Portable Trace Gas Sensor Using Fiber-Coupled Difference Frequency Generation Of Diode Lasers

R.Weidner, D.G. Lancaster, D. Richter and F.K. Tittel
Rice Quantum Institute, Rice University
Houston, TX, USA

J. Limpert, H. Zellmer, and A. Tünnermann
Institut für Angewandte Physik
Friedrich-Schiller-Universit←t Jena, Germany

1 Abstract

• A compact (1.1 ft^3) trace-gas sensor operating near 3029 cm^{-1} (3.3 μm) capable of real-time measurements of CH_4, H_2O, and H_2CO is reported.

• CH_4 was monitored continuously for 7 days (sub minute resolution) with a sensitivity of ~ ±14 ppb.

• CW tunable mid-IR radiation (~ 7 μW) is generated by frequency mixing an α-DFB diode laser (500 mW at 1066 nm) and a DFB diode laser (2 mW at 1572 nm) amplified to ~40 mW by an Er-doped fiber, in periodically poled Lithium Niobate (PPLN).

• A tunable (1535-1570 nm) external cavity diode laser as an alternative signal source was also evaluated.

2 Motivation

• Monitoring greenhouse gases such as CO_2, CH_4 and N_2O in the atmosphere is important from the perspective of global warming.

• Methane comes from 3 major sources: agriculture, natural sources and industry.

• Methane monitoring of gas pipe transmission lines and wells.

• Compact sensors utilizing laser diodes and difference-frequency generation permit **sensitive**, **selective** and **real-time measurements** of trace gases at low concentrations in ambient air[1,2].

• The use of optical fibers makes such a sensor more **robust**, **compact** and **lightweight** [2].

3 Fundamentals of Difference Frequency Generation

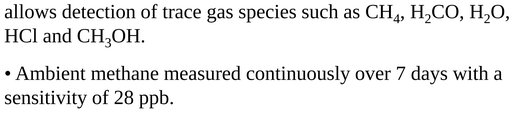
Difference Frequency: $\omega_{idler} = \omega_{pump} - \omega_{signal}$

Quasi Phase Matching Condition: $(k_p - k_s - k_i - 2\pi/\Lambda) = \Delta k = 0$

DFG Power:

$$P_i := \left[\frac{\left(2 \cdot \omega_i \cdot d_{eff}\right)^2}{n_p \cdot n_s \cdot n_i \cdot c^3 \cdot \pi \cdot \varepsilon_o} \cdot \frac{h(\mu, \xi)}{k_s^{-1} + k_p^{-1}} \right] \cdot L \cdot P_p \cdot P_s$$

L - crystal length; d_{eff} - effective nonlinear coefficient; $\mu = k_s/k_p$ Λ=grating period.
focussing parameter ξ=L/b; b - confocal parameter; h - focussing function -> max. @ ξ=1.3



PPLN Crystal with multiple Quasi-Phase-Matching periods (Λ)

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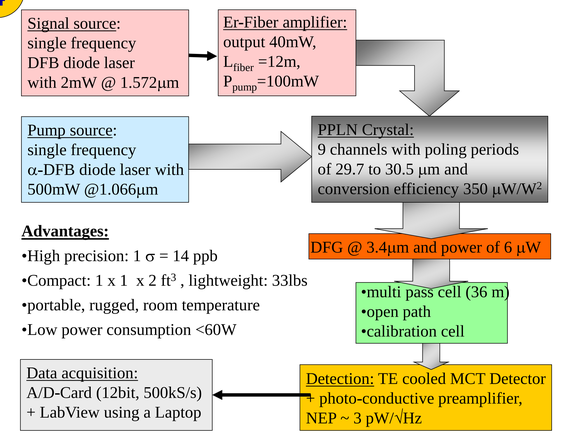
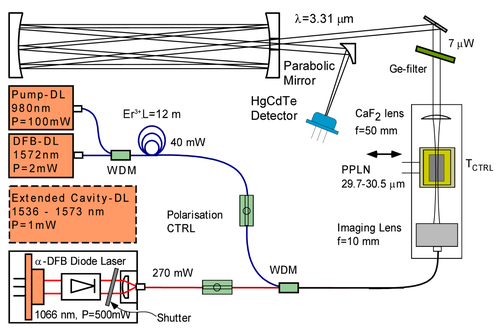


