Università degli Studi di Bari

DIPARTIMENTO INTERATENEO DI FISICA, 'MICHELANGELO MERLIN'

Scuola di Dottorato di Ricerca in Fisica XXXIV ciclo

Presentazione dell'attività di ricerca

Study of the electro-thermal properties and acoustic coupling of quartz tuning forks

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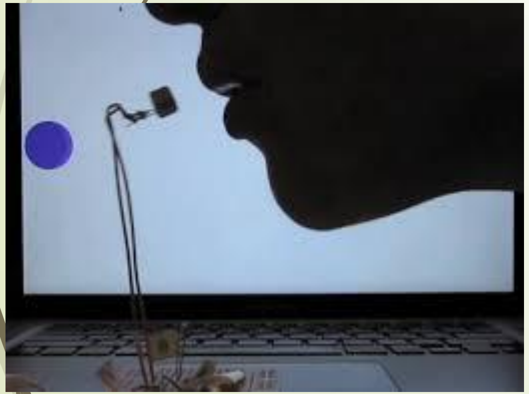
Gas sensing: fields of application

- Environmental monitoring
  CO, CO_2, CH_4, H_2CO, C_2HF_5, N_2O, NO_2

- Industrial processes control
  HCl, CO_2, CH_4, CO, NO_x, CH_2O

- Manufacturing processes
  SF_6, HCl

- Medical diagnosis
  NO, CO, NH_3, C_2H_6, H_2S, VOCs



urban emission, rural emission, toxic gases, planetary science…

Quartz-Enhanced Photoacoustic Spectroscopy

- Optical LASER absorption
- Non-radiative relaxation through molecular collisions ($\tau_{V-T} \backsim \mu s$)
- Acoustic wave generation
- Detection of the acoustic signal S with a QTF

$$S = \frac{Q \cdot P_L \cdot \alpha}{\sqrt{1 + (2\pi f_0 \tau_{V-T})^2}}$$

$$Q = f/\Delta f$$

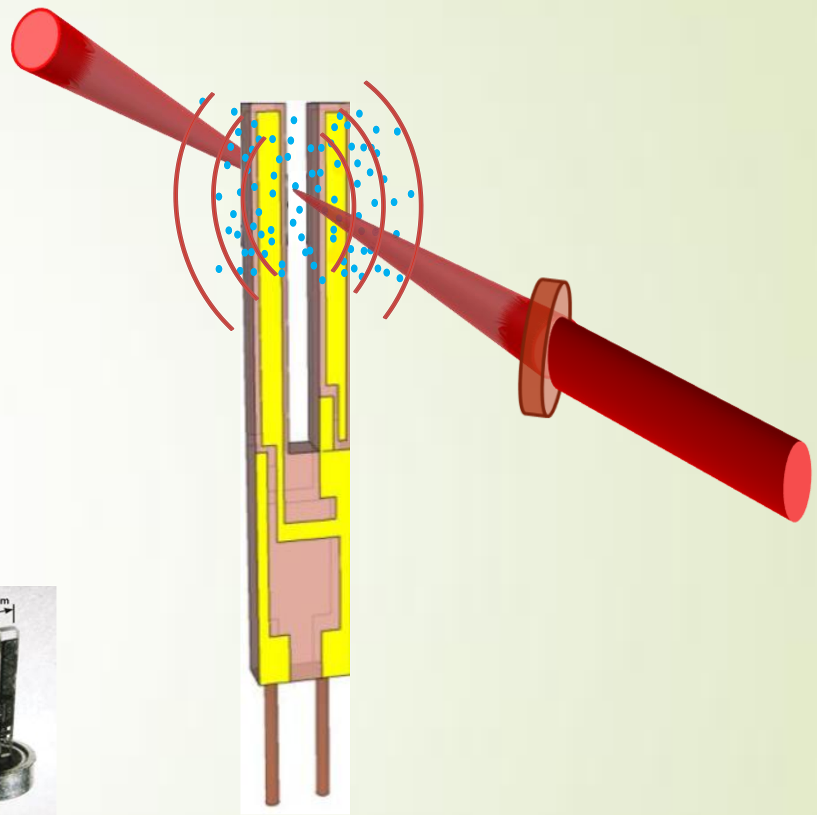
Main advantages

- High-Q element
- Narrow spectral passband
- Antisymmetric vibration inactive
- Gas samples volume of ~ *1 mm*^{3}

