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Mid–infrared detection of atmospheric CH_4, N_2O and H_2O based on a single continuous wave quantum cascade laser

OUTLINE

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http://www.ece.rice.edu/~lasersci/

Outline

- Introduction
- Absorption line selection and QCL characterization
- Sensor system configuration
- Performance optimization and assessment
- Laboratory air component measurements
- Atmospheric N_2O, CH_4 and H_2O concentration measurements
- Summary and futurework

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Introduction: Nitrous Oxide, Methane and Water

NO_2, CH_4 & H_2O are three major atmospheric greenhouse gases contributing to global warming and climate change.

- **Nitrous Oxide (N_2O)**
  - A global warming potential (GWP) of 298
  - A longer atmospheric lifetime than carbon dioxide (CO_2)
  - 330 ppbv atmospheric concentration level with an increasing rate of ~0.7ppbv/yr
- **Methane (CH_4)**
  - A global warming potential of 25
  - A short lifetime (12 yrs) compared with CO_2 and N_2O
  - 1.8ppm atmopsheric concentration level
- **Water vapor (H_2O)**
  - A dominant energy carrier in the atmosphere and regulates planetary temperatures through the absorption and emission of radiation.

A simultaneous detection of NO_2, CH_4 & H_2O s helpful for a better understanding of global warming and climate change

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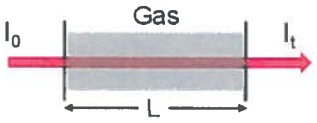
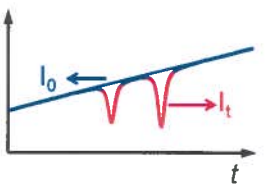
Spectroscopy Fundamentals

Beer's Law: $\frac{I_t}{I_o} = \exp(-k_v L)$



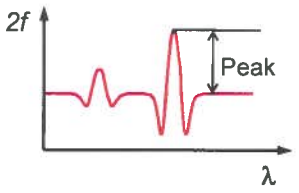
where: I_t is transmitted light intensity
I_0 is incident light intensity
k_v is absorption coefficient

$k_v = S(T)Px_i\phi_v$



WMS-2f detection:

- Ramp (Hz) I to sweep over absorption lines
- Fast sinusoidal modulation f ~kHz
- Demodulate at 2f (2nd derivative line-shape)



+ Multipass Gas Cell

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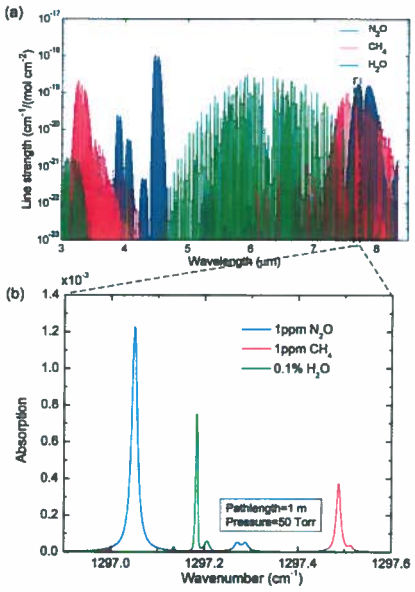
Absorption Line Selection



- Most gas species have their strong fundamental absorption lines in the mid-infrared spectral range
- N_2O, CH_4 and H_2O absorption lines occur at wavelengths from 3 to 8.5μm
- The strongest absorption bands are located at 3.3 μm for CH_4, 4.5 μm for N_2O, and 5.9 μm for N_2O
- A relatively strong absorption line at 7.7 μm is a good compromise for the detection of N2O, CH4 and H2O
- Three neighboring absorption lines are well separated from each other occur within a relatively small spectral range of 0.5 cm^{-1}

