Recent Updates in QCL- and ICL-based Applications

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Introduction and Outline

- PSI serves both government and industrial customers in many markets:
  - Aeronautic
  - Automotive
  - Environmental
  - Medical
  - Military
  - Pharmaceutical
  - Security-related

IQ/CL Applications include
- Engine exhaust gas analysis
- Communications
- Exhaled breath analysis
- Mapping of atmospheric species
- Stand-off detection of:
  - chemical warfare agents
  - toxic industrial compounds

1. Multi-QCL multi-species gas analyzer for SO$_2$ and SO$_3$
   - oil-consumption sensing in automobile engine development

2. ICL-based ambient methane sensor
   - evaluation of air quality and carbon sources/sinks in atmosphere

3. ICL-based ethane breath sensor
   - detection of reactive oxidative stress for assessment of exposure to environmental toxins

4. QCL seeded OPO for LIDAR transmitter
   - narrow-linewidth MWIR source for space-based atmospheric monitoring
1) SO$_x$ Spectroscopy in Engine Exhausts

- 700 K, 0.2 atm, 60 ppm SO$_2$, typical combustion products

- Target blended feature: 1332.4 cm$^{-1}$ for SO$_2$, 1396.6 cm$^{-1}$ for SO$_3$

Sensor Layout

- Laser for each species
- Balanced detection
-Insensitive to changes in broadening
**Calibration of SO$_x$ Absorption Sensor**

- First laser spectroscopy measurements of SO$_3$

**SO$_2$**
- 2 x $10^{-4}$ Hz$^{-1/2}$
- or -
- 1 ppm-m/Hz$^{1/2}$ of SO$_2$

**SO$_3$**
- 1 x $10^{-4}$ Hz$^{-1/2}$
- or -
- 2 ppm-m/Hz$^{1/2}$ of SO$_3$
2) **ICL-based Ambient Methane Sensor**

- Cryogenic ICL
  - 5mW at 3.4μm
  - 3mA threshold at 80K

- CH₄ ν₃ transitions: 2937 to 2938 cm⁻¹
- 6.8m optical path
- 2 TE-cooled InAs detectors

- rms precision is 15 ppbv for 60s integration time
  - Calibrated in lab and tested in University of New Hampshire Field Test Site
UNH Field Test Site
~Sallie’s Fen~

- Regional air quality monitoring network
- 10 chambers networked to central base station.
- Hand samples for CH$_4$ by gas chromatography
- Ten year measurement archive
- Operates around the clock
- Automatically samples CO, O$_3$, SO$_2$, CO$_2$, NO, NO$_y$ + Hg, aerosols, and volatile organic compounds

Go to: www.airmap.unh.edu
Methane Measurements at Sallies’ Fen ~7/20/06 12:00 EDT~

- Chambers [1-10] open to ambient for 8 min to flush, then close for 10 min
- Results in build up of CH$_4$ and CO$_2$

Excellent agreement with co-located gas chromatograph (GC)
3) **ICL-based Ethane Sensor using ICOS + WMS**

- **CW ICL laser at 3.3µm**
  - 0.1 mW
  - LN$_2$ cooled
  - ~1.5 cm$^{-1}$ current tuning range at fixed temp

- **ICOS cell**
  - Mirrors have R = 99.98%

- **TE-cooled InAs detector**

- **Single board controller**
  - Battery powered
  - Drives laser
  - Processes WMS signal
  - Continuous output at 10Hz
Ethane Sensor Performance

- Single pass through 50cm cell with 949 ppm ethane
- Tune across ethane absorption line at 2977 cm\(^{-1}\)

Demodulated WMS Output Signals
- 0.1ms integration time
- Ethane shut off at \(t = 180\) s

Normalized absorption feature

Results with ICOS cell
- 800 meter effective path length
- Detection limit 30 ppb in 0.4 s
4) **QCL Seeded Optical Parametric Oscillator (OPO)**

- **850mJ (~2.5ms)**
  - Tm:YALO Laser at 1.940 μm
  - 70mJ (6ns)
  - Ho:YLF Laser at 2.055 μm

- **4700mJ (3ms)**
  - Diode Laser at 0.793 μm

**LEGEND**
- **M3**: HT at 2.1 μm, 50%R at 3 to 5.5 μm
- **TFDP**: Thin-film dielectric polarizer
- **S1**: Rotary stage for ZGP angle tuning
- **S2**: 1-axis translation, 2-axis angle stage

**HWP**: Half-wave plate
- **M1**: HR at 5 μm, 45°
- **M2**: HR 2 to 5.5 μm

**Output**
- expect 7mJ at 4.6 μm
- line-narrowed

- **Injection seeding to achieve narrow linewidth OPO emission**
- **ZnGeP₂ crystal**
- **Ring geometry**
  - No isolator required
- **Type 1 phase matching**
- **~100nm bandwidth**
Grating Spectrometer View of OPO Output

- Pump OPO with 10mJ of 2.055 µm
  No seeding
  Broadband, very low energy

- With >0.5mW seeding from QCL
  1.5 mJ of narrow band 4.6 µm

- First demonstration of QCL seeded ZGP OPO
  – Also working on QCL-seeded CdSe OPO for LWIR
Ongoing Activities

- **THz QCL programs**
  - Differential absorption LIDAR for *stand-off explosives detection*
  - Optical heterodyne for *free-space communications*

- **Atomic oxygen sensor for high temperature flows**
  - 63 \( \mu \)m cryogenic QCL in external cavity
    - See Thursday’s talk by Alessandro Tredicucci

- **Broadly tunable LWIR QCL laser system**
  - 8 \( \mu \)m QCL, cryogenic and room temperature
  - Angled facets and AR coatings
  - Coupled to external diffraction grating
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