5 Schematic of CH_4 sensor



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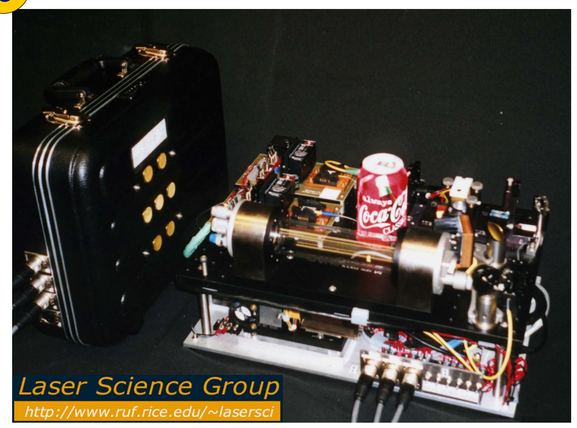
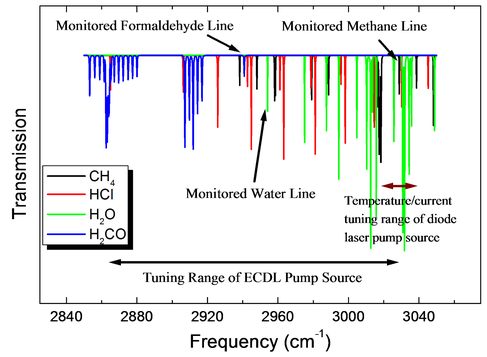
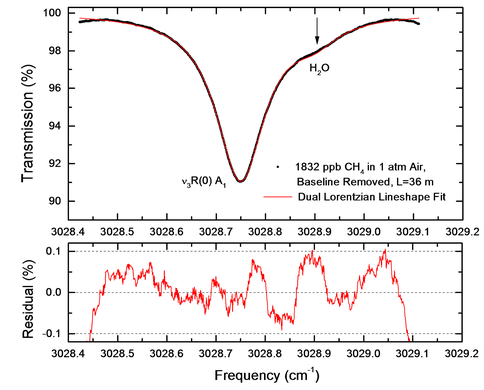


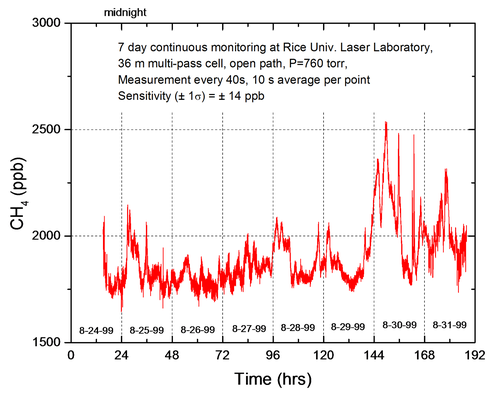
7 Absorption Spectrum (HITRAN-database)



8 Methane line @ 3028.75 cm^{-1} (ambient air)



9 Methane concentration measurement in ambient air



10 Comparison of CH_4 Sensors

Method	Technique	Wavelength	Limit of detection	Reference
FT-IR		500cm^{-1}-14300cm^{-1}	1.6ppm m	[3]
Laser absorption (overtone absorption)	DFB diode laser, 2-f detection	~6024cm^{-1} (1.66 μm)	70ppb m	[4]
Photoacoustic (PA) and laser absorption	DFB diode laser, 2-f detection	6047cm^{-1} (1.65 μm) overtone detection	12ppm m for PA, 1.15ppm m for Abs.	[5]
Laser absorption	***DFG: 3 DFB diode lasers, fiber optics***	***3028cm^{-1} (3.30 μ m)***	***540ppb m***	***Rice University Sensor***
Frequency modulated tunable diode laser absorption (FM-TDLAS)	Liquid-N-cooled lead salt diode laser, optical heterodyne	2979 cm^{-1} (3.36 μm)	14ppb m	[6]
Dual-beam laser absorption spectroscopy	DFG: DFB + DBR diode laser, fiber amplifiers	2989 cm^{-1} (3.35 μm)	64ppb m	[7]

11 Conclusions and future outlook

• A compact trace gas sensor for monitoring trace gases with fundamental ro-vibrational transitions in the 2840-3040 cm^{-1} spectral region is reported.

• The use of discrete DFB diode lasers or an ECDL pump source allows detection of trace gas species such as CH_4, H_2CO, H_2O, HCl and CH_3OH.

• Ambient methane measured continuously over 7 days with a sensitivity of 28 ppb.

• Compact size, low power consumption and weight.

12 References

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