Industrial applications of pulsed quantum cascade laser analyzer for trace-gas monitoring

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- Motivation and Technology Issues
- Specific challenges for QCL based industrial monitoring
- Justification and realization of precise ultrashort wavelength scan
- Data acquisition issues
- Summary and Outlook

Wide Range of Gas Sensor Applications

- Chemical Analysis and Industrial Process Control
  - Power Generation, Pharmaceutical, & Food Industries
  - Semiconductor Industry
- Urban and Industrial Emission Measurements
  - Industrial Plants
  - Combustion Sources
  - Automobile
- Rural Emission Measurements
  - Agriculture
- Environmental Monitoring
  - Atmospheric Chemistry
  - Volcanic Emissions
- Spacecraft and Planetary Surface Monitoring
  - Crew Health Maintenance & Life Support
- Medical Applications

Temperature distribution in industrial exhaust

SCR - Selective catalytic reduction, method of removing NOx from combustion gases using a catalyst and ammonia
NO and NH3 must be monitored at a few ppm level

750°C = 400°C

Simulated absorption spectrum

Path 2 m

630 K

Fractional absorption, %

CO 14%

NO 1 ppm

H 0.1%

NH3 5 ppm

Combined

0

1

2

3

1800.5

1900

2000.5

Frequency, cm⁻¹

Molecular absorption and laser sources

Absorption and laser sources

<table>
<thead>
<tr>
<th>Gas</th>
<th>Laser Source</th>
<th>Wavelength, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2O</td>
<td>OPO OPO</td>
<td>2000 - 2500</td>
</tr>
<tr>
<td>H2O</td>
<td>OPO OPO</td>
<td>2000 - 2500</td>
</tr>
<tr>
<td>NO2</td>
<td>OPO OPO</td>
<td>2000 - 2500</td>
</tr>
<tr>
<td>HNO3</td>
<td>OPO OPO</td>
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Laser Sources and Wavelength Coverage

- Gas Source
  - CO2 Laser
  - O2 Laser
  - Ar + Kr Laser
- Solid State Laser
  - Cr:LiCAF Laser
  - DFB Dye Laser
- Fiber Laser
  - Solid State Laser
  - Amplifier
- OPO Laser
  - OPA Laser
- Frequency Conversion Source
  - Dye Laser
  - Raman Laser
  - OPO Laser

Wavelength (nm)
Pulsed QC laser housing

Specific issues for industrial monitoring with a pulsed QCL

- Strong fluctuating nonselective attenuation (~70%) by aerosol particles and gas flow instabilities
- Unresolved individual absorption lines
- Overlapping absorption spectra of different species
- Pulse-to-pulse laser output fluctuations
- Laser frequency drift

- High-power laser, timed detection and very fast scan to freeze fluctuations (minimum number of points/scan, high repetition rate)
- Pre-acquired spectral envelopes used in data processing
- Integrated data processing to determine concentrations of all the components
- Reference channel for normalization
- Reference absorption cell

Minimum number of points in a frequency scan

\[ \alpha(v_k) = \sum_{k=1}^{n+1} c_k f_k(v_k) + b_k \]

Ideal orthogonality: \[ \sum_{k=1}^{n+1} f_k(v_i) f_k(v_j) = \delta_{ij} \] in practice - minimize

Wavelength dialing with sub-threshold current selection

Sub-threshold current pedestals determine wavelength

Schematic of QC laser based gas sensor platform

Step function generator

70 mm

75 mm
**Laser wavelength shift with sub-threshold current**

![Graph showing laser wavelength shift with sub-threshold current](image)

**Potential spectral positions suitable for concentration sampling**

![Graph showing potential spectral positions](image)

**F2812 Specifications**

- Processor Clock Speed: 150 MHz
- PC Interface: Parallel Port
- Timers: 3 (32-bit)
- Digital Inputs: 56
- Flash Memory: 512 Kbytes
- RAM: 72 Kbytes
- External Memory: Up to 1Mbytes
- ADC: 12-bit 16-channel 12.5MHz ADC (7-channel simultaneous sampling)
- Two Serial Communications Interfaces, Standard UART

**Data Acquisition System**

![Diagram of data acquisition system](image)
Summary and further development

• Specific challenges associated with spectroscopic gas analysis of industrial exhaust gases have been identified and addressed.

• Experimental setup for laboratory evaluation and preliminary calibration of a QC-laser based gas sensor was designed.

• A concept of very fast wavelength scanning using precise wavelength tuning of a pulsed QC-DFB laser was demonstrated.

• A DSP based system for fast data acquisition and autonomous gas sensor control is being developed.