  N_2O: 1297.05cm^{-1}
  CH_4:1297.486cm^{-1}
  H_2O: 1297.184cm^{-1}

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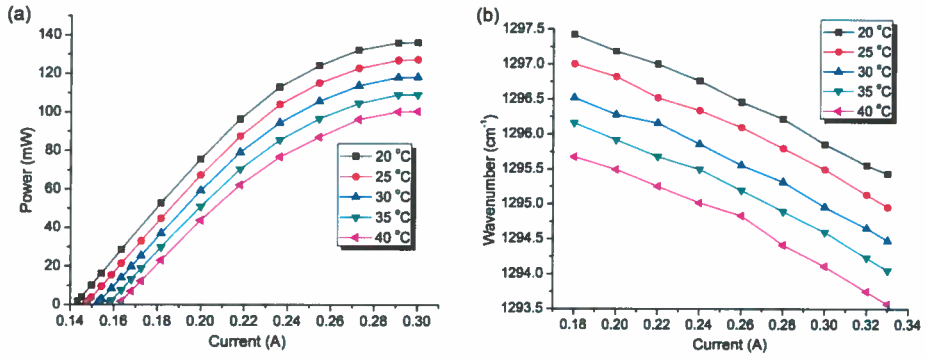
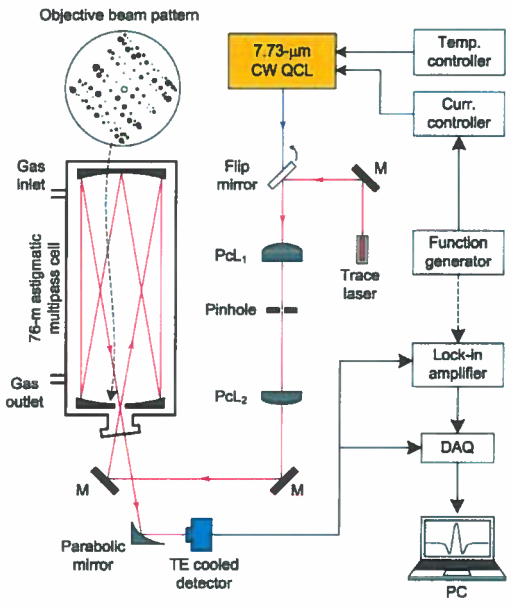
QCL Characterization & Performance Evaluation

Corning-Maxion- Thorlabs QCL, 7.73μm center-wavelength



Performance evaluation for a 7.73-μm CW DFB-QCL at different operating temperatures and injection currents. (a) QCL output power response curves; (b) Emission wavenumber curves.

Sensor System Configuration



- Laser source
  - Current: 240 mA
  - Temperature: 15 °C
- Spatial filter two lenses & one pin hole
  - f_1=50 mm and f_2=100mm
  - 400 μm pinhole
- Multipass cell
  - Aerodyne Reseach Inc.
  - 76m effective optical path length
  - 32cm mutipass cell length

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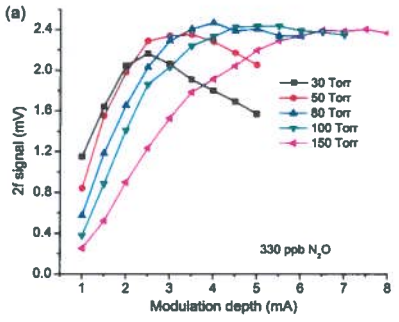
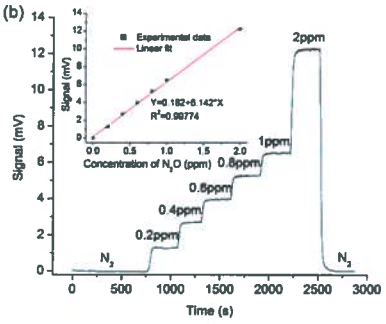
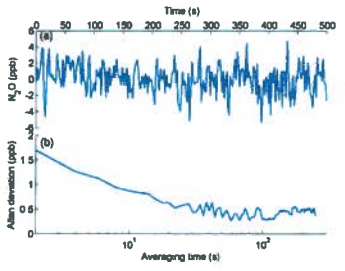
Performance Optimization and Assessment for N_2O Detection

