Compact QEPAS Four-gas Sensor for Early Fire Detection

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OUTLINE

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- Motivation
- QEPAS Technique
- Spectral Selection
- Sensor Design
- Compact Four-gas Sensor and Test Results
- Summary

Laser Science Group

Motivation

Post combustion products must be monitored on the International Space Station (ISS)

- Currently sensors on ISS are replaced every 7 months

Forthcoming Space Shuttle retirement

- 3-5 years gap until next generation shuttle

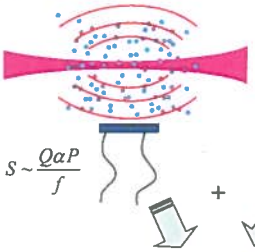
NASA's search for low-maintenance sensing technologies

Quartz Enhanced Photoacoustic Spectroscopy (QEPAS)

- Small and rugged
- Dynamic range
- Noise immunity
- Low cost
- Multi-year orbit service time

Quartz enhanced photoacoustic spectroscopy

Photoacoustic Spectrocopy



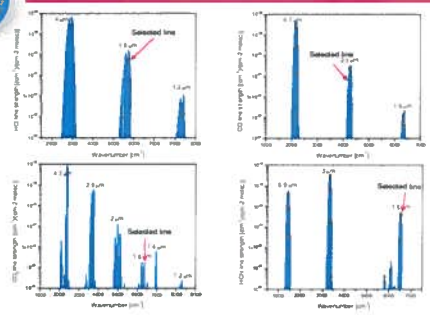
$$S \sim \frac{QaP}{f}$$

- Intrinsically high Q factor: Q_{vacuum} ~ 125 000, Q~10 000 at 1 atm
- Miniature size, <0.3 mm³ gap volume
- Piezoelectric: requires no transducer
- Piezoelectric signal form anti-symmetric vibration mode – noise immunity
- Mass produced – low cost

QEPAS!!!

Rafal Lewicki et al 1.30 μm; Longwen Gong et al 3 μm

Spectral Selection (HCl, CO, CO2, HCN)

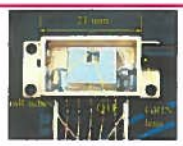


HCl	5739.26 cm⁻¹	1.74 μm	CO	4288.29 cm⁻¹	2.33 μm
CO	6361.25 cm⁻¹	1.57 μm	HCN	6539.11 cm⁻¹	1.53 μm

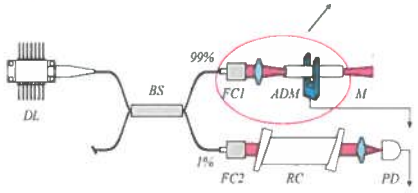
QEPAS based CO_2, HCl and HCN gas sensors

NIR Diode Laser features:

- Butterfly package
- Fiber pigtail
- ~40 mW power
- Build-in TEC and thermistor



Absorption Detection Module



QEPAS based CO sensor

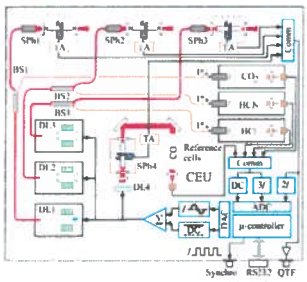
Laser features:

- Can package
- ~2 mW power
- Without TEC and thermistor

Photonic can packaged laser assembly with TECs and aspheric Black Diamond collimating lens

A compact QEPAS module incorporating diode laser assembly, QEPAS spectrophone, reference gas cell, and photodiode

Compact QEPAS four-gas sensor



No lasers installed

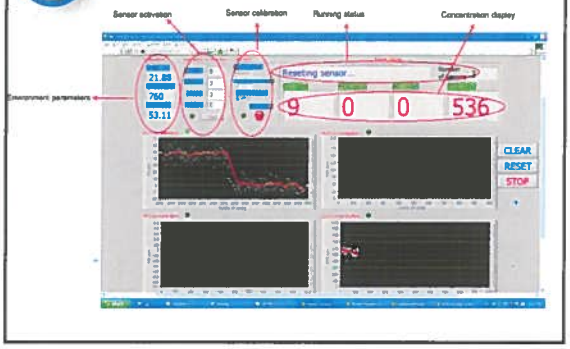
Lasers, fiber couplers and reference cells installed