Standard QTF

f = 32.7 kHz

Q_{ATM} ~ *10000*



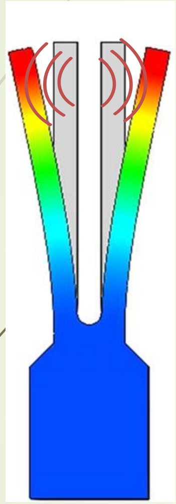
Custom QTFs

- Reduce resonance frequency
- Keep high Q

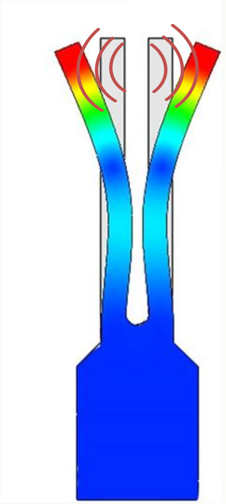
Custom 2nd generation QTF results

Resonance frequency

Fundamental



Overtone



Euler-Bernoulli beam theory

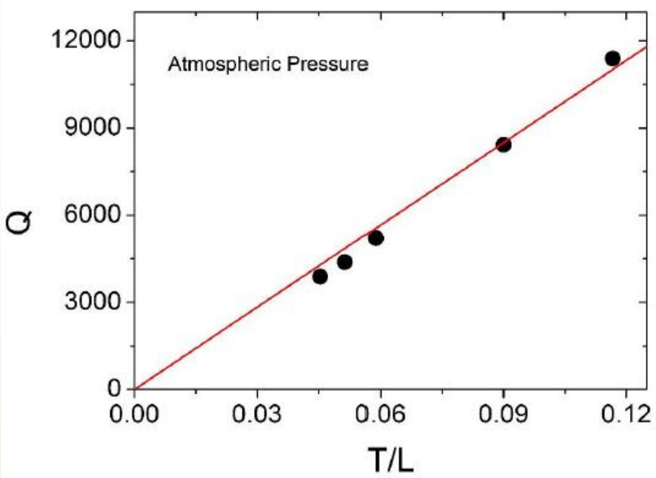
$$f_n = \frac{\pi T}{8L^2 12^{1/2}} \sqrt{\frac{E}{\rho}} {\upsilon_n}^2$$

