# Detection sensitivity comparison of different sized quartz tuning forks for use in a QEPAS trace gas sensor

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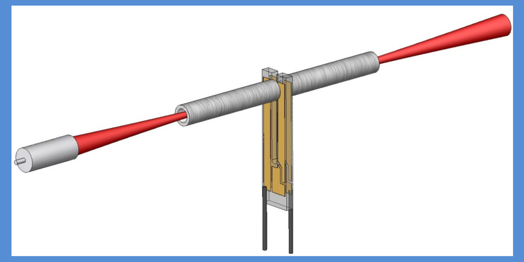
## 1 Background: QEPAS

Quartz enhanced photoacoustic spectroscopy (QEPAS) is a new technique of photoacoustic spectroscopy that utilizes a quartz tuning fork (QTF) instead of a traditional microphone as an acoustic resonator. QEPAS sensors operate by detecting an acoustic pressure wave generated when optical radiation interacts with a trace gas. The pressure wave excites the resonant vibration of the QTF which is converted into an electric signal that is proportional to the concentration of gas measured with a transimpedence amplifier due to the piezoelectric effect.



Two-tube configuration of QEPAS

## 2 Motivation

•32kHz QTF is very useful due to its small size, which allows it to be used in miniature gas sensors

•However, the 32kHz QTF should be less effective when used to detect gases with slow V-T relaxation rates with respect to modulation frequency

•Another disadvantage of the 32kHz QTF is its inability to be used in applications with incoherent light due to its small size

•In contrast, the larger 4kHz and 8kHz QTFs should be able to get stronger photoacoustic waves from gases with slow V-T relaxation rates

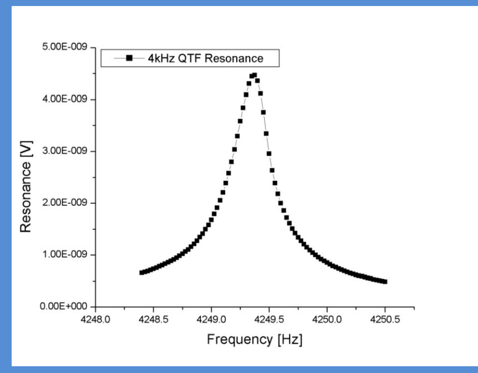
•The purpose of the testing was to see which tuning fork would provide the most sensitivity when used to detect gases with fast and slow V-T relaxation rates.

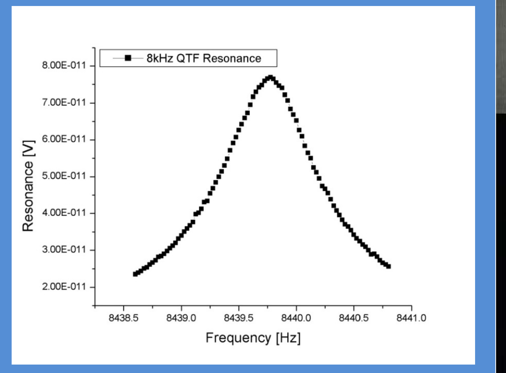
Relaxation Times of Gases[a]

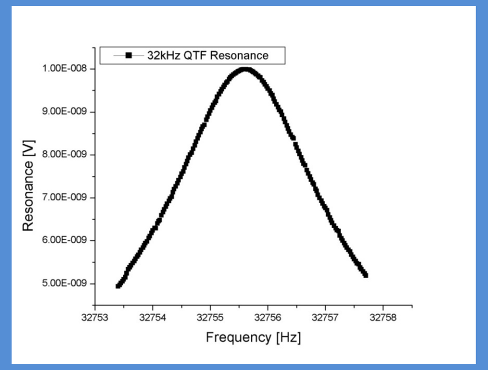
| Gas | Relaxation Time (μs) |
|---|---|
| $CO_2$ | 6.95 |
| $H_2O$ (vapor) | 0.037 |

