doi:10.2533/chimia.2015.708

Highlights of Analytical Sciences in Switzerland

Division of Analytical Sciences

A Division of the Swiss Chemical Society

Multi-Component Trace Gas Spectroscopy Using Dual-Wavelength Quantum Cascade Lasers

Lukas Emmenegger*[a], Jana Jágerská[b], Rolf Brönnimann[a], Jérôme Faist[c], Pierre Jouy[c], Herbert Looser[d], Patrik Soltic[a], and Béla Tuzson[a]

*Correspondence: Dr. L. Emmenegger, E-mail: Lukas.Emmenegger@empa.ch
[a]Empa, Swiss Federal Laboratories for Materials Testing and Research, CH-8600 Dübendorf; [b]Department of Physics and Technology, UiT The Arctic University of Norway, NO-9037 Tromsø; [c]Institute for Quantum Electronics, ETH, CH-8093 Zürich; [d]Institute for Aerosol and Sensor Technology, FHNW, CH-5210 Windisch

Keywords: Mid-IR spectroscopy · Nitrogen oxides · Quantum cascade lasers · Trace gas analysis

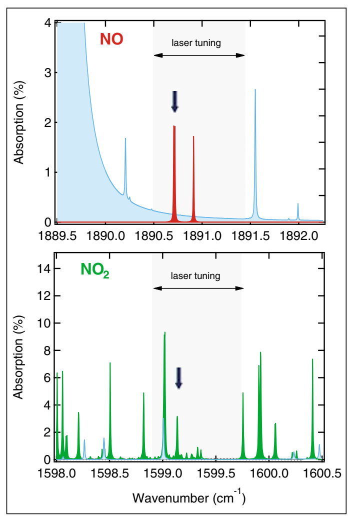
Simultaneous detection of multiple gas species using mid-infrared laser spectroscopy is highly desired for numerous applications ranging from air quality monitoring, medical breath analysis or drug and explosive detection to industrial process control. Since it is often impossible to address the high-resolution spectra of different gases with a single laser, state-of-the-art multi-wavelength spectrometers have to rely on the use of several lasers and elaborate beam combining solutions. This makes them bulky, costly, and highly sensitive to optical alignment.

We explored a new concept for multi-component spectroscopy based on a Dual-Wavelength Quantum Cascade Laser (DW-QCL). Such a laser can emit at two spectrally well-separated wavelengths, which share a common waveguide to produce one output beam. Thereby, it is possible to detect multiple gases without the need for any beam-combining optics.

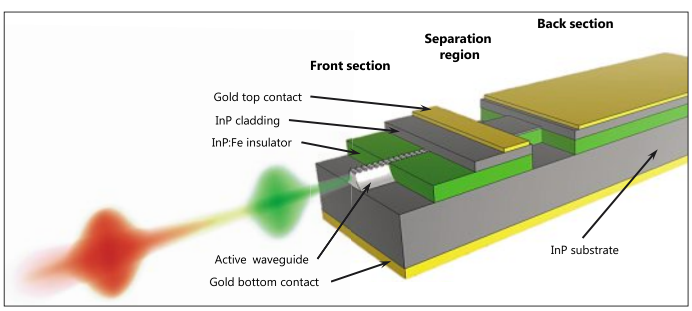
The active region of the DW-QCL consists of two different active layers stacked on top of each other, optimized for a broadband emission at 1600 cm^{-1} and 1900 cm^{-1}. These two spectral windows are ideally suited for the detection of nitrogen oxide (NO) and nitrogen dioxide (NO_2). Single-mode emission at the desired wavelengths is ensured by a succession of two distributed-feedback (DFB) gratings with different periodicities. Electrical separation of the respective laser sections makes it possible to address each wavelength independently and integrate the laser easily in a spectroscopic setup for gas analysis.

The spectrometer reached a precision (1σ) of 0.5 ppb for NO_2 and 1.5 ppb for NO after 100 s of averaging. It was successfully used for ambient air monitoring at a suburban site of the Swiss air pollution network (NABEL), as well as for fast, 10 Hz operation in harsh environment during automotive exhaust emission measurements. The latter is an excellent example for the value of multi-component detection, because the simultaneous measurement of both NO and NO_2 is needed to study and optimize modern diesel engines, which have nowadays complex exhaust gas treatment systems, such as selective catalytic reduction.

Diesel engines are deployed in heavy-duty and passenger cars. Modern engines include both de-NO_x systems and particle filters. This allows maximum efficiency (*i.e.* high NO_x during combustion) and low tailpipe emission.



Simulated transmission spectrum of NO_2 (green), NO (red) and water vapor (blue), and the tuning range of the DW-QCL. The targeted absorption peaks are indicated with a blue arrow.



Schematic drawing of the dual-wavelength laser. The laser is approximately 200 µm wide and 5 mm long. It emits at 5.26 µm (1900 cm^{-1}) and 6.25 µm (1600 cm^{-1}) as indicated by the two-colored beam.

This analytical approach can be applied to the whole mid-infrared region which comprises the strongest, fundamental absorption features of molecules. Current developments aim to combine and optimize the concept to obtain simple and cost-effective spectrometers for the simultaneous measurement of multiple trace gas species.

Acknowledgements

We acknowledge funding by Nanotera.ch, the Swiss National Research Foundation (SNF) and the Federal Office for the Environment (FOEN).

References

J. Jágerská, P. Jouy, A. Hugi, B. Tuzson, H. Looser, M. Mangold, M. Beck, L. Emmenegger, J. Faist, *Appl. Phys. Lett.* **2014**, *105*, 161109.

J. Jágerská, P. Jouy, B. Tuzson, H. Looser, M. Mangold, P. Soltic, A. Hugi, R. Brönnimann, J. Faist, L. Emmenegger, *Optics Express* **2015**, *23*, 1512.

Can you show us your analytical highlight?
Please contact: Dr. Veronika R. Meyer, Unterstrasse 58, CH-9000 St. Gallen
Tel.: +41 71 222 16 81, E-mail: VRMeyer@bluewin.ch