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Development and Application of a Real-Time Optical Sensor for Atmospheric Formaldehyde

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OUTLINE

GCHSRC
Site Visit
Oct. 29, 2001

- Motivation and Technology Issues
- Infrared Diode Laser-based Gas Sensors
- Formaldehyde Concentration Measurements
- Summary and Outlook

Wide Range of Gas Sensor Applications

- Urban and Industrial Emission Measurements
  - Industrial Plants - Fenceline perimeter monitoring
  - **Combustion Sources**
  - Automobile
- Rural Emission Measurements
  - Agriculture
- Environmental Monitoring
  - **Atmospheric Chemistry**
  - Volcanic Emissions
- Spacecraft and Planetary Surface Monitoring
  - **Crew Health Maintenance & Life Support**
- Chemical Analysis and Industrial Process Control
  - Petrochemical and Semiconductor Industry
- Medical Diagnostics

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Air Composition

Main Components		Trace Components	
Nitrogen	78%	Methane	1.7 ppm
Oxygen	21%	CO	0.4 ppm
Water	0.8%	N_2O	0.3 ppm
CO_2	0.03 %	O_3	0.03 ppm
		H_2CO	**0.001 ppm**
		…	

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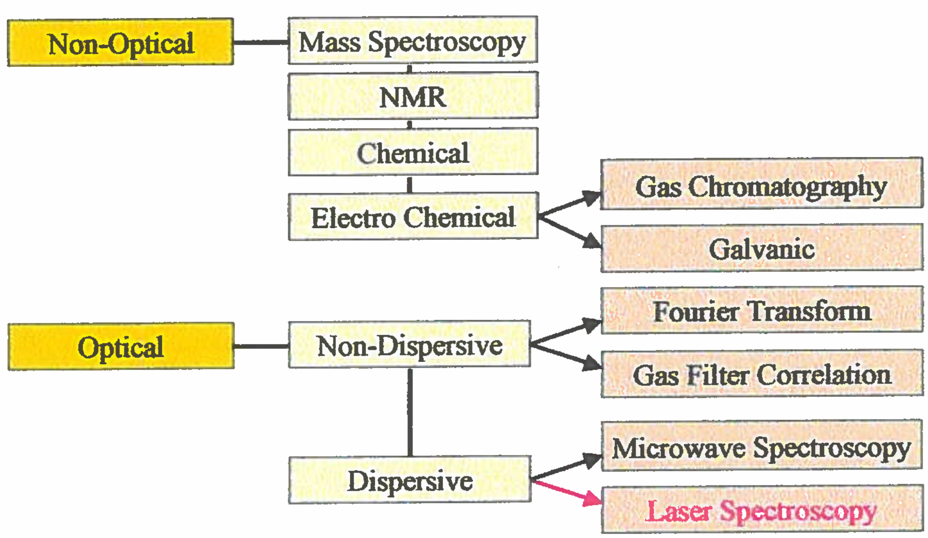
Existing Methods for Trace Gas Detection



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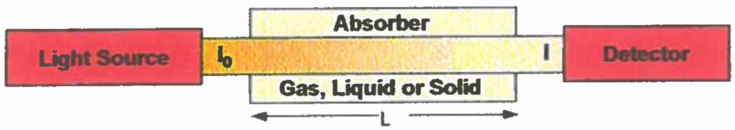
Absorption Spectroscopy



Beer – Lambert's Law

$$I(\nu)=I_0 \cdot e^{-\alpha(\nu)\cdot P_a L}$$

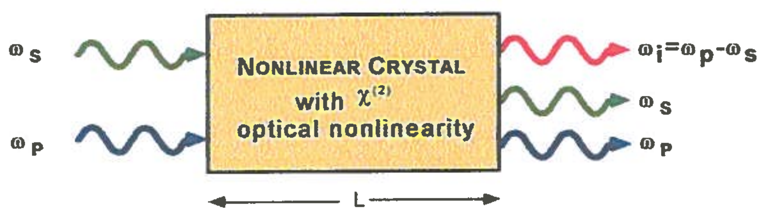
$\alpha(\nu)$ - absorption coefficient [cm^{-1} atm^{-1}]; L – path length [cm]
ν - frequency [cm^{-1}]; P_a- partial pressure [atm]

Molecular Absorption Coefficient

$$\alpha(\nu)=C\cdot S\cdot g(\nu-\nu_0)$$

C - total number of molecules of absorbing gas/atm/cm^3 [molecule$\cdot cm^{-3}\cdot atm^{-1}$]
S - *molecular line intensity [cm $\cdot$molecule^{-1}]*
$g(\nu-\nu_0)$ - normalized lineshape function [cm],(Gaussian, Lorentzian, Voigt)

