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Multi-species trace-gas spectroscopy using dual-wavelength QCLs

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Mid-infrared (mid-IR) laser absorption spectroscopy is a highly attractive method for trace gas analysis, offering outstanding selectivity and sensitivity. Most frequently, however, this technology is limited to one or very few compounds because of the narrow spectral coverage of distributed feedback (DFB) lasers. This can be overcome by combining several dual-wavelength continuous wave (cw) Quantum Cascade Lasers (QCLs) at specific frequencies to simultaneously monitor a multitude of species in a single instrument.

We report on the concept, performance, and implementation of dual-wavelength DFB QCLs emitting at several wavelengths in the mid-IR spectrum. Three designs are presented: (i) twin DFB QCL, with two active regions designed for different emission wavelengths in a single waveguide, (ii) neighbor DFB QCLs, where two single-mode DFBs are placed next to each other with minimal lateral distance, resulting in a virtually single light source that allows efficient beam-coupling into multi-pass absorption cells, and (iii) an electrically switchable laser device with digitalized dual-frequency grating, where the Vernier effect is used to switch between two frequencies [1].

In this work, multiple dual-wavelength cw DFB-QCLs are combined into a single compact laser absorption spectrometer to measure up to ten different compounds [2]. The lasers are driven time-multiplexed in intermittent cw mode [3], sharing a single detector. The transmission spectra of each QCL section are recorded and averaged by an FPGA-based data acquisition and pre-processing system with a sampling rate of 125 MS/s and 14-bit resolution [4]. Atmospheric measurements of the greenhouse gases CO_2, N_2O, CH_4, and H_2O, and the pollutants CO, NO, NO_2, O_3, SO_2 and NH_3 in a single optical setup can be achieved. The best precision as determined from Allan-Werle plots is obtained for NH_3 with 0.02 ppb at 100 s integration time. Typical values for the other trace gases are 0.1 ppb, with NO showing somewhat higher values of about 0.3 ppb. These results along with field validation indicate that spectrometers using dual-wavelength QCLs can serve as an all-in-one solution for environmental monitoring stations. They significantly reduce the footprint and cost by replacing several instruments, while delivering direct, selective, and precise measurements of many target molecules.

References:

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