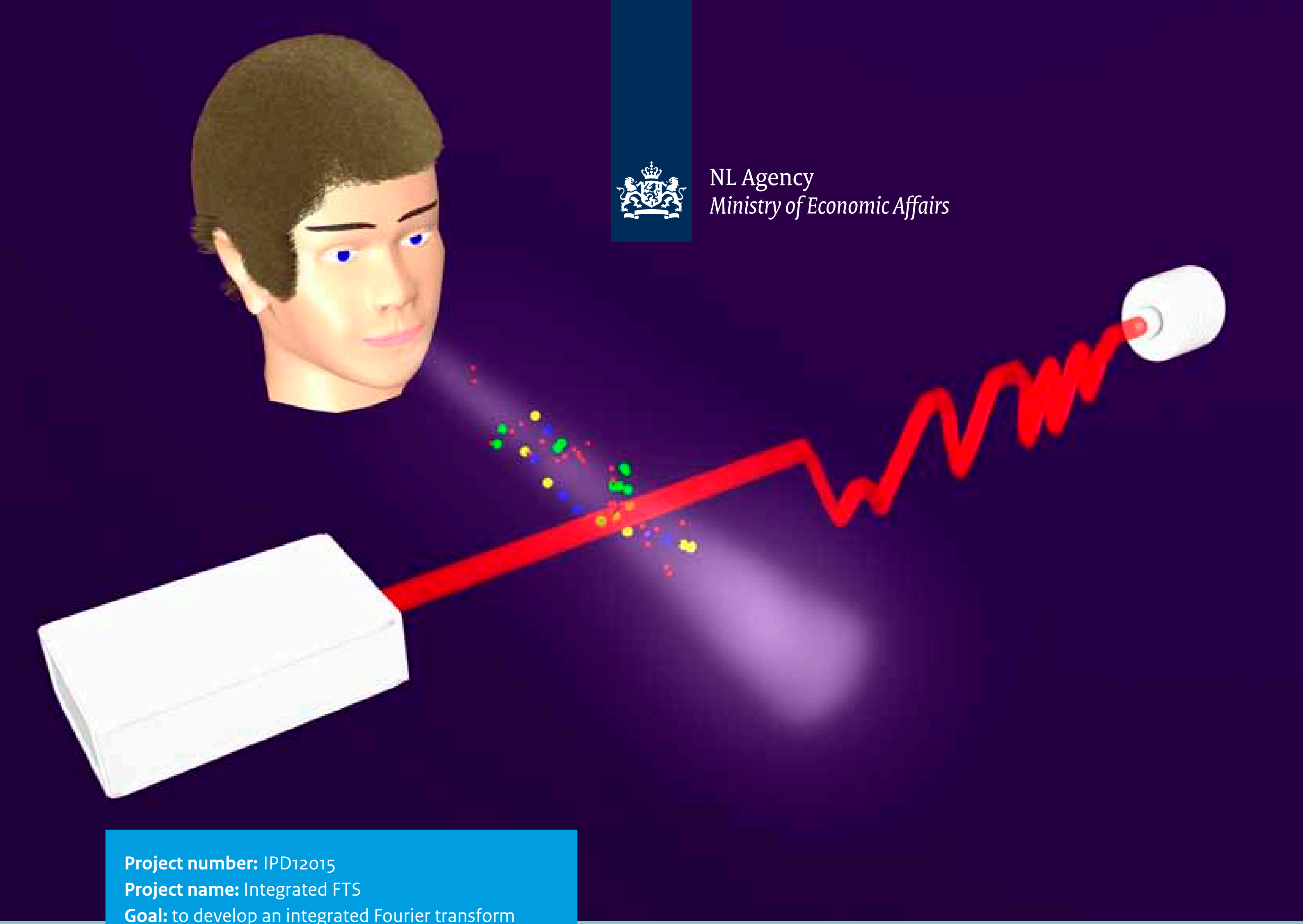
NL Agency
Ministry of Economic Affairs



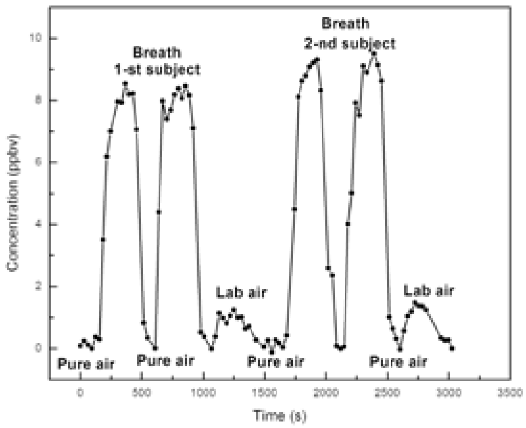
Project number: IPD12015
Project name: Integrated FTS
Goal: to develop an integrated Fourier transform spectrometer (FTS) for chemical sensing based on multiple mode-locked lasers

Breath analysis using trace gas analysis techniques based on absorption spectroscopy

Integrated gas sensor

Patients suffering from the lung disease cystic fibrosis are prone to respiratory infections with Pseudomonas aeruginosa. Such bacterial infections cause progressive damage to the lungs and airways and are the most important cause of mortality. A quick, patient-friendly, reliable and sensitive method is needed to detect infections in an early stage. The IOP project ‘Integrated FTS’ will develop a gas sensor based on absorption spectroscopy that meets these requirements. Other application areas will also benefit from the sensor.

Currently, monitoring infections with Pseudomonas aeruginosa is not feasible, since samples for cultures can only be reliably obtained through bronchoscopy. Most cystic fibrosis patients are young children or adolescents, and their condition makes this procedure unsuitable for routine screening. “Trace gas analysis techniques based on absorption spectroscopy can provide a very good solution to this problem, because you can detect P. aeruginosa bacteria by looking for the presence of hydrogen cyanide in breath,” says Dr Frans Harren of the Institute for Molecules and Materials at Radboud University Nijmegen. “Doctors would only need a sample of exhaled breath from the patient to perform the analysis.”



Examples of HCN concentration levels in human breath

Absorption spectroscopy