Difference Frequency Generation



MID-IR POWER: $P_i \sim C\cdot P_{PUMP}\cdot P_{SIGNAL}\cdot L\ h(\zeta,\mu)$
$C=(\omega_i\ d_{eff})^2$, $\mu=k_s/k_p$, $\zeta=L/b$

EXAMPLE: FOR PPLN AT 3.5 μM
C~450 μW / cm W^2
~3 μW for 6mW and 540mW LD pump sources

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Design Features of CW DFG Sensor

- Adequate Mid-infrared DFG Power
- High Sensitivity (ppb concentrations)
- High Selectivity (<30 MHz)
- Wavelength Tunable (Single or Multiple Trace Gases)
- Fast Data Acquisition and Analysis
- Room Temperature
- Non-invasive, Point or Remote Monitoring
- Compact, Lightweight and Robust
- Power Efficient
- No Consumables , Low Maintenance and Cost Effective

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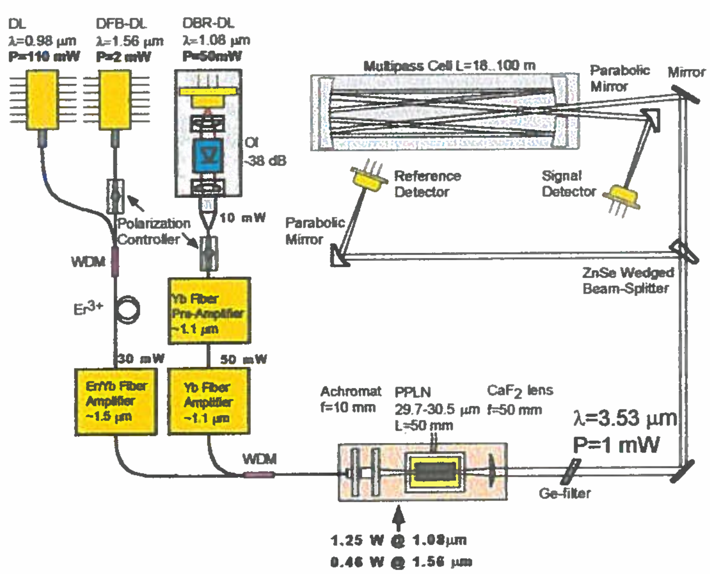
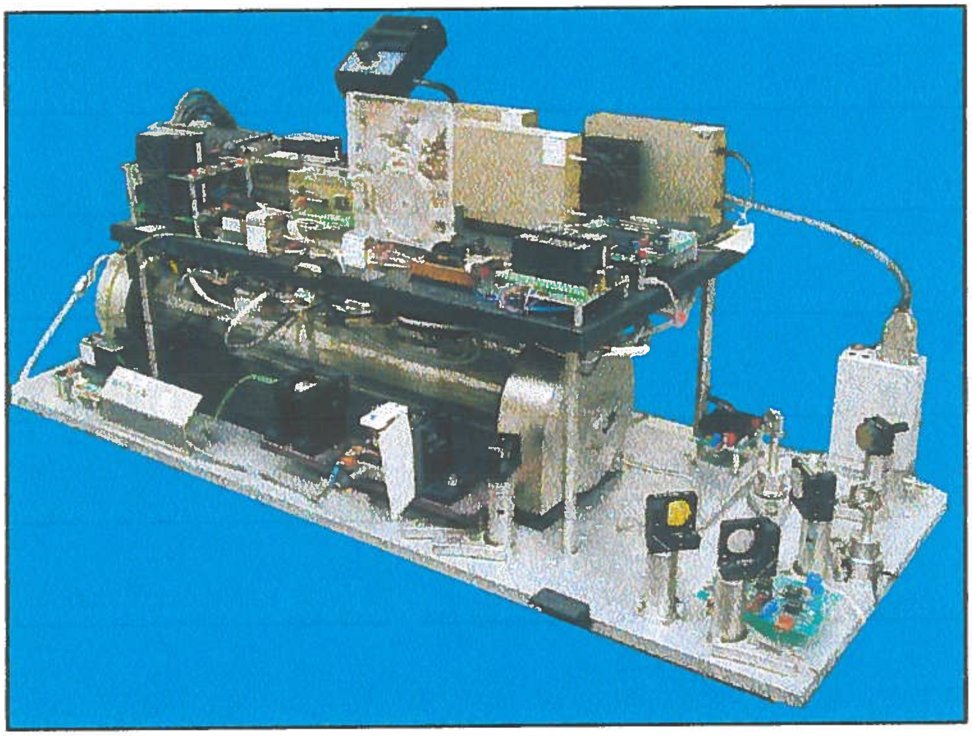
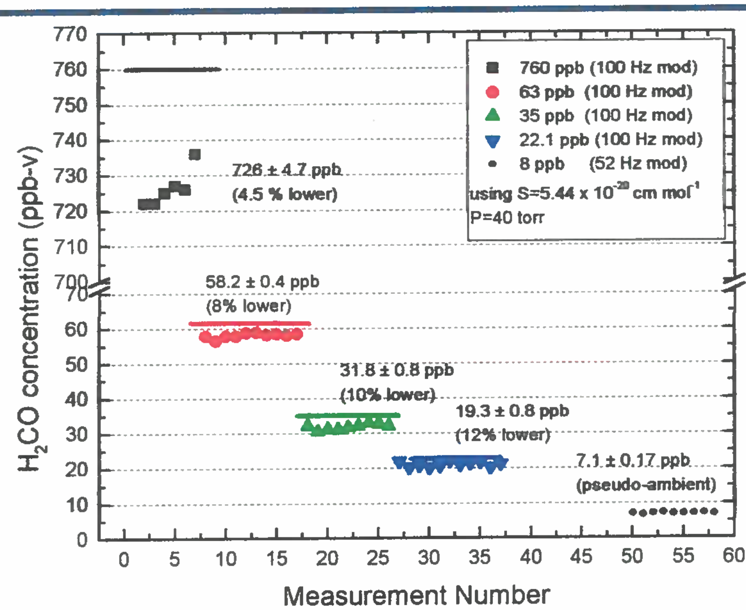
Diode Laser Based H_2CO Sensor

