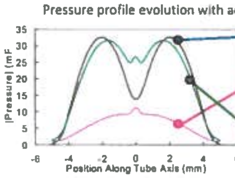
Optimal tube length has two maxima due to interactions between the fork and the structure.



Optimal distance calculated as 0.15 mm



Pressure profile evolution with acoustic resonators illustrates this interaction



We are now working to experimentally validate these modeling results, and to extend the model to examine the effect of changing the radius on the system.

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