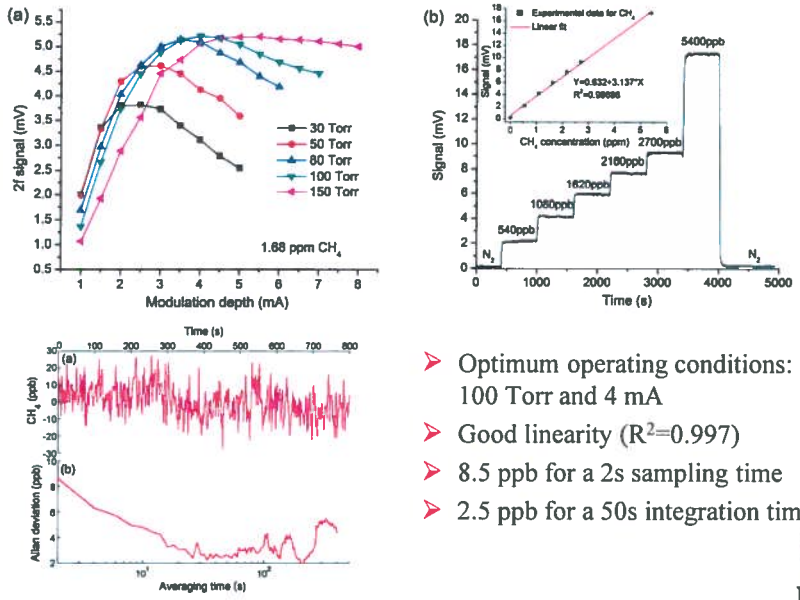






- Optimum operating conditions: 80 Torr and 4 mA
- Good linearity (R^2=0.9977)
- 1.7 ppb for a 2s sampling time
- 0.3 ppb for a 100s integration time

Performance Optimization and Assessment for CH_4 Detection



- Optimum operating conditions: 100 Torr and 4 mA
- Good linearity (R^2=0.997)
- 8.5 ppb for a 2s sampling time
- 2.5 ppb for a 50s integration time

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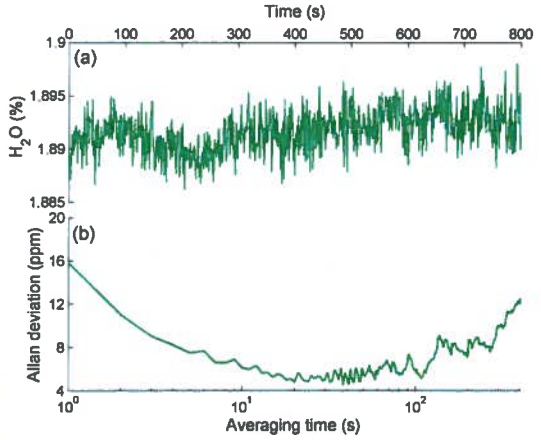
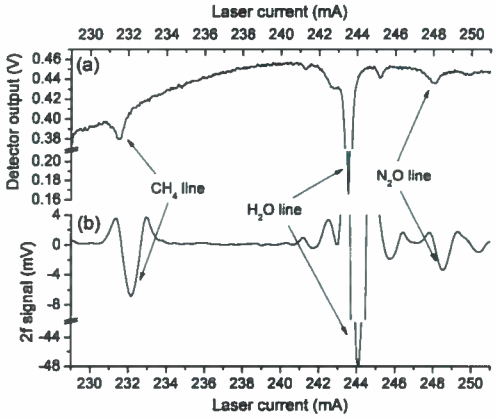
Performance Optimization and Assessment for H_2O Detection



- Optimum operating conditions: 400 Torr and 5.5 mA
- Good linearity (R^2=0.997)
- 16 ppm for a 1s sampling time
- 5 ppm for a 30s averaging time

Simultaneous Detection of CH_4, N_2O and H_2O



(a) Direct output of the mid-infrared detector,
(b) 2*f* signal of the sensor system for simultaneous three gas species (N_2O, CH_4, and H_2O) detection at a pressure of 100 Torr and a modulation depth of 4 mA.