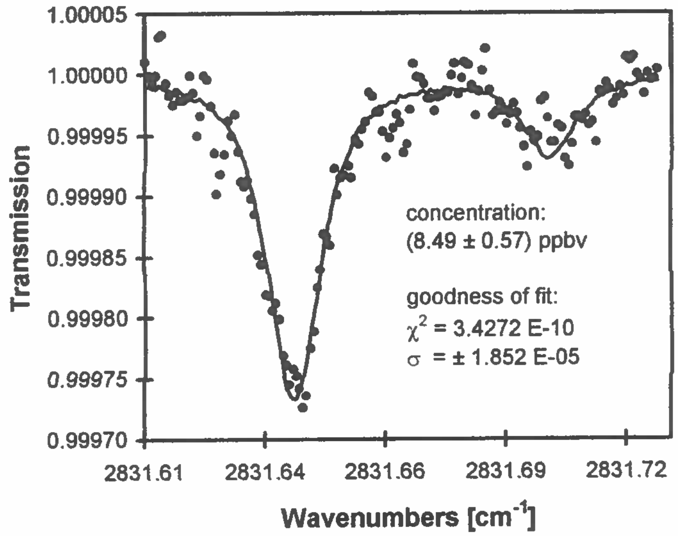




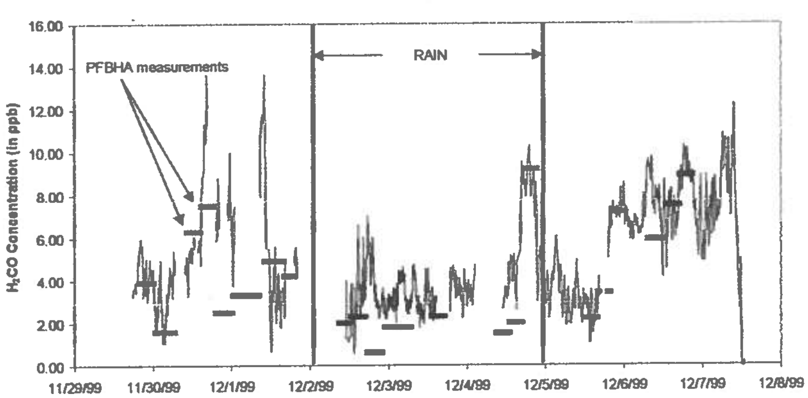
H_2CO Calibration of Dual Beam DFG Sensor



H_2CO Detection in Ambient Air at 3.53 μm



9 Day H_2CO Detection at 3.53 μm in Houston



Map of the Greater Houston Area

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Texas Natural Resources Conservation Commission Monitoring Site, Houston

