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IR-N-ox: Multicomponent Trace Gas Spectroscopy using a Twin Quantum Cascade Laser

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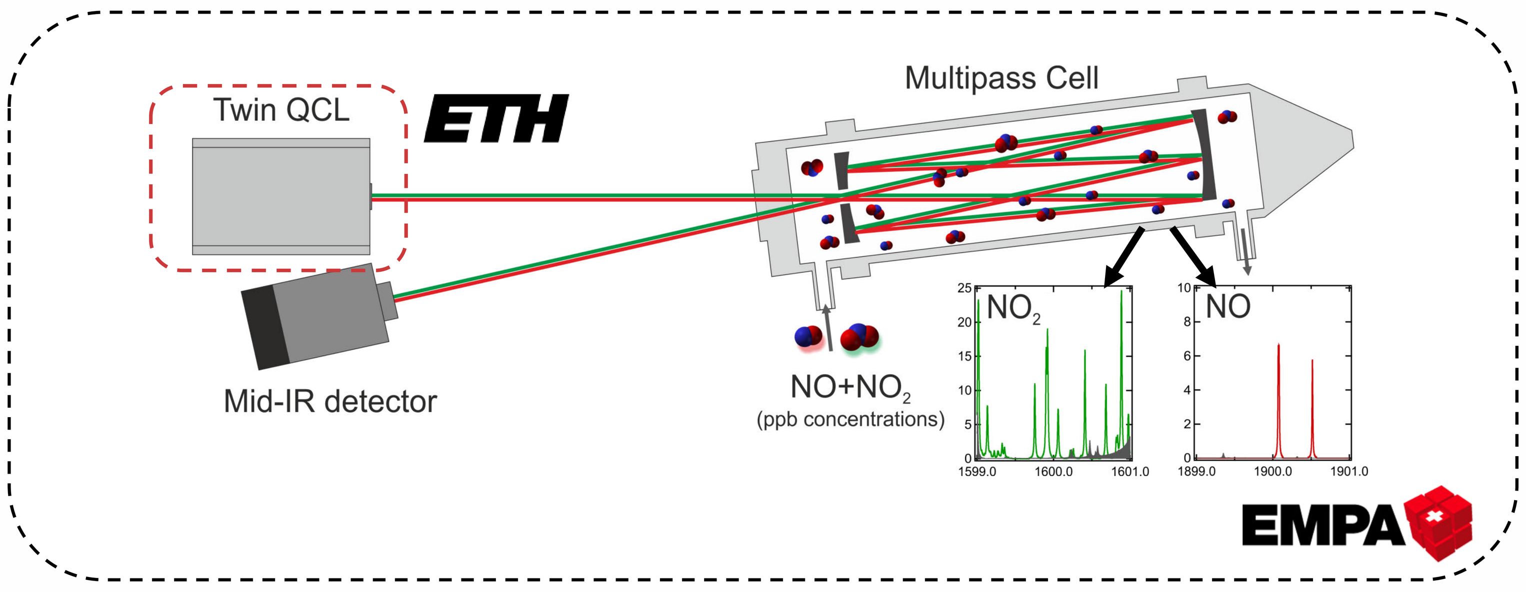
Introduction

