Recent Progress in Infrared Semiconductor Laser Based Chemical Sensing Technologies

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Introduction

This poster describes the novel mid-infrared quantum cascade laser (QCL) based trace gas sensor technology using both QEPAS and traditional PAS. Two current sensor applications are reported: 1) a 0.5 μm CW TEC DFB QCL based QEPAS sensor that is used to quantify NH3 in exhaled human breath and 2) a 10.3 μm broadly tunable CW TEC EC-QCL based PAS sensor that monitors NH3 in Houston, TX, an urban environment.

Future Directions of trace gas applications
- Improvements of existing sensing technologies using state-of-the-art QCLs and ICLs
- Further development of spectroscopy technology based on new fabrication techniques
- Ultra-compact, low cost, robust trace gas sensors
- Development of laser based gas sensor networks based on QEPAS and LAS
- New applications enabled by novel tunable EC-QCLs (i.e. sensitive concentration measurements of H2, U, and multiple species detection)

Quartz Enhanced Photoacoustic Spectroscopy

Unique Properties
- Miniature size, ~3 mm³ detection volume
- Dimensions in mm: length = 3.8, gap size = 0.3, thickness = 0.3, width = 0.38
- Preamplifier active material
- Signal current = pA
- Intrinsically high Q factor, ~10,000 at ambient pressure, ~125,000
- Optimum micro-reactor (mR) tubes are 4.4 mm long (1/16/4-H2O) and 0.6 mm in diameter
- Maximal SNR of QEPAS with mR tubes: ~30 (depending on gas composition and pressure)

Important Biomedical Molecules

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Formula</th>
<th>Biological Pathway/Infection</th>
<th>Center Wavenumber [cm⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>CO(NH₂)₂</td>
<td>Inflammatory disease, respiratory infection</td>
<td>8.8</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>CCl₄</td>
<td>Inhibits protein-protein interaction</td>
<td>6.2</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>Respiratory, carbon dioxide poisoning</td>
<td>4.4</td>
</tr>
<tr>
<td>Lacitrol</td>
<td>DMSO</td>
<td>Liver disease, acetone production</td>
<td>4.6</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>Heart and lung disease, tissue destruction</td>
<td>4.6</td>
</tr>
<tr>
<td>Anesthetics</td>
<td>N₂O</td>
<td>Oxygen and nitrous oxide anesthesia</td>
<td>5.2</td>
</tr>
<tr>
<td>Nitric Oxide</td>
<td>NO</td>
<td>Nitric oxide synthesis, inflammation, cardiovascular, respiratory disease</td>
<td>9.3</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>Respiration, carbon monoxide poisoning</td>
<td>3-4 ppm</td>
</tr>
<tr>
<td>Ethanol</td>
<td>C₂H₅OH</td>
<td>Oxidation stress, cancer</td>
<td>18.9</td>
</tr>
<tr>
<td>Acetone</td>
<td>C₃H₆O</td>
<td>Oxidation, diabetes mellitus</td>
<td>7.3</td>
</tr>
</tbody>
</table>

QEPAS based NH₃ Gas Sensor Architecture

Advantages of using CW DFB-EC-QCL in the sensor architecture:
- Small laser package
- DFB-EC-QCL, room temperature operation
- Performing WM spectroscopy at optimum modulation depth
- Baseline reduction with 2f WM

NH₃ Sensor Deployment at Moody Tower, University of Houston

Monitoring of atmospheric NH₃ in the Greater Houston Area

Mid-IR EC-QCL based AM-PAS Sensor for NH₃ Detection

NH₃ Data from Sensor located on 60 m high Moody Tower Roof

NH₃ sensor and electronic monitoring Moody Tower located near LSCC campus, Houston, TX

NH₃ time series: May 1 to July 6, 2010 and August 4 to 22, 2010

NH₃ sensor data from Moody Tower showing significant spikes in NH₃ concentrations in the early morning hours.