Prediction of resonance frequencies

Quality factor

- AIR DAMPING LOSSES
- SUPPORT LOSSES
- TED LOSSES

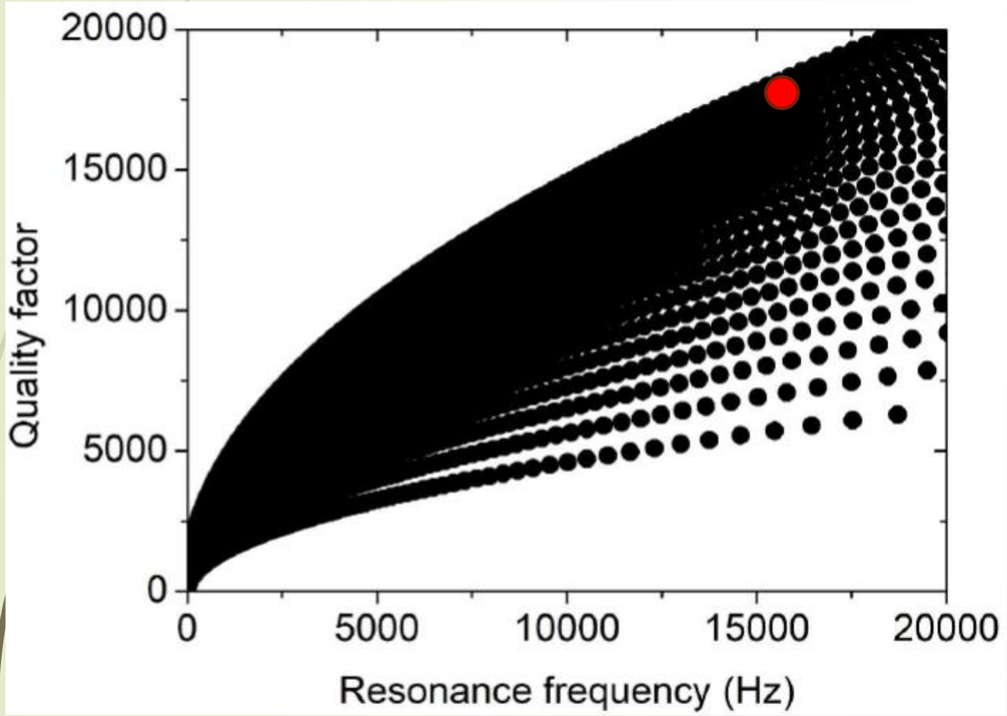
$$Q = 9.44 \cdot 10^4 \frac{T}{L}$$



Quality factor vs resonance frequency

Thesis work

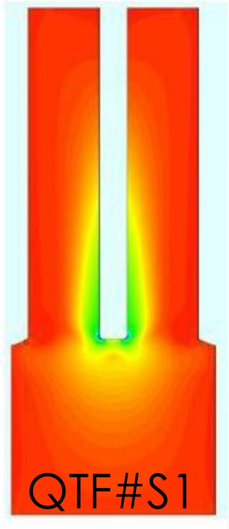
Combining both trends for different geometries



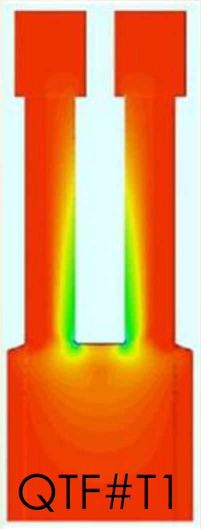
Starting from:

- Euler Bernoulli equation (f_0)
- 2nd generation results (Q)

● 3rd generation QTF



f = 15842
Q = 15710



f = 12463
Q = 15260

COMSOL simulation

P. Patimisco, A. Sampaolo, M. Giglio, S. Dello Russo, V. Mackowiak, H. Rossmadl, A. Cable, F. K. Tittel and V. Spagnolo, *Tuning forks with optimized geometries for quartz-enhanced photoacoustic spectroscopy*, Optics Express (in press)

Influence of molecular relaxation on QEPAS

PAS-based sensors: **f << 1/ τ_R**

QEPAS sensors: **f ~ 1/ τ_R**

Signal is strongly dependent from molecules relaxation rate!

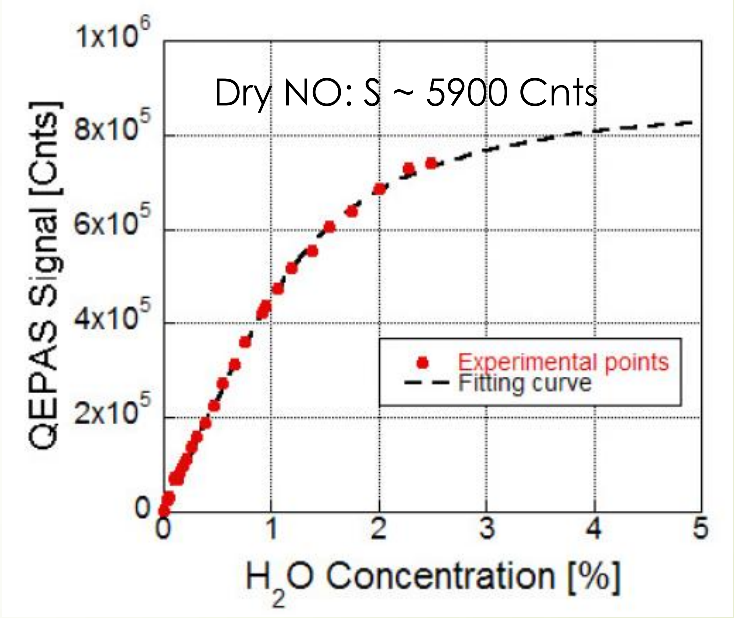
Slow relaxing molecules
(NO, CO, CO_2)
Fast relaxing molecules
(H_2O, SF_6)

OBJECTIVE: QEPAS response independent from the gas species.