Gas sensors based on absorption spectroscopy can detect certain chemical substances in a breath sample by sending light of a wavelength that approximates the absorption peak of a specific type of molecule through the sample. The amount of light that reaches a detector at the other end is indicative of the number of those particular molecules present, in this case hydrogen cyanide (HCN).
The current industrial standard for absorption spectroscopy is Michelson-based Fourier transform spectroscopy (FTS). In FTS, light from a broadband light source is passed through a sample and analysed by a Michelson interferometer. The output of the interferometer is sent to a photodiode, where all the spectral features are recorded at once. The signal is then Fourier transformed to calculate the exact frequencies at which absorption takes place.

Doctors would only need a sample of exhaled breath from the patient to detect P. aeruginosa infections

Nobel Prize winners

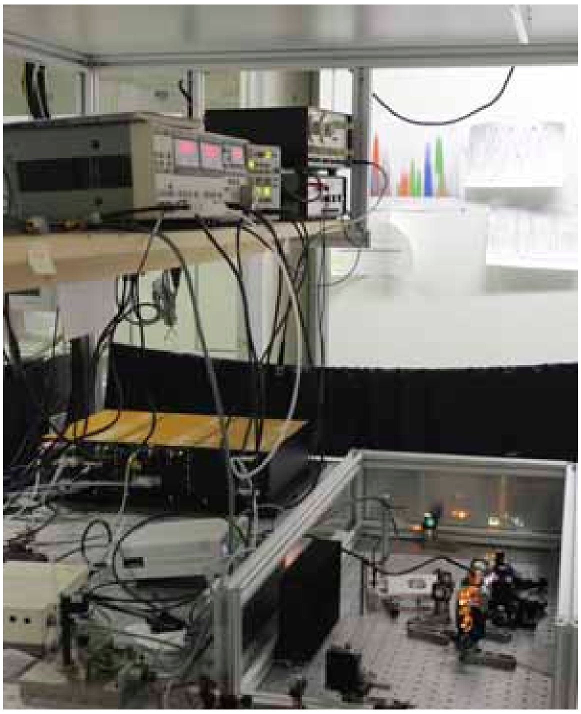
Although FTS has unique advantages and is relatively simple, it lacks sensitivity, comes with a large footprint and is very expensive. “For the real-time detection of molecules at a high resolution and with a high sensitivity – a concentration level in the parts-per-billion range – it is simply not suitable,” says Harren. Promising new strategies for the next generation of spectroscopic instruments have emerged from research on laser-based precision spectroscopy, including the work done on the optical frequency comb technique by Theodor Hänsch and John Hall, winners of the 2005 Nobel Prize in Physics. “Frequency combs will replace both the light source and the Michelson interferometer that are used in traditional Michelson-based FTS. They are a very promising solution because one frequency comb is equivalent to hundreds of thousands of single-mode lasers emitting at perfectly well-known frequencies. This makes it possible to cover a large spectral bandwidth without the complex FTS setup.”

