Photoacoustic spectroscopy in gases with high-finesse solid-state resonators

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OSA'02

Orlando
September
2002

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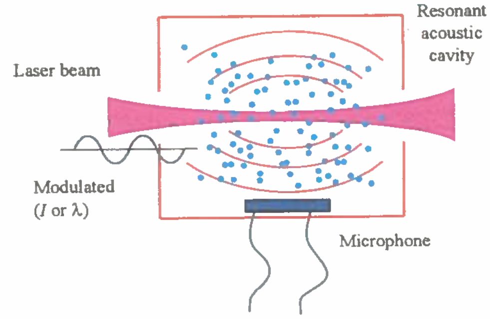
OUTLINE

- Principles and problems of traditional PAS
- Quartz tuning fork as a resonant microphone
- Implementation and results
- Summary and outlook

Resonant photoacoustic spectroscopy



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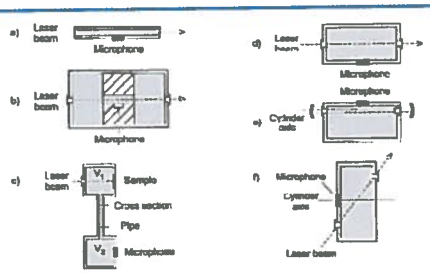
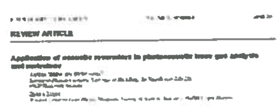
Acoustic resonators





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Traditional PAS issues

- Accumulated energy in air
- Relatively low Q

  Examples: f=8,000 Hz, Q=200 ⇒ Q/f=25 ms

  f=4,000 Hz, Q=18 ⇒ Q/f=4.5 ms
- Signal proportional to Q/f
- Resonant cell size ~λ/2; for f=1000 Hz λ=30 cm
- Signal inversely proportional to the acoustic mode volume
- Ambient noise, especially flow noise; S_n~1/f

Solution: Store energy in a MICROPHONE instead of the GAS!

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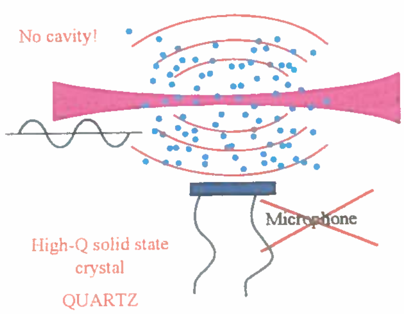
Quartz-Enhanced PAS (QEPAS)



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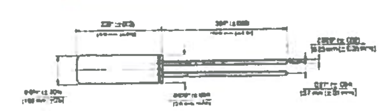
A ready solution – watch tuning fork

RALTRON

WATCH CRYSTAL TUNING FORKS



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Frequency: 32.768kHz ±30ppm. **Operating temperature:** −10°C to +60°C

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

QUANTITY DISCOUNTS AVAILABLE !

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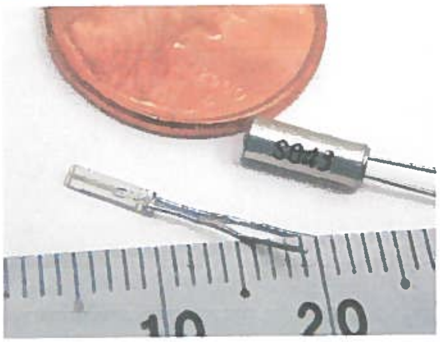
Watch tuning fork



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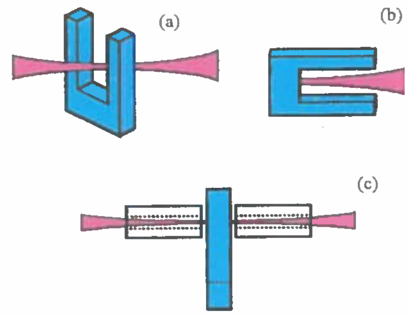
Possible QEPAS configurations



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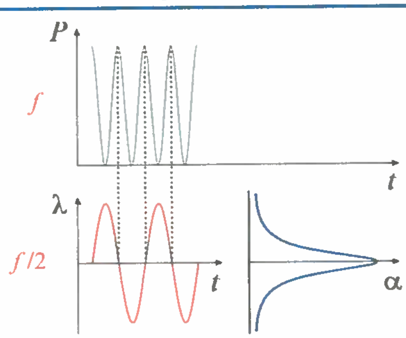
Wavelength modulated PAS



