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

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1 Abstract

We report a new compact trace-gas sensor operating near 3029 cm^{-1} (3.3 μm) and allowing real-time measurements of CH_4, H_2O, and H_2CO at low concentrations.
4 μW of difference-frequency radiation is generated by mixing in periodically poled Lithium Niobate (PPLN) 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.
An alternative signal source using a widely tunable (1535-1570 nm) Er^{3+} fiber amplified external cavity diode laser is also reported.

2 Motivation

•Monitoring greenhouse gases such as CO_2, CO, CH_4 and N_2O in the atmosphere is important from the issue of global warming. Methane is produced in large quantities by wetlands, landfills, rice fields, animal farms, oil plants, volcanoes etc.

•Recently, compact sensors utilizing laser diodes and difference-frequency generation allowed highly accurate measurements of such trace gases at low concentrations and high reliability [1-3].

•The use of optical fibers makes this sensor more rugged and lightweight [2,3].

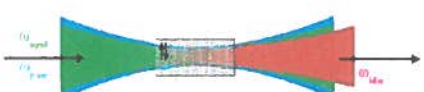
3 Principle of Difference Frequency Generation

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

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

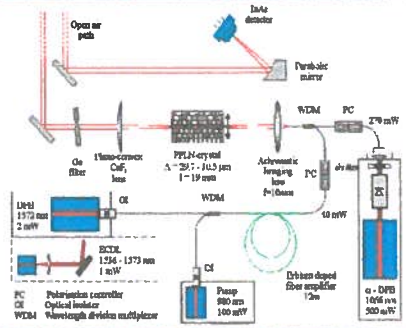
DFG Power: $P_i \sim (\omega_i d_{eff})^2 P_s P_p L h(\xi,\mu)$

L - crystal length, d_{eff} - effective nonlinear coefficient
focusing parameter ξ, μ - confocal parameter, h - DFG conversion efficiency



PPLN Crystal with multiple Quasi-Phase-Matching periods

4 Schematic of CH_4 sensor



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Signal source: single frequency DFB diode laser with 2mW @ 1.572μm

Er-Fiber amplifier: output 42mW, L_{fiber} ~12m, P_{pump}=100mW

Pump source: single frequency α-DFB diode laser with 500mW @1.066μm

PPLN Crystal: 9 channels with poling periods of 29.7 to 30.5 μm and conversion efficiency 350 μW/W²

DFG @ 3.4μm and power of 3.5μW

•multi pass cell (18m)
•open path
•calibration cell

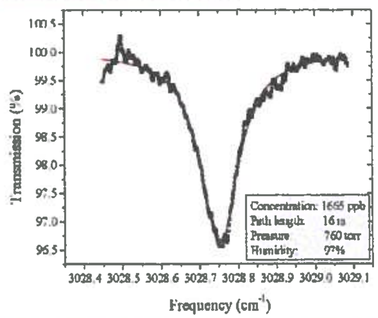
Detection: TE cooled InAs Detector + transimpedance preamplifier, NEP ~ 8 pW/√Hz

Data acquisition: A/D-Card (12bit, 500kS/s) + LabView using a Laptop

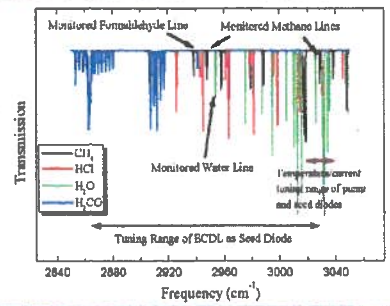
Advantages:

•High accuracy ~70ppb Standard Deviation
•Compact: 1 x 1 x 2 ft³, lightweight: 33kg
•portable, rugged, room temperature
•Low power consumption <60W

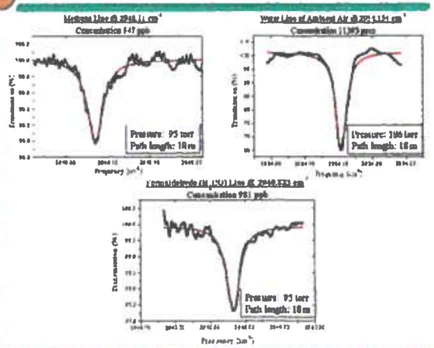
6 Methane line @ 3028.75 cm^{-1} (ambient air)



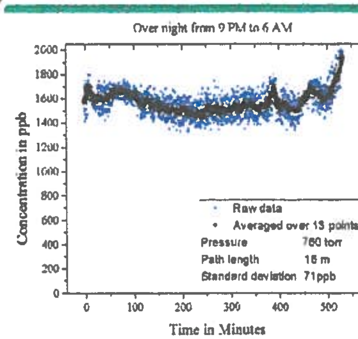
7 Absorption Spectrum (HITRAN-database)



8 Lines of other monitored species



9 Methane concentration measurement in ambient air



10 Comparison of CH_4 Sensors

Methode	Technique	Wavelength	Limit of detection	Reference
FT-IR Laser absorption	InGaAs diode laser	500cm^{-1}-14350cm^{-1} ~7700cm^{-1} (1.30 μm) overtone detection	1 ppm m 30ppm m	[4] [5]
Laser absorption	DFB diode laser, second harmonic detection technique	~6034cm^{-1} (1.66 μm) overtone detection	70ppb m	[6]
Photoacoustic (PA) and laser absorption	DFB diode laser, second harmonic detection technique	6047cm^{-1} (1.65 μm) overtone detection	12ppm m for PA, 1.13 ppm m for Abs.	[7]
Laser absorption	*DFB diode laser, fiber optics*	*3029cm^{-1} (3.30 μm)*	*2ppm m*	*Rice University Source*
Frequency modulated tunable diode laser absorption (FM-TDLAS)	Liquid-N-cooled lead salt diode laser, optical heterodyne	2979 cm^{-1} (3.36 μm)	470ppb m	[8]
Laser absorption	Liquid-He-cooled lead salt diode laser	~1331cm^{-1} (7.40μm)	0.1ppb m	[9]

11 Conclusions and outlook

•A new compact trace gas sensor for monitoring methane (CH_4) is reported.

•This sensor can currently measure concentrations of methane with a lower limit of 100 ppb and a standard deviation of 70ppb in real-time.

•Features include compact size, low power consumption and weight.

•By using a widely tunable signal source or discrete diode lasers, species such as formaldehyde (H_2CO) and H_2O can be measured in real-time.

•Potential for improvement includes the use of an optimized achromat imaging lens and an improved detector/preamplifier combination.

12 References

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