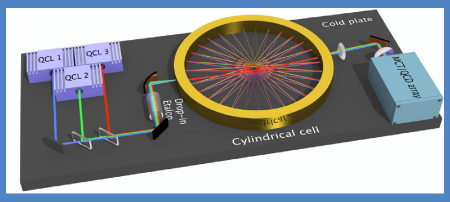
Prof. Jérôme Faist, ETHZ

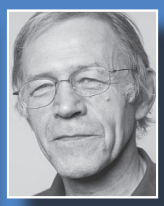
IrSens II

A MULTI-COMPONENT SENSOR FOR AIR POLLUTANTS AND GREENHOUSE GASES



Dr. Rolf Broennimann, EMPA

Dr. Lukas Emmenegger, EMPA



Prof. Herbert Looser, FHNW

Prof. Thomas Südmeyer, UniNE

What it's about…

Developing a laser based gas sensor for the simultaneous detection of up to ten components in environmental monitoring, medicine and industrial applications.

Context and project goals

Progress in sensor technologies and their applications has become a key ingredient for a sustainable development of today's society. Gas sensors, in particular, are essential to address some of the major challenges, such as air quality in urban areas and their effect on human health, as well as monitoring, predicting and reducing environmental impacts due to air pollutants and greenhouse gases. In this respect, mid-infrared (mid-IR) optical absorption techniques offer the possibility to realize highly sensitive detection of gases, which have inherently low molecular densities compared to liquids or solids.

In fact, the mid-IR spectral region contains the fundamental and most intense vibrational frequencies, which may be used to obtain an unambiguous signature of the targeted molecules, even at very low concentrations. The NanoTera project IRSens has explored the development of a technological platform for high sensitivity, portable and low-cost sensors based on new near- and mid-IR technologies such as VCSELs, quantum cascade lasers (QCL) and new optical elements. This project led to the industrialization of a hydrogen fluoride sensor based on near-IR VCSEL, a compact instrument measuring CO_2 isotopes with record precision, as well as the first detection of cocaine in saliva using mid-IR sensing techniques.

We, therefore, intend to leverage on these previous achievements to go several steps further by realizing new exceptional tools for gas monitoring in two strongly connected and complementary activities: the development of a highly specific and sensitive analyzer for nitrogen dioxide (NO_2) and an "all-in-one" spectrometer covering the ten major air pollutants and greenhouse gases. These two breakthrough instruments will exploit the developments of photonic elements with very low footprint and dissipation, made during IRSens, to create a new generation of high-precision and multi-species mid-IR sensors.

The first instrument will detect nitrogen dioxide, which is one of the most prominent air pollutants and a key substance in photochemical processes. The detection will be based on a miniaturized QCL based sensor for NO_2 that will be deployed on field. This sensor will be highly selective, unlike chemiluminescence, the standard method for NO_2 analysis, which is influenced by other nitrogen containing compounds because it is based on the reduction of NO_2 to NO prior to its detection.

The second instrument will detect the ten most relevant air pollutants (NO, NO_2, NH_3, SO_2, O_3, CO) and greenhouse gases (CO_2, H_2O, CH_4, N_2O) in a single instrument that does represents a "Holy Grail" for environemental sensing. It combines very broadband QCLs, having up to three DFBs for "multi-color" operation with novel optical arrangements, fast electronics and new laser driving schemes. This device will revolutionize air sensing and would be an excellent starting point for the future development of a medical breath analyzer.

To reach these ambitious goals, the group of ETH (Faist) will tackle the broadband, multi-color QCL; EMPA (Emmenegger) the optical and spectroscopic aspects of gas sensing; UNINE (Hofstetter) the detectors; EMPA (Brönimann) the electronics for laser driving and signal processing, and the University of Applied Sciences FHNW (Looser) the prototype system, spectral analysis software and the graphical user interface. Benchmarking and field validation will be performed in collaboration with the GAW World Calibration Center of the World Meteorological Organization and the Swiss National Air Pollution Monitoring Network who expressed their keen interest in our results. In addition, this research proposal has also attracted a strong industrial interest from ABB and AlpesLasers.

How it differentiates from similar projects in the field

The main difference between this project and others is the use of multi-color DFB lasers which allow obtaining several wavelength sources coming out from the same laser. This considerably decreases the complexity of the optical setup of the sensor.

The different wavelengths can be electrically controlled independently giving the possibility to sequentially address the different absorption lines. The integrated sensor will be based upon new developments for the optical cell, the quantum cascade detector, the controlling electronics and the signal processing.