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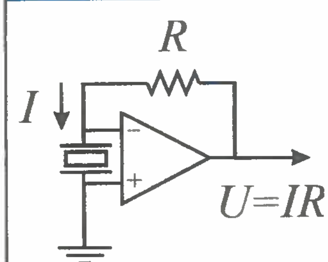
Electrical circuit: transimpedence amplifier



Noise sources:

- Thermal noise of R
- Thermal noise of the TF: kT energy per vibrational mode

Noise : $1.1\mu V/\sqrt{Hz}$ rms with $R = 4.4M\Omega$

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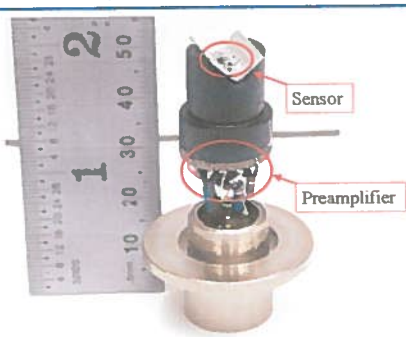
QEPAS Module



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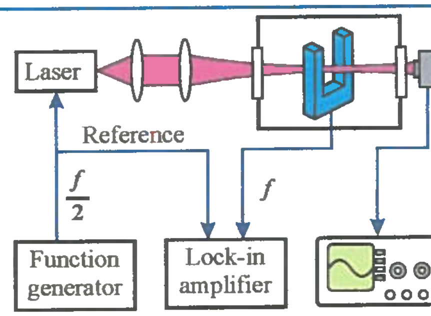
QEPAS Setup



DFB laser at λ=1.66 μm was kindly provided by Dr. Carlo Sirtori, Thales Research and Technology, Orsay, France

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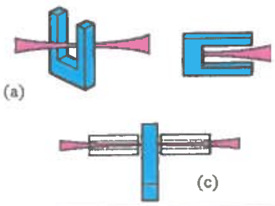
Achieved QEPAS sensitivity



Configuration	a	b	c
Responsivity, V/(W·cm^{-1})	1.24	5.03	9.45
Detectivity, cm^{-1}·W/√Hz	8.8×10^{-7}	2.2×10^{-7}	1.2×10^{-7}

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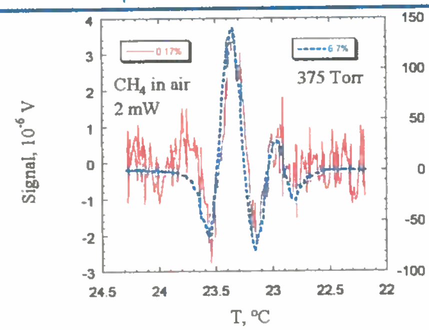
CH_4 detected with QEPAS



ν=5999. 5 cm^{-1}, configuration (b)

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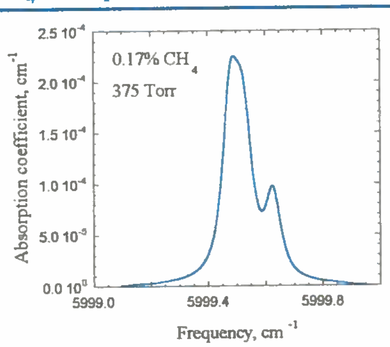
CH_4 absorption at 0.17% concentration



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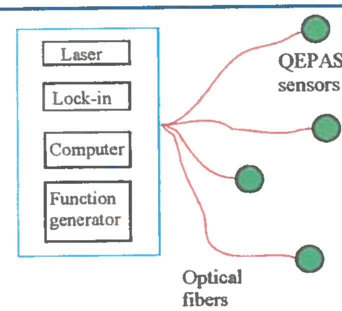
Multipoint QEPAS sensor



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Summary

- Shifting the resonance from a gas-filled cavity to a solid-state crystal results in a dramatic increase of the Q-factor
- Readily available watch tuning forks can be used as resonant sensors for photoacoustic spectroscopy in gases
- TF based sensor is immune to ambient noise because of its geometry and high operational frequency
- The proposed QEPAS technique opens an opportunity for chemical analysis of ultrasmall gas samples
- The sensitivity of QEPAS scales linearly with the laser power. It is also expected to be improved if specially designed quartz crystals are used.

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