Development of a Real-Time Optical Sensor for Atmospheric Formaldehyde Monitoring

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- Motivation and Technology Issues
- Infrared Diode Laser-based Gas Sensor
- Formaldehyde Concentration Measurements in the Greater Houston Area
- Summary and Outlook

Motivation for Precision Monitoring of $\text{H}_2\text{CO}$

- **Precursor to atmospheric $\text{O}_3$ production**
- Pollutant due to incomplete fuel combustion processes
- Potential trace contaminant in industrial manufacturing products
- Medically important gas
H$_2$CO Detection in Ambient Air at 3.53 $\mu$m

- Concentration: $(8.49 \pm 0.57)$ ppbv
- Goodness of fit:
  - $\chi^2 = 3.4272 \times 10^{-10}$
  - $\sigma = \pm 1.852 \times 10^{-5}$
Map of the Greater Houston Area

Nine Days of Continuous HCHO Data
Five Days of Continuous HCHO Data at Channel View, TX

HCHO and O$_3$ Concentrations at Deer Park, TX for July 20-31, 2002
Environmental data at Deer Park, TX for July 20-31, 2002

HCHO Concentrations at Deer Park, TX for August 2-14, 2002
HCHO and O₃ Concentrations at Deer Park, TX for August 2-14, 2002

HCHO and O₃ Concentrations at Deer Park, TX for September 2-25, 2002
Current Development Highlights: “Plug-and-Pray” to “Plug-and-Play”

- Fiber Laser Seed Source
  - 60 ppb (16 MHz) absolute frequency stability over 24 hours
  - No pump diode laser dependency ($\Delta f, \Delta f'$)
  - $<100$ kHz linewidth (free-running)

- DFB Diode Laser Seed Source
  - 173 ppb (33 MHz) absolute frequency stability over 24 hours
  - 100 Hz frequency tuning accuracy (over 12 GHz [0.4 cm$^{-1}$])
  - $<2$ MHz linewidth (free-running)

- DFG Module
  - Rugged, close-coupling design
  - Clean, predictable near Gaussian spatial mid-IR beam
  - $<0.0003\%$ / h power stability ($\approx 1/1000$ of Fiber Amplifier Stability)
  - Self-compensating temperature induced drift (Residual $<5.8$ MHz/h)

Airborne High-Power DFG Based Trace Gas Sensor

[Diagram of DFG Stage and Multi-Pass Cell]
DFG Spatial Beam Propagation

Summary

- **Diode Laser Based Trace Gas Sensors**
  - Compact, tunable, robust (alignment insensitive), fieldable
  - High sensitivity (<2·10^{-4} to 10^{-3}) and selectivity (10–300 MHz)
  - Fast data acquisition and analysis
  - Detected trace gases: H₂CO, NH₃, CH₄, NO₂, N₂O, H₂O, CO₂,
    CO, NO, HCl, SO₂, C₂H₅OH, isotopic species of ¹²,¹³C,
    ¹⁶,¹⁷,¹⁸O, ³⁵,³⁷Cl

- **Applications in Trace Gas Detection**
  - Environmental monitoring: H₂CO, CO, CH₄ (EPA, NASA, NCAR, NOAA)
  - Industrial process control and chemical analysis
  - Medical diagnostics (NO, CO, CO₂, NH₃)

- **Future Directions**
  - Fiber lasers and amplifiers
  - Longer mid-IR wavelengths, with orientation patterned GaAs
    and QC lasers, detection of complex molecules