## 3 QTF Properties

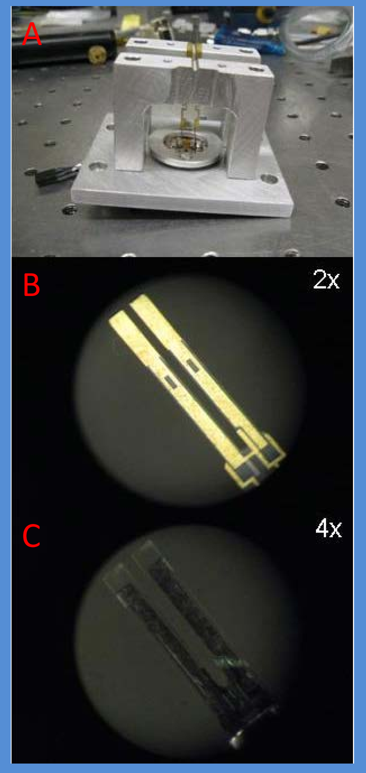
QTF Resonance in Air



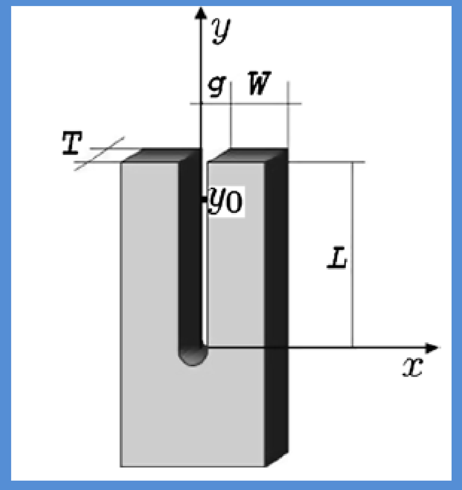




A: 4kHz QTF
B: 8kHz QTF
C: 32kHz QTF

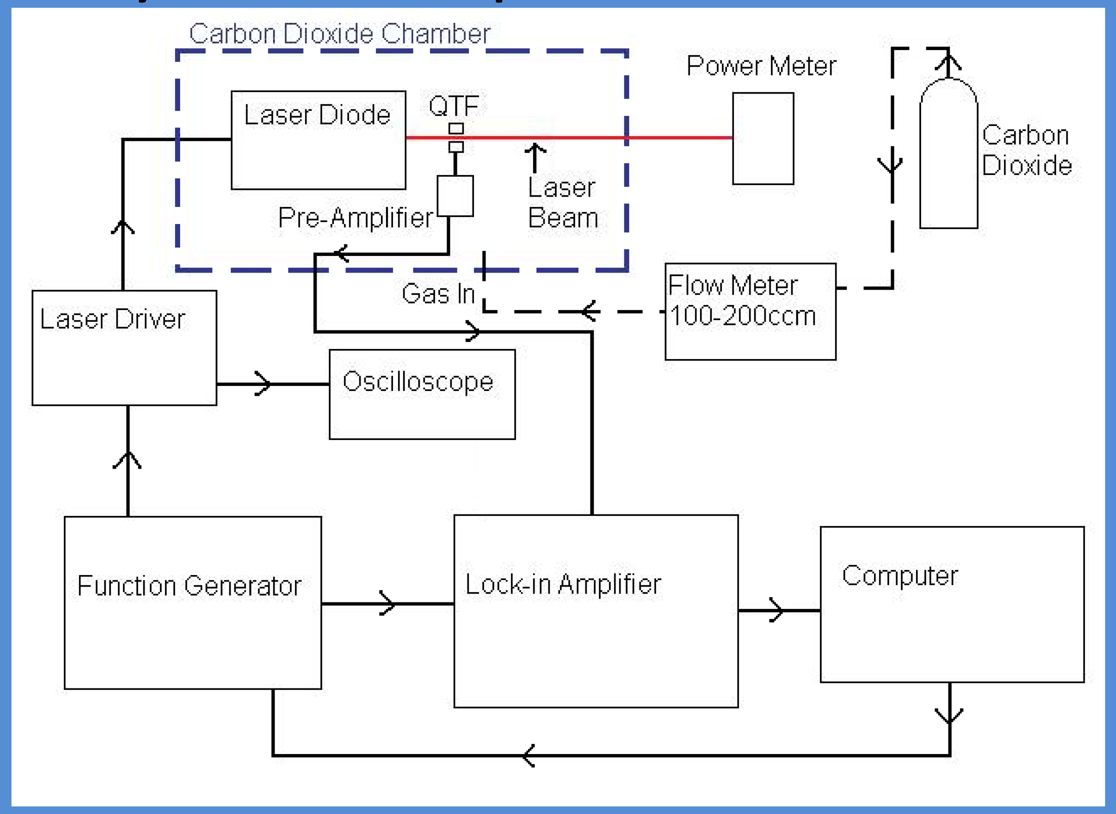


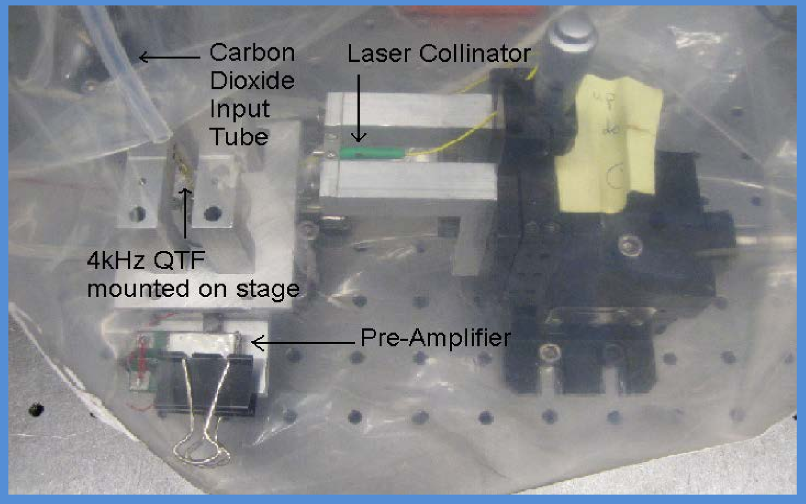

Right: Diagram of QTF dimensions
Bottom Right: Table of QTF resonant frequency, Q factor, and dimensions

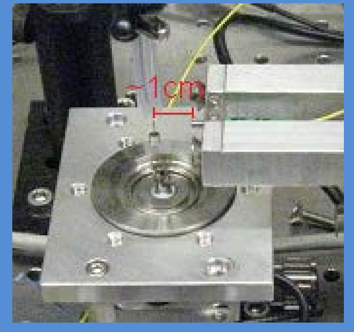



| QTF (in air) | $F_0$ (Hz) | Q | L (mm) | T (mm) | W (mm) | G (mm) |
|---|---|---|---|---|---|---|
| 4kHz | 4249.34 | 17302 | 20 | 1 | 2 | 1 |
| 8kHz | 8439.18 | 11410 | 9.4 | 0.4572 | 0.95 | 0.5 |
| 32kHz | 32755.62 | 14388 | 3.8 | 0.34 | 0.6 | 0.3 |