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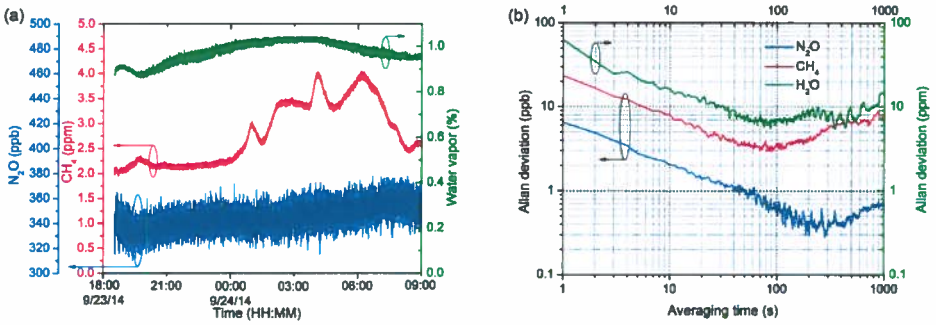
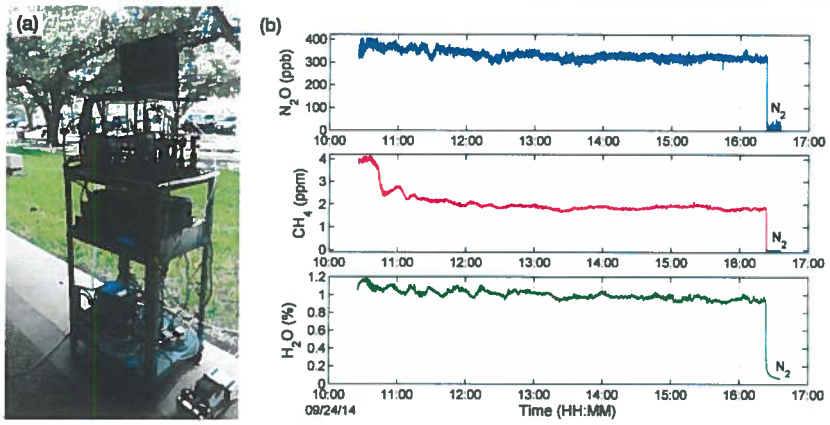
Laboratory Measurements



(a) Simultaneously measured concentrations of N_2O, CH_4, and H_2O in laboratory ambient air .
(b) Allan deviation of N_2O, CH_4, and H_2O within constant concentration periods.

Atmospheric N_2O, CH_4 and H_2O Concentration Measurements



(a) A CW QCL based N_2O, CH_4 and H_2O sensor system;
(b) Measurement results of simultaneous monitoring of three gas concentrations in the atmosphere for a 6 hour time duration.

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Summary and Conclusions

- Development of a 7.73 μm CW DFB QCL based absorption sensor for simultaneous detection of nitrous oxide, methane, and water vapor using a 76 m commercial optical path length astigmatic multipass Herriott.
- A minimum detection concentrations of 1.7 ppb for N_2O, 8.5 ppb for CH_4, and 11ppm for H_2O with 2 sec integration time were achieved.
- This single QCL based multi-gas detection system possesses application in environmental monitoring and breath analysis.

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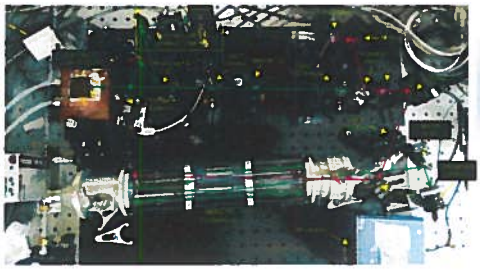
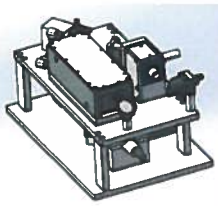
Future Outlook of mid-IR Sensor Technologies





Current sensor platform:

- 18 in multipass cell
- 24in x 18in board
- QCL
- High power consumption for current and temperature control

Next generation sensor platform:

- 6.5 in novel multipass cell
- 12.5in x 8in board (folded optical path)
- Interband cascade laser(s)
- low power consumption for current and temperature control

Innovative sensor platforms to funded by DOE ARPA-E (mid 2015-2018)

Sensor size : 2 in cube

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