- Study QEPAS signal vs QTF frequency, for different gas species

- The presence of a catalyst opens an additional relaxation path

NO at fixed concentration



Design and realization of QTFs with different frequencies for the **study of molecules relaxation times**

Simultaneous dual-gas detection

Standard QEPAS

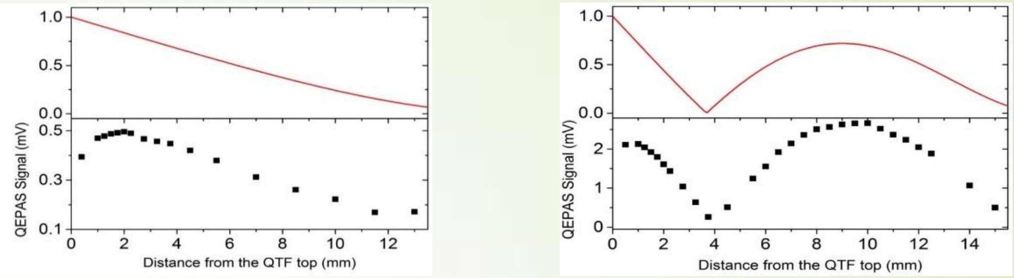
Delay in time in the measurements of two different target gas concentrations

Design and realization of QTFs capable to work at both fundamental and first overtone mode for QEPAS analysis

Simultaneous dual-gas QEPAS
Frequency Division Multiplexing

- Monitoring of gas concentration in a ***matrix that rapidly changes in time***
- Rigorous measurement of ***isotopic ratios***
- Measurement of ***slow-relaxing gas*** concentration