Semiconductor lasers

However, the frequency comb setups currently used in metrology and physics research laboratories have several drawbacks. They are bulky because they use solid-state lasers or fibre lasers, but they are also expensive: a typical setup costs €100,000. They also require experts to maintain and stabilise the lasers. To solve these problems, this IOP project will take advantage of the integrated technology of femtosecond mode-locked semiconductor lasers. Harren: “Such lasers are very small and the optical chips that contain them can be mass produced. This will make it possible to develop a compact gas sensor that is potentially much cheaper, at approximately €10,000 to 15,000 per sensor.”
By using two mode-locked lasers in the same integrated design, multiple gaseous molecular compounds can be analysed in real time. This will widen the applicability of gas sensing to include other gases such as H_2O, CO_2 and its isotopes, and ammonia (NH_3).

Expertise

The project consortium brings together expertise in laser engineering, high-resolution spectroscopy, digital signal processing and trace gas sensing and its applications. “The consortium partners have been carefully chosen to cover all these areas,” explains Harren. The Photonic Integration



The current frequency comb setup at the Life Science Trace Gas Facility at Radboud University Nijmegen

Life Science Trace Gas Facility at Radboud University Nijmegen

group of the Eindhoven University of Technology (TU/e) will conduct the research on the proposed mode-locked lasers and the necessary electronics. SMART Photonics, a spin-out company of Philips and TU/e, will design and produce the optical chips containing the lasers. The packaging of that chip and the electronics will be done by EFFECT Photonics, another spin-off of the TU/e. Sensor Sense, a Nijmegen-based developer and manufacturer of trace gas detectors based on optical techniques and itself a spin-off company of Radboud University Nijmegen, will provide a proof-of-principle system and develop a valorisation plan. Last but not least, Radboud University Nijmegen will provide the requirements for the integrated system and be responsible for the first demonstrations of the gas sensor in three healthcare trace gas sensing applications.

Kidney diseases

In one demonstration, a compact test setup specifically for HCN monitoring will be used at the Radboud University Nijmegen Medical Centre to detect infections with P. aeruginosa bacteria. “The possibility of rapidly analysing complex gas mixtures is also relevant for monitoring patients with kidney and/or liver diseases, as we will show in the second demonstration,” says Harren. “Using breath tests to detect NH3 – an indicator for such diseases – could reduce dialysis time. The third medical demonstration involves the detection of Helicobacter pylori infections in the stomach by looking for the presence of isotopes of CO_2.” The latter two proofs of concepts will be conducted in collaboration with the UMC Utrecht.

Agrotechnology is another interesting application area for real-time gas sensing. “Take the real-time monitoring of food-storage conditions and especially the amount of CO_2 in the air, for instance. By maintaining optimal conditions for fruit and vegetables, you can protect the crops against moisture loss, decay and ageing.”

Participants:

- Radboud University Nijmegen
- EFFECT Photonics
- Eindhoven University of Technology
- Sensor Sense
- SMART Photonics

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