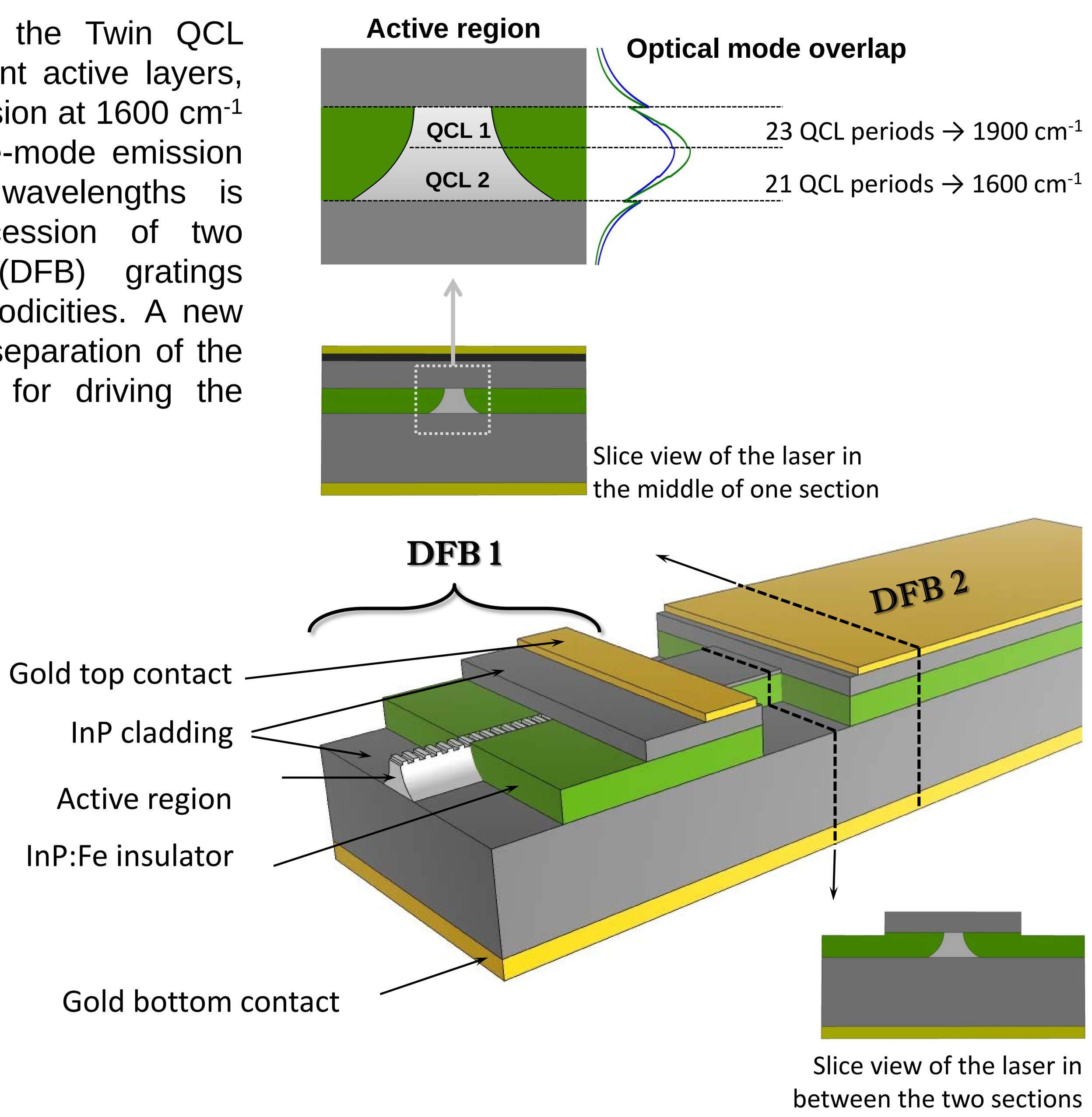
Simultaneous detection and monitoring of gaseous nitrogen oxides NO, N_2O and NO_2 at sub-ppb concentrations is highly desired in numerous environmental and industrial applications. Mid-IR laser spectroscopy is the best suited measurement technique, nevertheless, for the simultaneous detection of all three species simultaneously with one instrument, multi-color Mid-IR laser sources are needed.

This project explores the concept of a dual-wavelength Quantum Cascade Laser (Twin QCL) [1] combined with a prototype spectrometer to investigate the feasibility of multi-color QCLs for laser spectroscopy. The main advantage is to have a single output beam for both wavelengths, thus simplifying the system alignment and reducing complexity.



