Ultracompact photoacoustic sensor based on a quartz tuning fork

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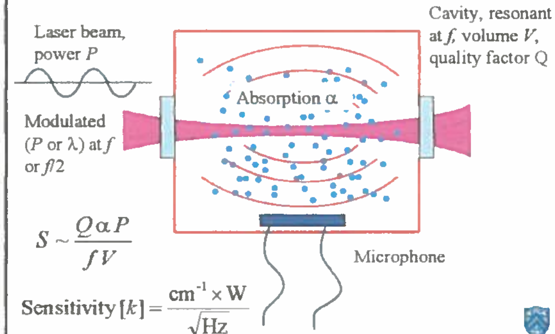
OUTLINE

- Basic concepts of QEPAS
- Quartz tuning fork as a resonant microphone
- Implementation and results
- Summary and outlook

Resonant photoacoustic spectroscopy



$$S \sim \frac{Q \alpha P}{f V}$$

$$\text{Sensitivity } [k] = \frac{\text{cm}^{-1} \times \text{W}}{\sqrt{\text{Hz}}}$$

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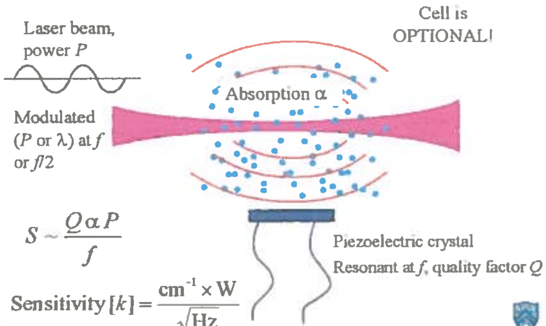
Photoacoustic spectroscopy with a resonant microphone



$$S \sim \frac{Q \alpha P}{f}$$

$$\text{Sensitivity } [k] = \frac{\text{cm}^{-1} \times \text{W}}{\sqrt{\text{Hz}}}$$

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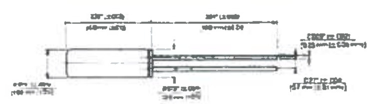
A readily available solution – wrist-watch tuning fork

RALTRON
WATCH CRYSTAL TUNING FORKS



R26

Frequency: 32.768kHz ±30ppm **Operating temperature:** −10°C to +60°C
ESR: 35kohms max (R26), 50kohms max (R38)

Price: 1-50 $0.32 ea. (Newark Electronics)

QUANTITY DISCOUNTS AVAILABLE

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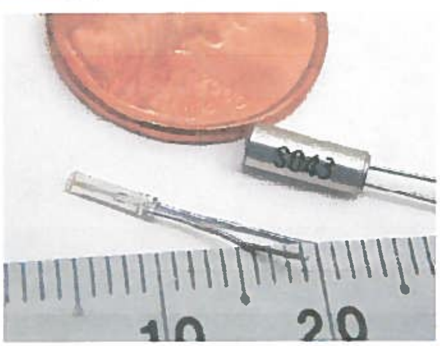
Wrist-watch tuning fork



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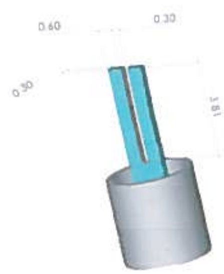
Typical tuning fork (TF) dimensions (mm)



Gap volume
<0.35 mm^3

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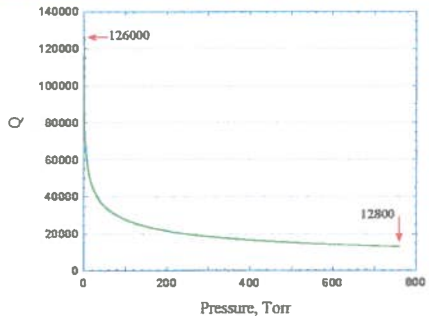
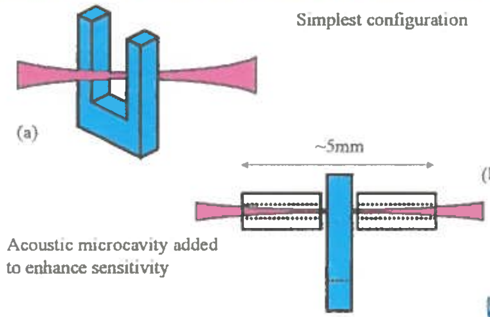
Pressure dependence of Q factor of a typical TF



7

Tested QEPAS configurations



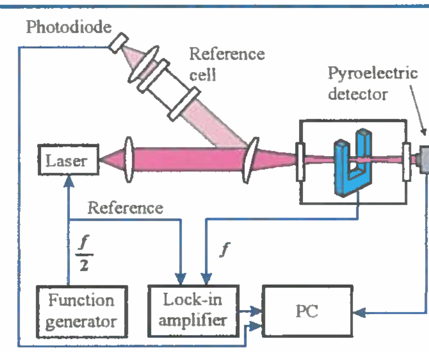
8

QEPAS vs. traditional PAS

Parameter	Traditional PAS	QEPAS
f, Hz	100 to 4000	Presently ~32 760
Q	20 to 200	10 000 to 30 000
Q vs. pressure	INCREASES (high spectral resolution is problematic)	DECREASES (high spectral resolution is achievable)
Sample volume	>10 cm^3	<1 mm^3
Sensitivity to ambient acoustic and flow noise	Usually high	None observed
Pathlength involved	~10 cm	(a) 0.3mm, (b) 5mm

