Recent Progress in Infrared Semiconductor Laser Based Chemical Sensing Technologies

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Introduction

This poster describes the novel mid-infrared quantum cascade laser (QCL) based trace gas sensor technology using both QEPAS and traditional PAS. Two current sensor applications are reported: 1] a 10.34 µm CW TEC DFB QCL based QEPAS sensor that is used to quantify NH_3 in exhaled human breath and 2] a 10.3 µm broadly tunable CW TEC EC-QCL based PAS sensor that monitors NH_3 in Houston, TX, an urban environment.

Future Directions of trace gas applications

- Improvements of existing sensing technologies using state-of-the-art QCLs and ICLs
- Further development of spectrophone technology based on cnc fabrication techniques.
- Ultra-compact, low cost, robust trace gas sensors
- Development of laser based gas sensor networks based on QEPAS and LAS
- New applications enabled by novel tunable EC-QCLs (i.e. sensitive concentration measurements of HCs, UF_6 and multiple species detection)

Robert F. Curl, Federico Capasso, Claire Gmachl, Anatoliy A. Kosterev, Barry McManus, Rafal Lewicki, Michael Pusharsky, Gerard Wysocki, and Frank K. Tittel "Quantum Cascade Lasers in Chemical Physics" Chemical Physics Letters, Frontiers Article 487, 1-18 (2010)

Lei Dong, Anatoliy A. Kosterev, David Thomazy and Frank K. Tittel, "QEPAS spectrophones: design, optimization, and performance", *Appl. Phys. B* 100, 627-635 (2010).

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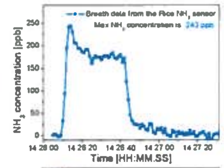
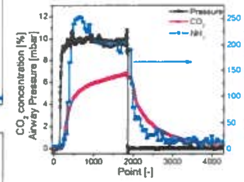
Real-time human breath data of NH_3



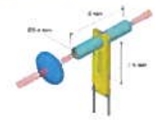


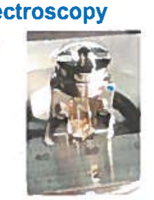
For each patient, a separate folder is created on the Loccioni memory stick.
Each folder contains:
-excel worksheet with 3 columns data: CO_2 [%], airway pressure [mbar] and ammonia [ppb]
-CO_2 [%] plot
-airway pressure [mbar] plot

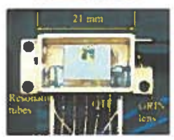
Quartz Enhanced Photoacoustic Spectroscopy

Unique Properties

- Miniature size, <3 mm³ detection volume
- Dimensions in mm: length = 3.8, gap size = 0.3, thickness = 0.3, width = 0.58
- Piezo-active material
- Signal currents ≈ pA
- Intrinsically high Q factor, ~10,000 at ambient pressure; Q in vacuum ~ 125,000
- Optimum micro-resonator (mR) tubes are 4.4 mm long (~λ/4<l<λ/2 for sound at 32.8 kHz) and 0.6 mm in diameter
- Maximum SNR of QTF with mR tubes: ×30 (depending on gas composition and pressure)







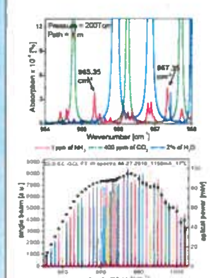
NH_3 Sensor Deployment at Moody Tower, University of Houston

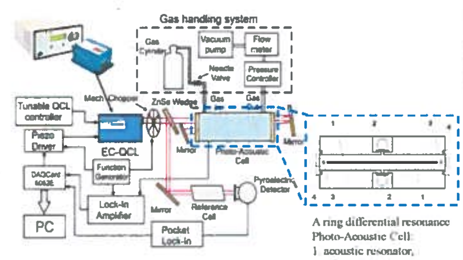
Monitoring of atmospheric NH_3 in the Greater Houston Area

Important Biomedical Molecules

Molecule	Formula	Biological/Pathology Indication	Center wavelength [µm]
Pentane	C_5H_{12}	Inflammatory diseases, transplant rejection	6.8
Ethane	C_2H_6	Lipid peroxidation and oxidation stress, lung cancer (low ppbv range)	6.2
Carbon Dioxide isotope ratio	$^{13}CO_2/^{12}CO_2$	Helicobacter pylori infection (peptic ulcers, gastric cancer)	4.4
Carbonyl Sulfide	COS	Liver disease, acute rejection in lung transplant recipients (10-500 ppbv)	4.8
Carbon Disulfide	CS_2	Disulfiram treatment for alcoholism	4.5
Ammonia	NH_3	Liver and kidney diseases, exercise physiology	10.3
Formaldehyde	CH_2O	Cancerous tumors (400-1500 ppbv)	5.7
Nitric Oxide	NO	Nitric oxide synthase activity, inflammatory and immune responses (e.g. asthma) and vascular smooth muscle response (6-100 ppb)	5.3
Hydrogen Peroxide	H_2O_2	Airway inflammation, oxidative stress (1-5 ppbv)	7.8
Carbon Monoxide	CO	Smoking response, lipid peroxidation, CO poisoning, vascular smooth muscle response	4.7
Ethylene	C_2H_4	Oxidative stress, cancer	10.5
Acetone	C_3H_6O	Ketosis, diabetes mellitus	7.3

Mid-IR EC-QCL based AM-PAS Sensor for NH_3 Detection

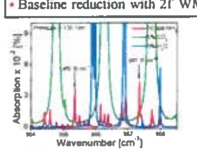




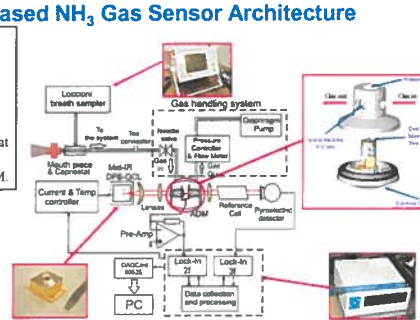
A ring differential resonance Photo-Acoustic Cell:
1. acoustic resonator,
2. microphone,
3. gas input and output,
4. window

QEPAS based NH_3 Gas Sensor Architecture

Advantages of using CW DFB-QCL in the sensor architecture:
- Small laser package ⇒ system compactness
- DFB-QCL room temperature operation
- Performing WM spectroscopy at optimum modulation depth
- Baseline reduction with 2f WM.



HITRAN simulated spectra @ 130 Torr indicating two NH_3 absorption lines of interest

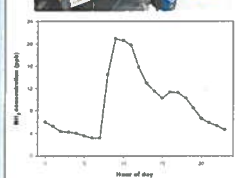


HAMAMATSU (HHL) CW TEC DFB QCL

Control Electronics Unit (CEU)

NH_3 Data from Sensor located on 60 m high Moody Tower Roof

NH_3 sensor and electronics installed on Moody Tower roof top, located on UH campus, Houston, TX



Accidental release of NH_3

NH_3 time series: midnight Aug 14-15,2010 indicating a NH_3 release due to a chemical fire lasting from 6 am to 10 pm as the result of a major fertilizer truck collision on the Gulf Freeway (I-45) ~ 2 miles from the Moody Tower

Diurnal trend of NH_3 concentration for two periods: May 28 - July 6, 2010 and August 4 – 23, 2010