Spectrophones added

QEPAS Four-gas Sensor prototype

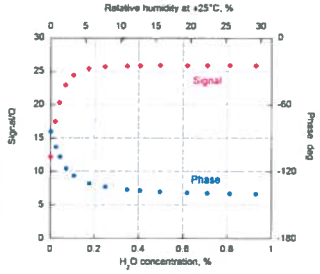
- 25 cm×25 cm×10 cm
- Display Screen
- Tube connector is mounted on top
- Serial communication with computer
- Fan to enhance air exchange
- Build-in battery can operate >8 hours

Sensor software



Gas humidity impact

- Humidity in the target gas was found to be extremely important
- H_2O affects the V-T relaxation rate of the target gas
- For example in the case of CO_2, the QEPAS signal must be corrected for relevant H_2O concentration level below humidity saturation



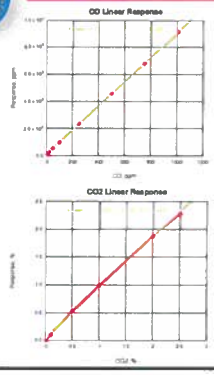
CO_2 signal for different humidity values

Sensitivity of the QEPAS sensor

Gas	CO	HCN	HCl	CO_2
Concentration	50 ppm	14 ppm	10 ppm	1500 ppm
Carrier gas	N_2	N_2	N_2	N_2
Water concentration	1.1%	0%	0%	1.2%
Signal amplitude	835.4 cnt	7883 cnt	2057 cnt	5493 cnt
SNR	6.46	31.07	7	15.42
Noise bandwidth	0.196 Hz	0.785 Hz	0.785 Hz	0.785 Hz
Laser Power	2 mW	35.5 mW	14.7 mW	37 mW
NEC[1]	7.74 ppm	450 ppb	1.48 ppm	97 ppm
NNEA[2]	1.41×10^{-8} $cm^{-1}W/\sqrt{Hz}$	5.3×10^{-9} $cm^{-1}W/\sqrt{Hz}$	5.17×10^{-8} $cm^{-1}W/\sqrt{Hz}$	5.73×10^{-9} $cm^{-1}W/\sqrt{Hz}$

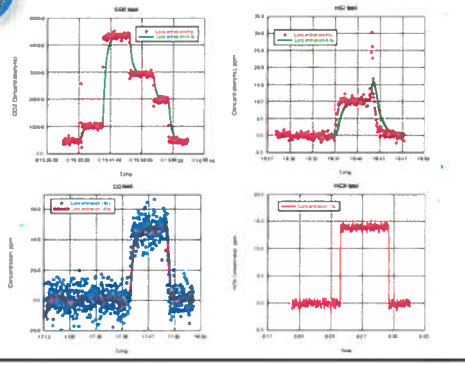
1 NEC: Noise-Equivalent Concentration
2 NNEA: Normalized Noise-Equivalent Concentration

Linear response of QEPAS based sensor



- CO, HCN and CO_2 have an excellent linear response

Test data of QEPAS sensor



Summary and outlook

- A compact four-gas sensor for the monitoring of CO, HCN, CO_2 and HCl concentration based on QEPAS technology combined with three fiber-coupled and a can packaged commercial near-IR DFB diode lasers was designed, fabricated, and optimized.
- Detection sensitivity and linearity were determined.
- Humidity plots for CO_2 and HCN were obtained experimentally to correct the QEPAS signal for different humidity concentration levels.
- In the case of CO detection, the low sensitivity of 7.74 ppm is due to the low laser power and V-T relaxation rate. Further development of the CO sensor will focus on improving its detection sensitivity.