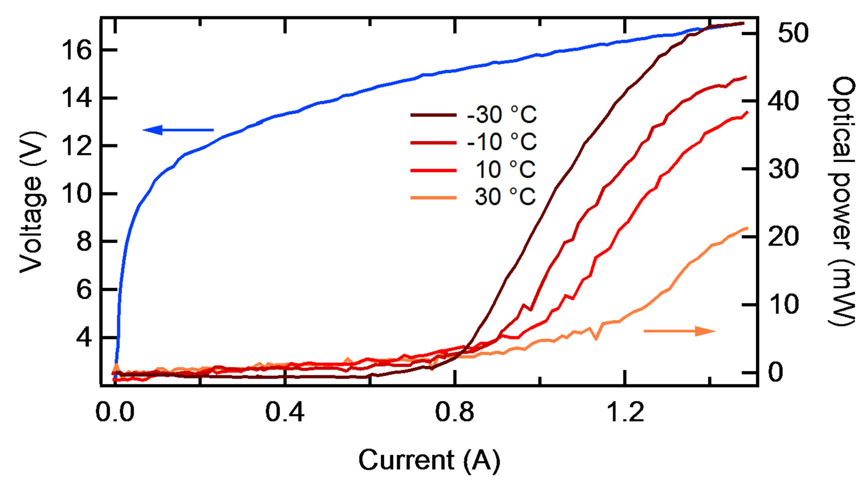
Twin QCL Design

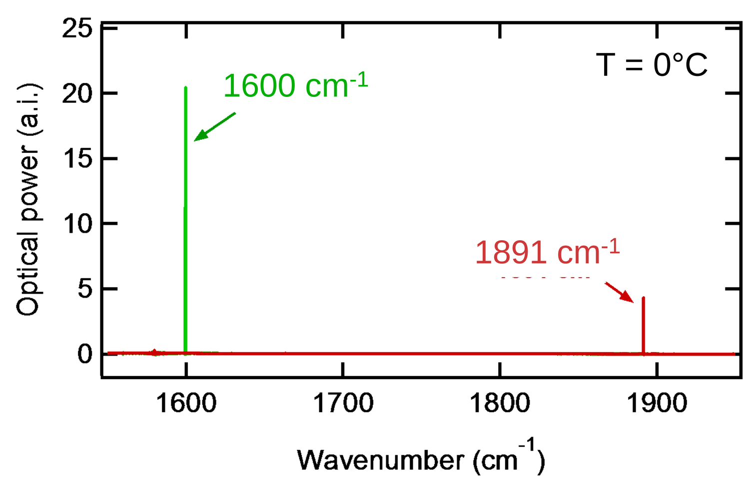
The active region of the Twin QCL consists of two different active layers, optimized for the emission at 1600 cm^{-1} and 1900 cm^{-1}. Single-mode emission at both respective wavelengths is ensured by a succession of two distributed-feedback (DFB) gratings with two different periodicities. A new process for electrical separation of the DFB sections allows for driving the lasers independently.



Emission and Spectral properties

Room temperature operation in the pulsed mode and threshold current of 800 mA are demonstrated for the both sections of the Twin QCL.





By applying the driving current on the front (green) or the back laser section (red), singlemode emission is achieved at 1600 cm^{-1} and 1891 cm^{-1}, respectively. Both emission wavelengths can be tuned over ±5 cm^{-1} by changing the laser temperature.

Driving the Twin QCL

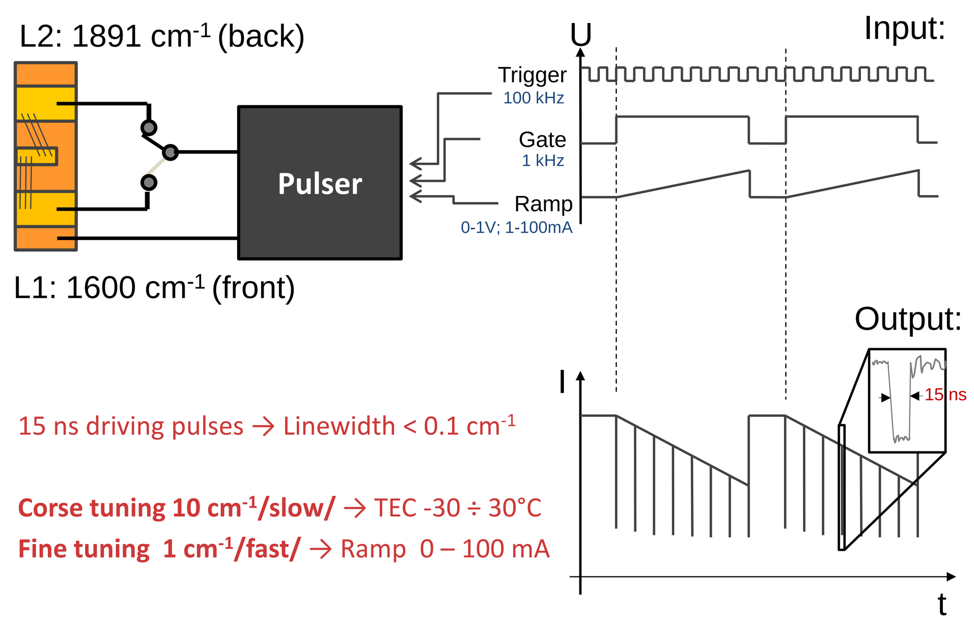
Mid-IR gas spectroscopy requires:

- Narrow laser linewidth.