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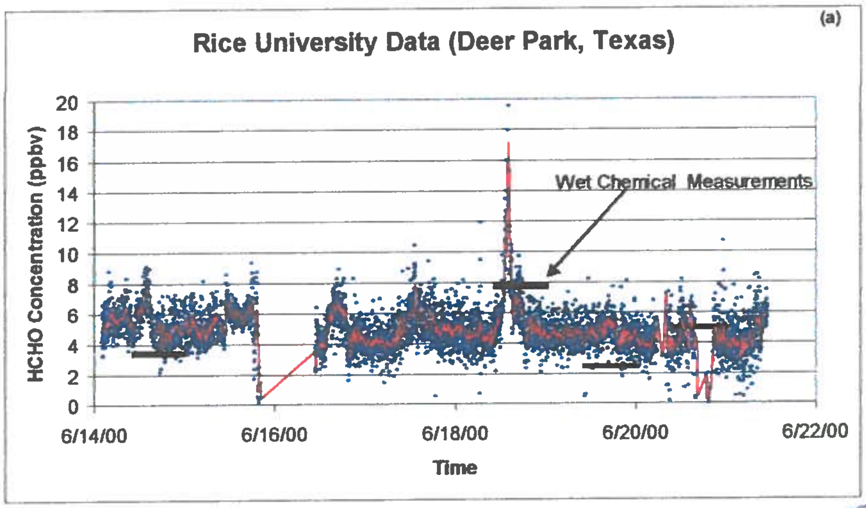
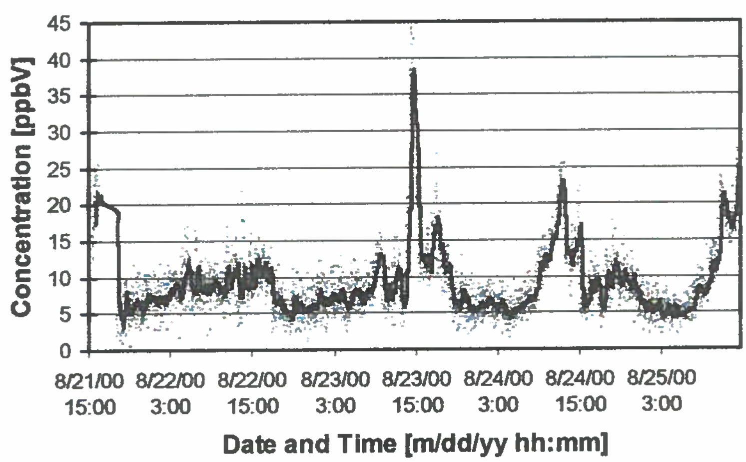
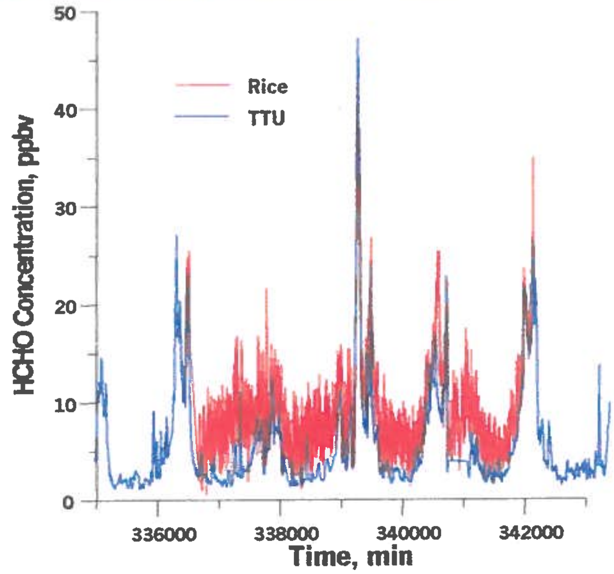
Nine Days of Continuous HCHO Data



Five Days of Continuous Channel View HCHO Data



HCHO Data Comparison TTU-Rice



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Summary

- Diode Laser Based Trace Gas Sensors
  - Compact, tunable, robust (alignment insensitive),fieldable
  - High sensitivity (<$2 \cdot 10^{-4}$ to 10^{-5}) and selectivity (10–300 MHz)
  - Fast data acquisition and analysis
  - Detected trace gases: **H_2CO,** NH_3 ,CH_4,, NO_2, N_2O, H_2O, **CO_2**, CO, NO, HCl, SO_2, C_2H_5OH, **isotopic species of ^{12,13}C**, ^{16,17,18}O, ^{35,37}Cl
- Applications in Trace Gas Detection
  - Environmental monitoring: **H_2CO**, CO, CH_4 (EPA, NASA, NCAR, NOAA,)
  - Industrial process control and chemical analysis
  - Medical diagnostics (NO, CO, CO_2, NH_3)
- Future Directions
  - Fiber lasers and amplifiers
  - Longer mid-IR wavelengths with orientation patterned GaAs and QC lasers, detection of complex molecules
  - Cavity enhanced and cavity ringdown spectroscopy

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