In-situ multi-component trace gas measurements with a fiber coupled, mid-IR difference-frequency mixed laser sensor

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- Merits and Advantages of DFG
- Wavelength tuning and quasi-phase matching
- Applications
- Summary and Future Directions
Applications of Trace Gas Detection

- Urban Emission Measurements
  - Industrial Plants
  - Combustion Sources
  - Automobile
  - Waste Dumps

- Rural Emission Measurements
  - Agriculture
  - Forest Fires

- Environmental Monitoring
  - Atmospheric Chemistry
  - Volcanic Emissions

- Spacecraft and Planetary Surface Monitoring
  - Crew Health Maintenance & Life Support

- Chemical Analysis and Process Control
  - Semiconductor Industry

- Medical Applications

- Aircraft Identification
Mid-IR DFG Trace Gas Detection: Merits and Advantages

- Finger print region: Stronger line intensities (x20 to 200) compared to overtone absorptions
- Hence: Direct absorption spectroscopy can be used
  > absolute measurement technique
  > High sensitivity: $2 \times 10^{-4}$
- Wide, mode-hop free tunability: 3.25 $\mu$m to 4.4 $\mu$m
  > detection of 8+ gas species:
    - CH$_4$, H$_2$CO, CO$_2$, N$_2$O, NO$_2$, HCl, CH$_3$OH, H$_2$O
- Selective: ~40 MHz DFG linewidth
- Near real time concentration measurements (1-10 s)
- Robust: Alignment and maintenance free operation
  using fiber coupled diode laser pump sources
- Automated: Stepper motor controlled tuning and quasi-phase matching
Schematic of DFG based gas sensor

Dimension: 24" x 21" x 8"
Including:
- laser driver
- stepper motor controller

DBR
\( \lambda = 1083 \text{ nm} \)
\( P = 50 \text{ mW} \)

ECDL
\( \lambda = 814 - 870 \text{ nm} \)
\( P_{\text{peak}} = 25 \text{ mW} \)

Yb Fiber Amplifier
V-Groove pumped
\( 2W @ 975\text{nm} \)

~15mW

\( \lambda = 3.3 - 4.4 \mu\text{m} \)

2.9\( \mu\text{W} \)

Multiple Reference Cell Assembly
CaF\(_2\) lens
\( f = 50 \text{ mm} \)

Beam-dump

Achromat
\( f = 10 \text{ mm} \)

PPLN fanout
22.4-23.3 \( \mu\text{m} \)

WDM

2% to Wavemeter

M1

M2

M3

Parabolic Mirror

HgCdTe Detector

 Optical Path Length 18 or 36 m

Baratron

Two-stage Diaphragm Pump
\( \sim 0.15 \text{ slt/min} \)

Filter

12" x 9" x 5.5"
ECDL Tuning Characteristics

DFG Wavelength

3.25 μm  3.83 μm  4.40 μm

Fixed Signal: 9233.7 cm⁻¹

ECDL Frequency (cm⁻¹)

12400
12200
12000
11800
11600
11400

Hysteresis off-set: 4.3 cm⁻¹

ECDL Dial Position

0  2  4  6  8  10  12  14

CH₄, NO₂, H₂CO, HCl, N₂O, CO₂

CW  CCW
ECDL Tuning Characteristics

DFG Wavelength

Fixed Signal: 9233.7 cm\(^{-1}\)

ECDL Frequency (cm\(^{-1}\))

ECDL Dial Position

Hysteresis off-set: 4.3 cm\(^{-1}\)

- CH\(_4\)
- NO\(_2\)
- H\(_2\)CO
- HCl
- CO\(_2\)
- N\(_2\)O

+ CW
+ CCW
Continuous quasi-phase matching using a fan-out PPLN crystal

Phasematching ECDL Wavelength (nm)

Relative Crystal Position (mm)

DFG Wavelength (µm)

PPLN Fan-out grating

$\lambda_{pump} = 1082.98$ nm
Spectroscopic Performance

- Ambient $\text{N}_2\text{O}$ (c=315 ppb)
- Sampling pressure: 88 Torr
- Optical path length: 18 m
- Averaging time: 2 s
- Sensitivity: $2 \times 10^{-4}$
Ambient CO₂ Laboratory Sampling over 42 hours

![Graph showing CO₂ concentration over time with markers for lunch and seminar events.]
Spectroscopic Performance: $\text{N}_2\text{O} \odot 25 - 72 \text{ cm}^{-1}$

- Ambient N$_2$O (c=315 ppb)
- Sampling pressure: 88 Torr
- Optical path length: 18 m
- Averaging time: 2 s
- Sensitivity: $2 \times 10^{-4}$
Cross Comparison: CH₄ Long Term Detection of Two Independent DFG Based Gas Sensors

Dedicated CH₄ DFG based sensor:
36 m multi-pass cell, **open path**, (P=760 torr)

Multi-component DFG based sensor:
36 m multi-pass cell, **extractive sampling**, (P=80 torr)
Formaldehyde Measurements from a Car Exhaust

Sample Line = 17 m, Ø 6.35 mm
Pump rate = 0.1 stlpm

Sample line disconnected
VoCAT analysis: Generation of H$_2$CO

VoCAT: Volatile Organic CATalyst

![Graph showing H$_2$CO concentration and reactor temperature over time]

AUG-17-1999

- Test 1 (Used VoCAT)
- Zero Air (TechniPure)
- H$_2$CO Cal. Gas (772 ppb)
- Reactor Temperature (Deg C)

H$_2$CO concentration, TCCS output (ppb)

Time (hh:mm)

10:48 to 18:00

0 to 6000 ppb

300 to 500 Degrees C
ECDL Operation: Open and Closed Loop

ECDL switched on

Ambient Air Temperature Variation ~1.5 Deg.C

Deviation: 0.03 cm⁻¹

Deviation: 0.159 cm⁻¹
Summary and Future Directions

- Reliable, longterm operation
- Robust and compact
- Autonomous operation using stepper motor controlled ECDL tuning and quasi-phase matching

- Continuous multi-component detection
- Higher power version using Yb and Er/Yb fiber amplified 1 μm ECDL and 1.5 μm pump sources
- Dual beam spectroscopy (\(\sim 2 \times 10^{-5}\))
- QPM GaAs to extend wavelength coverage (6 to 16 μm)
Summary and Future Directions

- Reliable, longterm operation (7 days)
- Robust and compact
- Autonomous operation using stepper motor controlled ECDL tuning and quasi-phase matching

- Continuous multi-component detection
- Higher power version using a Yb and Er/Yb fiber amplified 1 μm ECDL and 1.5 μm pump sources

- Dual beam spectroscopy (~2x10^{-5})

- QPM GaAs to extent wavelength coverage (6 to 16 μm)