9

Laboratory setup for QEPAS based gas sensor evaluation



10

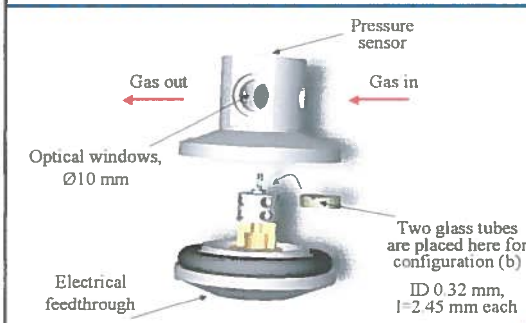
Gas cell for QEPAS experiments

Bottom part with a mounted TF

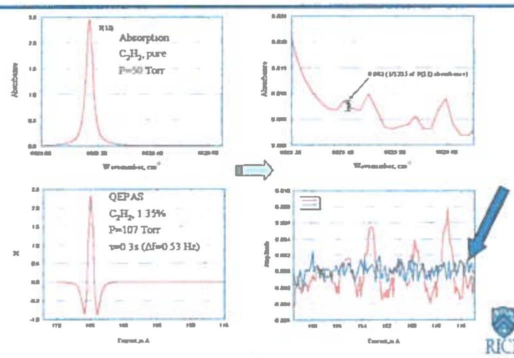
Assembled cell with a pressure sensor mounted on top

11

Gas cell for QEPAS experiments

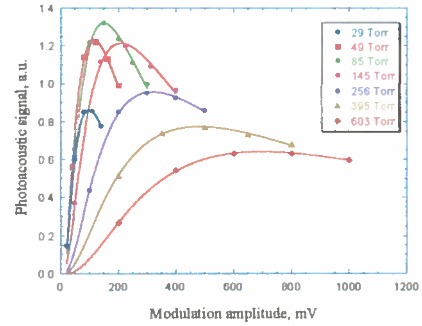


An example of QEPAS data



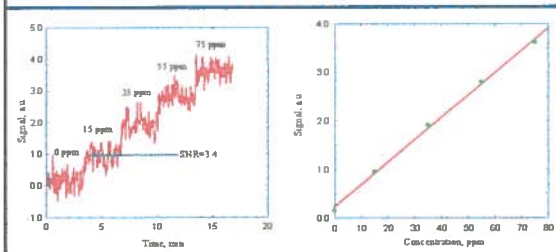
13

Optimum pressure: C_2H_2 signal



14

NH_3:N_2 sensitivity test



Time constant τ=1 s, laser power in the cell 5.2 mW

Total pressure 90 Torr, peak absorbance 2.1×10^{-6} cm^{-1} at 15 ppm

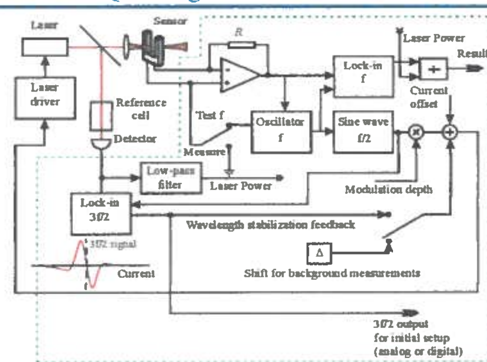
⇒ **noise-equivalent sensitivity k=8.1×10^{-9} $cm^{-1}W/\sqrt{Hz}$**

(Traditional PAS† – 1.5×10^{-9} $cm^{-1}W/\sqrt{Hz}$)

†Webber et al., APPLIED OPTICS April 2003 Vol. 42, No. 12, p.2119

15

QEPAS gas sensor architecture



16

Packaged QEPAS control unit (v. 1.0)

17

Summary and Outlook

- QEPAS is immune to ambient noise. Experimentally measured noise level coincides with theoretical limit.
- Required sample volume is very small. It is ultimately limited by the gap size between the TF prongs, which is 0.15 mm^3 for the presently used TF
- The best experimentally demonstrated sensitivity of QEPAS approach to date is 8.1×10^{-9} $cm^{-1}WHz^{-1/2}$
- The achieved sensitivity corresponds to a NH_3 detection limit (SNR=3) of 1.7 ppm with commercially available NIR DFB lasers (40 mW at 1.53 μm) with τ=1s time constant, or 170 ppb with 5 min acquisition time (τ=100 s)
- A new advanced version of a compact dedicated control unit for an autonomous QEPAS sensor is currently under development

NEXT STEPS:

- Optimize acoustic microresonator design (geometry and material)
- Investigate TFs with lower resonant frequencies
- Combine QEPAS with mid-IR laser sources (e.g. QC lasers) for improved gas sensing (ammonia: >200 times stronger absorption line)

18