Possible application: NO/H_2O detection for breath analysis

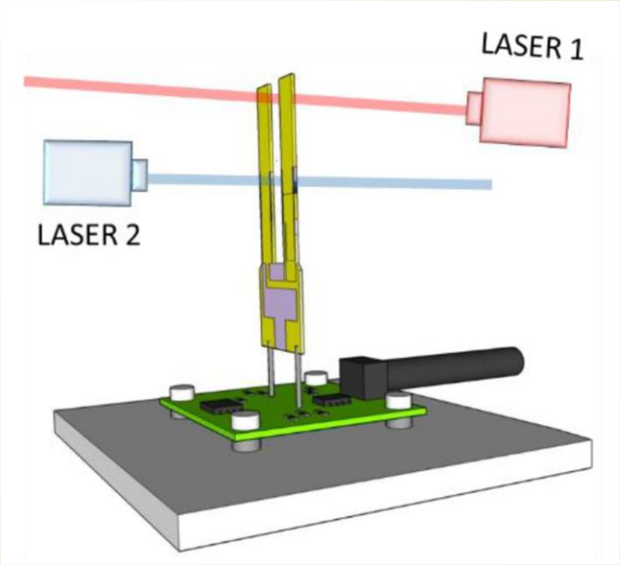


Fundamental   Overtone

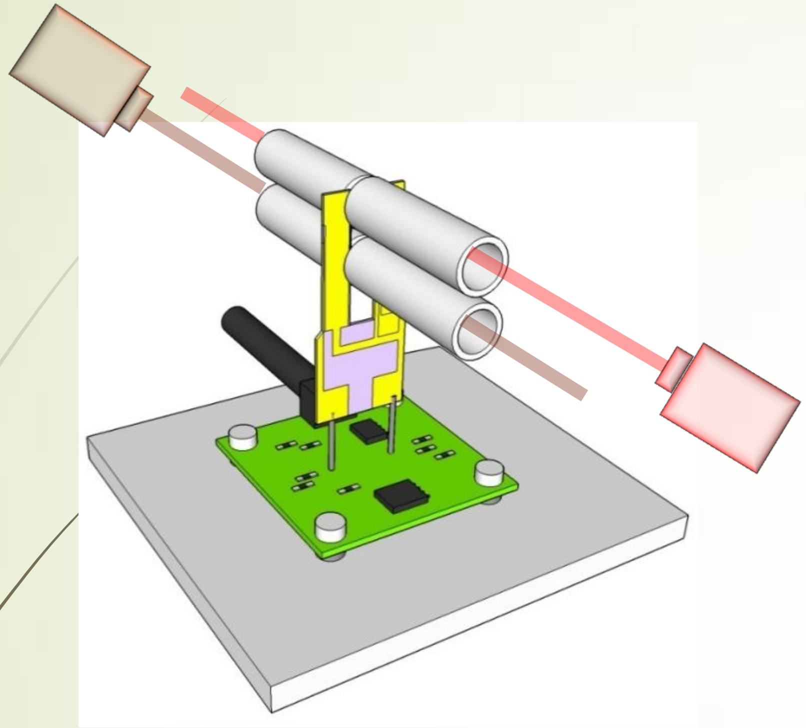
Lower fundamental frequency

↓

1st overtone available!

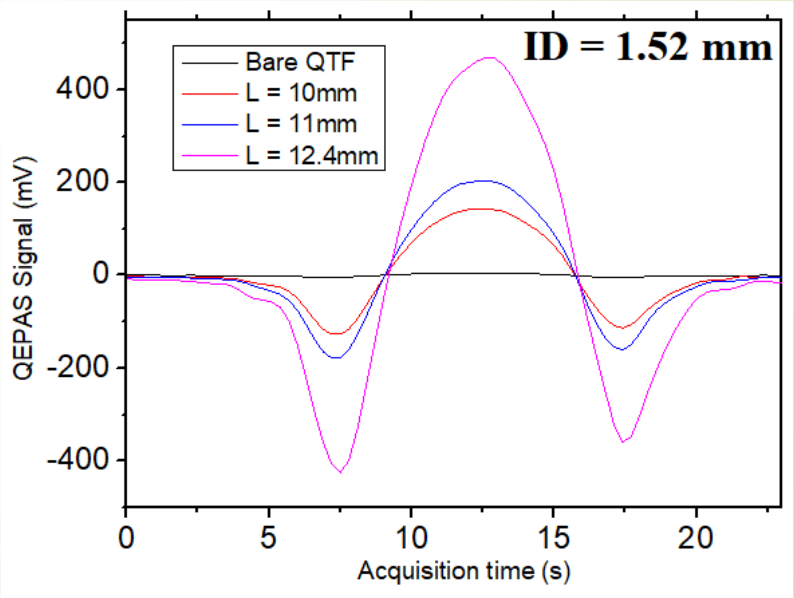


Acoustic coupling studies



Double-tube dual-gas detection

Acoustic coupling between QTFs and AmRs for QEPAS SNR enhancement



- SNR enhancement shows a strong dependence from tube length and internal diameter
- A record value of signal enhancement in the MID-IR spectral range was reached

P. Patimisco, A. Sampaolo, M. Giglio, S. Dello Russo, V. Mackowiak, H. Rossmadl, A. Cable, F. K. Tittel and V. Spagnolo, *Tuning forks with optimized geometries for quartz-enhanced photoacoustic spectroscopy*, Optics Express (in press)

Objectives of the first and the following years

First year goals

- Design and realization of a set of custom QTFs (4th gen) for QEPAS having resonance frequency in the range 3 – 30 kHz, with high quality factor

- Realization of a setup to measure the electro-mechanical properties (*Q*, *f*, *R*) of QTFs, at different pressure and gas matrix conditions

Following years goals

- Realization of a setup to detect different gas species (fast and slow relaxing) by using different laser sources

- Study of the acoustic coupling between QTFs and AmRs in the conventional and dual-gas QEPAS system

- Study the influence of molecular relaxation rates on QEPAS signal

- Realization of a QEPAS sensor for the simultaneous dual-gas spectroscopy.

Thanks for the attention

GRAZIE