Robust Mid-Infrared Spectrometer Based on Difference Frequency Generation for Trace Gas Sensing Applications

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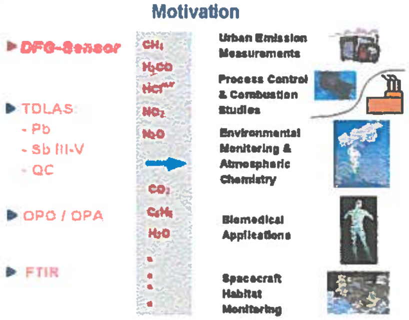
1 Abstract

This work describes a recent development of a robust, compact and light weight trace gas sensor based on difference frequency generation (DFG) suitable for realworld applications ranging from urban, industrial, rural emission studies to spacecraft habitat monitoring. This development of the sensor has taken advantage of recent technological advances of semiconductor diode and solid state lasers, new nonlinear optical materials, optical fiber and data acquisition techniques. Difference mixing in a periodically doped lithium niobate (PPLN) of an external cavity diode laser (25 mW, 814-870 nm) and DBR laser (50 mW, 1083 nm) amplified to 550 mW by an Yb doped fiber amplifier generates ~ 3 mW (@ 3.4mm) of tunable mid-infrared radiation, which enables sensitive (parts per billion) and selective detection of trace gases in a 18 m long multipass gas cell. Real-time concentration measurements of CO_2, N_2O, H_2CO, HCl, NO_2, and CH_4 are reported.

2 Motivation



3 Enabling DFG Technologies

Fiber Coupled Single Frequency Diode Lasers:
ECDL
-814nm to 870nm
-25mW
DBR
-1083nm
-50 mW

+

Yb-Fiber Amplifier:
550mW@1083nm
Pump 2W@976nm

+

Frequency Conversion to Mid-IR:
3.3 µm to 4.4 µm
2.5 µW@3.5 µm
QPM-PPLN
Λ=22.4µm to 23.3µm
fan-out grating

Single-Line Absorption Spectroscopy:
Multipass Cell:
L= 18m to 100 m
TE-cooled HgCdTe-detectors
NEP ~5pW $Hz^{-1/2}$

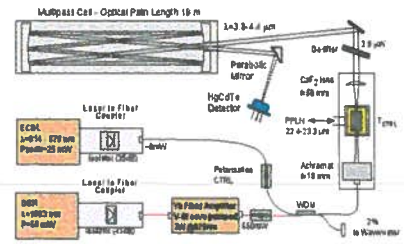
+

Real-time Data Acquisition and Control:
-Analog / Digital PCMCIA Card
-Notebook PC
-LabVIEW 5.0 Software

+

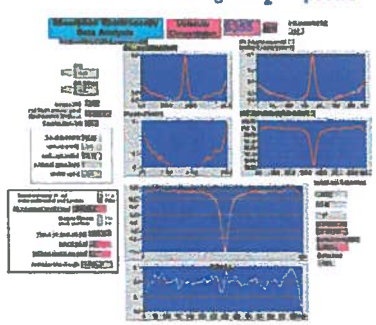
Calibration and Reference:
- Wavemeter
- Cal. Reference Gas Cells
- Hitran Database

4 Schematic of the Optical Gas Sensor



5 Picture of DFG Based Gas Sensor

6 LabView Processing of N_2O Spectra



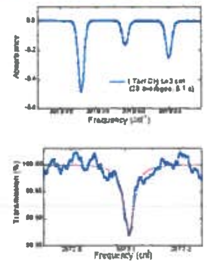
7 Spectroscopic Performance

Selectivity

- High resolution doppler limited CH_4 spectra at 3.3 microns
- DFG linewidth of present system ~40 MHz

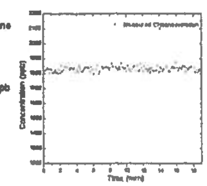
Sensitivity

- Ambient N_2O (c=316 ppb)
- Sampling pressure: 88 Torr
- Optical path length: 18 m
- Averaging time: 2 s
- Sensitivity: $2x10^{-4}$



8 Calibration of Ambient CH_4

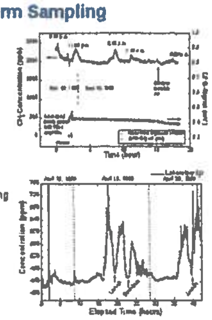
- Calibration using CH_4 absorption line at 3028.751 cm^{-1}
- Scan every 8.7 sec
- Average Concentration = 1829.8 ppb
- Standard Deviation = 18.4 ppb
- Calibration Gas Value = 1773 ppb
- Off-set: 3.1 %



9 Longterm Sampling

- Ambient CH_4 Laboratory and Outside Sampling
- DFG-Power Signal vs Time

- Ambient CO_2 Laboratory Sampling over 42 Hours



10 Detection Characteristics of Trace Gases

Gas species	Scan Center (cm⁻¹ (µm))	Measured Concentration	Specified Concentration	MDC (L=18m)
CO	[illegible]	[illegible] ppm	[illegible]	[illegible] ppb
[illegible]	[illegible]	[illegible] ppb	[illegible]	[illegible] ppb
H_2CO	[illegible]	[illegible] ppb	[illegible]	[illegible] ppb
HCl	[illegible]	[illegible] ppm	[illegible] ppm	[illegible] ppb
[illegible]	[illegible]	[illegible] ppb	[illegible] ppm	[illegible] ppb
CH_4	[illegible]	[illegible] ppb	[illegible]	[illegible] ppb

Sampling Conditions

- Scan range: 0.3 cm^{-1}
- Sampling pressure: 88 Torr
- Averaging time: 2 s

11 Future Directions

- Increased mid-IR probe power using high power fiber amplifiers (1W to 2W) To date: 0.5 mW DFG @ 3.5 µm
- Improved packaging (Fiber coupling, Hybrid driver electronics)
- Implement automatic scanning using a stepper motor for the ECDL and PPLN crystal with fan-out designed grating mask (continuous QPM)
- Introduction of quasi-phase matched GaAs to access the longer wavelength region (8 - 18 microns)
- Lower diode laser pump power requirements with tapered QPM-waveguide DFG devices
- Advanced data acquisition and signal processing techniques (DSP)

12 References

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- L. Goldberg, D. G. Lancaster, J. Koplow, R. F. Curl, and F. K. Tittel, "Mid-IR difference frequency generation source pumped by a 1.1 - 1.5 microns dual-wavelength fiber amplifier for trace-gas detection." *Optics Letters* 23, 1517-1519
- D. G. Lancaster, D. Richter, and F. K. Tittel, "Portable fiber coupled diode laser based sensor for multiple trace gas detection," accepted by *Applied Physics B* (June, 1999)
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