Linewidth < 0.1 cm^{-1} was achieved by driving the laser with short, 15-ns current pulses.

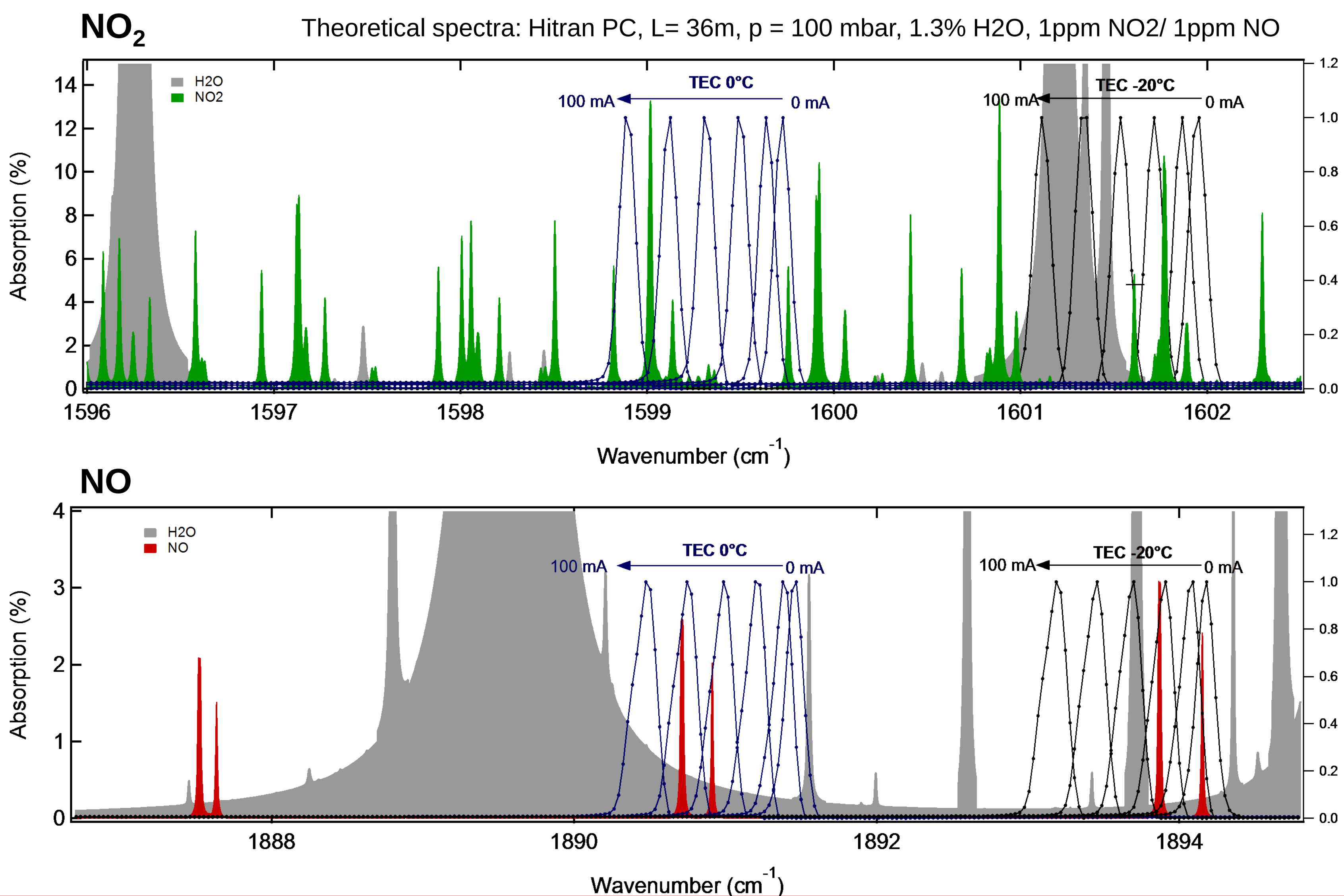
- Fast and linear tuning of the emission wavelength.