Quick summary of the project status and key results

- Development of a new geometry for the multi-color DFB giving a better yield of independent single mode lasers and improving the dynamical range usable for spectroscopy.
- Low phase noise 400 MHz oscillator realized and FPGA based system, with ADC obtained with commercial available building blocks.
- QCL driver for the NO_2 platform developed.
- Definition of the targeted wavelength, resulting in the need for only 7 different wavelength instead of 9 in the original proposal
- New geometry for the optical cell for a longer optical path and better tolerance for misalignment
- New scheme for low dissipation driving of QCLs.

Success stories

Result

Development of a new geometry for the multi-color DFB lasers allowing a better yield for independent single mode emission samples

Award

IrSens prototype wins first runner-up innovation prize at SPIE Photonics Europe 2014.

The prototype analyzer developed within the IrSens project has been presented at the innovation village of SPIE Photonics Europe 2014 in Brussels. Markus Mangold from Empa won the first runner-up prize in the category "best innovation" for the prototype entitled "Portable mid-IR trace gas sensor for mobile applications".

The IrSens prototype is a truly portable MIR spectrometer based on direct absorption laser spectroscopy. Miniaturization-driven development of each building block and careful consideration of the power dissipation led to a high-sensitivity trace gas sensor with a footprint no larger than an A3 sheet of paper. The sensor is packaged to withstand weather conditions and is fully field deployable. The small footprint and ruggedized construction make it highly suitable for a variety of industrial, medical, and environmental applications.

Successful collaboration with industrial partner Alpes Lasers

An important step towards compact QCL based sensors is the miniaturization of each individual component. A close collaboration between Empa and the industrial partner Alpes Lasers SA, led to successful packaging of a QCL including a collimation lens into an HHL housing. The combined know-how of spectroscopy experts and laser developers allowed solving severe issues caused by unwanted back-reflections of light. The developed solution is a good example of how collaboration of research and industry strengthens the innovation in Switzerland.

Start-up company IRsweep develops from IrSens collaboration

In summer 2014, the company IRsweep is founded as a limited liability company (GmbH). The company's aim is to develop spectroscopic sensors for the multi-species analysis of gases and liquids. Key features are speed, spectral bandwidth, operation in the mid-infrared (MIR) wavelength range, compactness, and robustness. Such sensor systems are in high demand for on-line and in-line process analysis, as the MIR range hosts the strongest absorption features of many molecules.

The IRsweep team consists of three co-founders. Two of them are former PhD students of Prof. J. Faist, PI of IrSens. The third co-founder is postdoc at Empa and was for the last three years employed to advance the instrument development within the IrSens project. Though the core-technology of IRsweep – quantum cascade laser frequency combs – is not a result of the NanoTera project, IRsweep in part relies on IrSens technology. Very recently, IRsweep and Empa successfully agreed on terms for licensing the absorption mask patent that resulted from Empa's IrSens activities.

Within the next two years, IRsweep wants to develop its sensing platform and demonstrate its suitability for high-precision multi-species analysis. Based on that, first commercially available sensing solutions of IRsweep are to be expected.

Patents

- M. Mangold, B. Tuzson and L. Emmenegger, "Method for reducing fringes in laser spectroscopy measurements using an absorption mask in combination with multi-pass optical cells". Switzerland Patent 01884/12, 2012.
- J. Jágerská, M. Mangold, B. Tuzson and L. Emmenegger, "Time-multiplexed driving of multicolour lasers for quasi-simultaneous spectroscopic analysis," EP 14166907, 2014.

Main publications

M. Fischer, B. Tuzson, A. Hugi, R. Brönnimann, A. Kunz, S. Blaser, M. Rochat, O. Landry, A. Müller, L. Emmenegger, Intermittent operation of QC-lasers for mid-IR spectroscopy with low heat dissipation: tuning characteristics and driving electronics, Opt. Expr. 22, 7014-2027 (2014).

J. Jágerská, P. Jouy, B. Tuzson, H. Looser, A. Hugi, M. Mangold, P. Soltic, M. Beck, J. Faist, L. Emmenegger, Dual-Wavelength Quantum Cascade Laser for Trace Gas Spectroscopy, Appl. Phys. Lett. 105, 161109 (2014).

P. Jouy, C. Bonzon, J.M. Wolf, M.J. Süess, M.Beck, J. Faist, Surface emitting, single-mode quantum cascade laser array, CLEO 2015, STu4G.2.

P. Jouy, C. Bonzon, J.M. Wolf, E.Gini, M.Beck, J. Faist, Surface emitting multi-wavelength array of single frequency quantum cascade lasers, Appl. Phys. Lett. 106, 071104 (2015).

"All-in-one detection of air pollutants and greenhouse gases"