## 4 System Setup: Laser and QTF



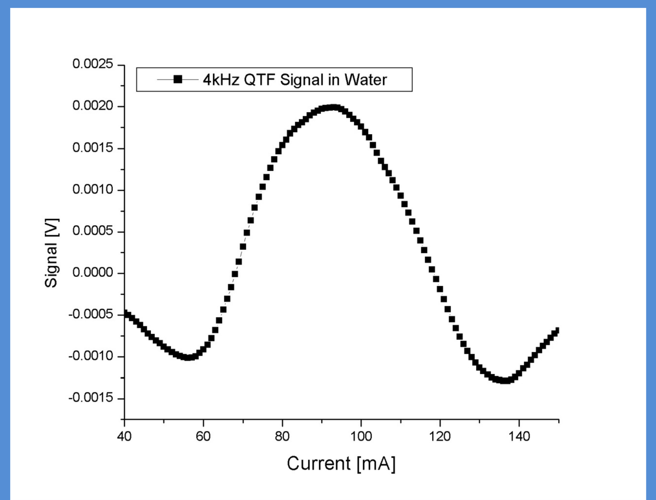



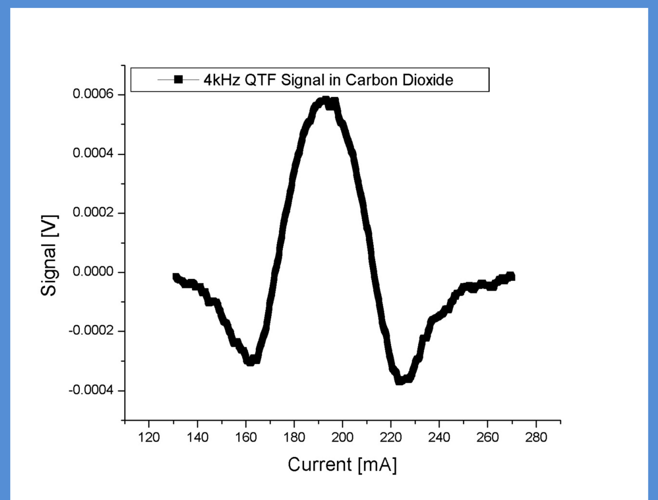



Above: Setup Schematic
Bottom Left: QTF and Laser Setup
Bottom Right: QTF and laser focuser scale

## 5 Results: QEPAS Signal Strength

The final comparison was done with all the QTFs being tested under the same conditions. For $CO_2$ detection, the laser current was 200mA, time constant of lock in amplifier was 1s, pure $CO_2$ was used as the target gas. For $H_2O$ detection, the laser current was 120mA, time constant of lock in amplifier was 1s, $H_2O$ in the air was used as the target gas.




Signal amplitude is determined by
•Q factor of QTF
•Gap between the QTF's prongs
•Gas V-T relaxation rate

| Gas | 4kHz QTF | | 8kHz QTF | | 32kHz QTF | |
|---|---|---|---|---|---|---|
| | Signal mV | Signal/Q | Signal mV | Signal/Q | Signal mV | Signal/Q |
| 100% $CO_2$ | 0.5865 | $3.38\times10^{-5}$ | 0.3543 | $3.11\times10^{-5}$ | 0.8457 | $5.87\times10^{-5}$ |
| 12.9% $H_2O$ | 1.9 | $1.1\times10^{-4}$ | 1.4 | $1.2\times10^{-4}$ | 2.5 | $1.7\times10^{-4}$ |

## 6 Conclusion

•32kHz QTF had the highest signal for both $CO_2$ and $H_2O$ detection. This is because the sound wave produced by a laser beam is an outgoing cylindrically symmetric pressure wave which quickly decays from its source. The larger gaps between the prongs of the 4kHz and 8kHz QTFs caused the weaker signal.

•With $H_2O$, the signal of 4kHz QTF is 1.4 times higher than 8kHz QTF's. However, with $CO_2$, the signal of 4kHz QTF is 1.7 times higher than 8kHz QTF's. The stronger signal stems from the 4kHz QTF's lower resonant frequency.

•With an instant relaxation gas, such as $H_2O$, 8kHz QTF should have a higher signal amplitude than the 4kHz QTF considering the smaller gap of the prong. The unexpected result is attributed to the higher Q factor of 4kHz QTF.

•The 4kHz QTF is not more effective than the 32kHz QTF in low V-T relaxation rate, but it still has an advantage for applications with incoherent light sources.

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References: [a]Vibrational Relaxation Times in Gases by Wayland Griffith, Harvard University