Tuning over 1 cm^{-1} at the rate of 2 kHz is reached by modulating the injection current using a linear ramp of 0-100 mA.

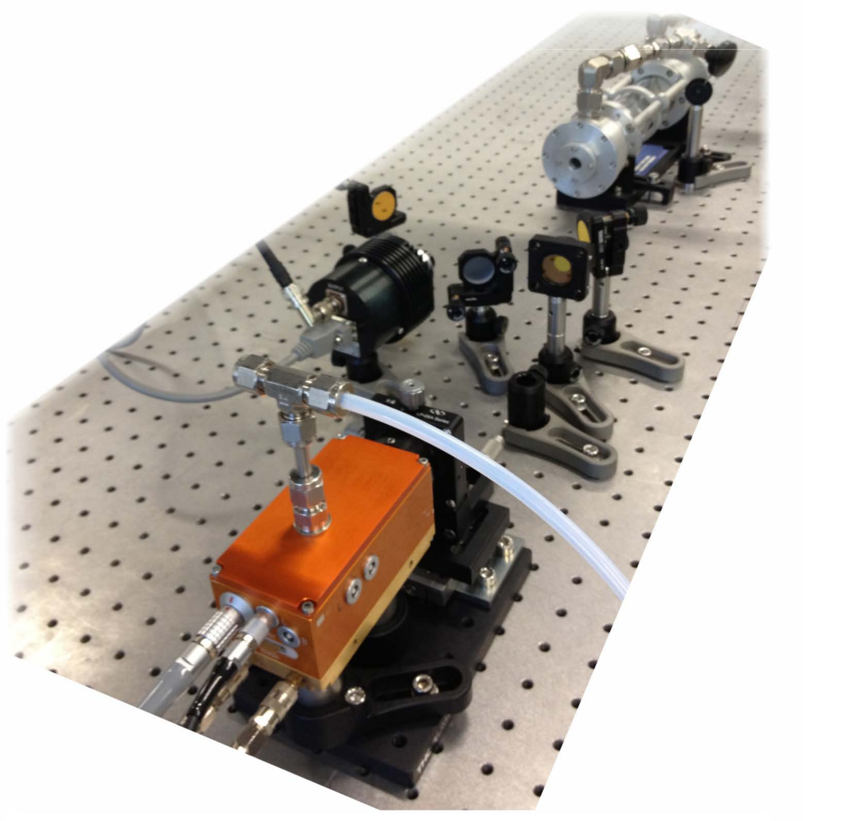


NO and NO_2 spectroscopy

According to simulations based on HITRAN data [2], the targeted species exhibit strong absorption lines around 1600 cm^{-1} (NO_2) and 1890 cm^{-1} (NO) and a good spectral overlap with the Twin QCL emission. By setting the laser temperature to either 0°C or -20°C, spectral signatures of NO and NO_2 are accessed simultaneously.



Experimental setup and outlook



The prototype spectroscopic setup consists of the Twin QCL, a 36 m multipass cell and a thermo-electrically cooled MTC detector.

Custom written LabView-based program controls and synchronizes the laser with a high-speed digitizer/oscilloscope that acquires the data at 200MS/s rate. Separate module of the program will provide for real-time fitting of the absorption spectra with, thus allowing for highly-sensitive NO_x detection down to ppb levels.

References: [1] Gmachl, C., Straub, A., Colombelli, R., Capasso, F., Sivco, D. L., Sergent, A. M., *et al.*, "Single-mode, tunable distributed-feedback and multiple-wavelength quantum cascade lasers," *IEEE J. Quantum Elect.*, vol. 38, pp. 569-581, 2002.
[2] L.S. Rothman, I.E. Gordon, A. Barbe *et al.*, "The HITRAN 2008 molecular spectroscopic database," *J. Quant. Spectrosc. Radiat. Transfer,* vol. 110, pp. 533-572, 2009.