Development of a QC-laser based system for industrial gas monitoring

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Abstract: Development of a pulsed quantum cascade laser based spectroscopic gas sensor suitable for the detection of nitric oxide and other molecular species in harsh industrial combustion exhaust systems will be reported.

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Regulations concerning the maximum concentrations of toxic pollutants in industrial exhaust gases have tightened in recent years. Therefore, there is a need for sensitive gas sensors for real-time concentration monitoring of such gases as NO, NO_2, CO and NH_3 at parts per million (ppm) levels to ensure regulatory compliance. This work reports details of a thermo-electrically cooled, distributed feedback quantum cascade (QC-DFB) laser based sensor[1,2] for open path monitoring of NO at elevated temperatures. Specific environmental challenges that are encountered when measuring industrial exhaust gases include:

1. High temperature effects (interference from CO_2 and H_2O – absent at room temperature)
2. Atmospheric pressure – overlapping of NO, NH_3, CO_2 , and H_2O absorption lines
3. Spectrally nonselective absorption effects – e.g. soot (30% transmission for a 2 m path in industrial ducts)
4. Turbulence resulting in absorption fluctuations.

To address these specific challenges encountered with the harsh environmental conditions of the target gases at atmospheric pressures, we have developed a novel QC laser based NO sensor platform. To detect NO, we selected an isolated and intense R(6.5) fundamental vibration-rotation transition at 1900.08 cm^{-1}. This line exhibits the least interference from other species present in hot exhaust gases. However, the absorption by NH_3, CO_2 , and H_2O must be taken into account due to pressure line broadening. In order to capture and resolve the four overlapping lines we ensured a sufficiently large QC-DFB laser wavelength tuning range and minimized the laser linewidth. This allows simultaneous concentration measurement for all four species identified in condition 2. A utilization of fast and sensitive thermoelectrically cooled detectors ensures a sufficient sensitivity to allow for strong nonselective absorption. In order to address issue 4, fast wavelength scanning requiring a minimum number of data points was implemented, which resulted in "freezing" of potentially occurring turbulent fluctuations in industrial exhaust ducts (e.g. typically 2 m in diameter).

The architecture of the sensor using a QC-DFB laser closely resembles the sensor architecture described in Ref. 2. However, to address the need for very fast scanning, the system to be reported here incorporates high-speed data acquisition electronics and digital signal processing (DSP) technology capable of sampling and analyzing data at rates of 1 MHz. Briefly, a QC-DFB laser is placed on a thermoelectric cooler inside a sealed housing. The QC-DFB laser is excited with ~15 ns current pulses at repetition rates up to 1 MHz. A beam splitter located outside the laser housing provides a reference beam. This beam is employed for both the laser wavelength stabilization and for the laser power normalization. The main beam is used to probe the open path absorption. Each wavelength scan consists of less than 10 sequential pulses with individually pre-set subthreshold currents. The resulting output signals from the reference detector and sample detector are digitized, accumulated and processed by the DSP chip to yield a concentration for each target gas.

A 1 m long gas cell was designed for laboratory simulations of the gas mixture absorption at the elevated temperatures characteristic for exhaust ducts conditions encountered in industrial plants. The cell could maintain temperatures up to 350°C and operate at different pressure levels including atmospheric pressure.

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