

Multi-Wavelength QCL Based MIR Spectroscopy for Fluids and Gases

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Abstract: We demonstrate multi-color DFB QCLs with separated electrical pumping for independent single-mode emission of several wavelengths from the same ridge. This will be implemented in our mid-infrared spectroscopy sensors for gases (CO_2) and liquids (cocaine).

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The progresses in the past decades to improve performances of quantum cascade lasers (QCLs) [1] and detectors (QCDs) [2] technologies allowed since few years to reach the maturity necessary for the development of promising applications. To this end, the mid-infrared domain is of particular interest as most of the molecules present strong fundamental rotational and vibrational absorption lines in this range. Therefore the IrSens project aims to develop a miniaturized platform based on those technologies to perform spectroscopy both for gas and liquid phases at these wavelengths, allowing a large panel of applications (pollutant detection, medical analysis, drugs detection, ...). The detection of CO_2 isotopes in air [3] and of cocaine in saliva [4] were chosen to realize the demonstrators. The sources are CW distributed feedback (DFB) QCLs with low energy dissipation (Peltier cooling) and the detectors are either QCDs developed for this project or commercial detectors.

For CO_2 (wavelength around 2310 cm^{-1}), multiple reflections in a cylindrical mirror with a diameter of 80mm allows to reach optical path length up to 4 m in a remarkably small volume [5]. Such length is achieved with use of a toroidal mirror which re-focuses the beam in the center of the cell after each reflection and the development of an optic filter to reduce the optical aberrations and avoid interference fringes (Fig. 1a). In such a configuration and associated with a specially developed QCD, limits of detection for $^{16}\text{O}^{12}\text{C}^{18}\text{O}$ of 0.4‰ (resp. <0.1‰) in a 1s (resp. 300s) averaging time have been reached (see fig 1b).

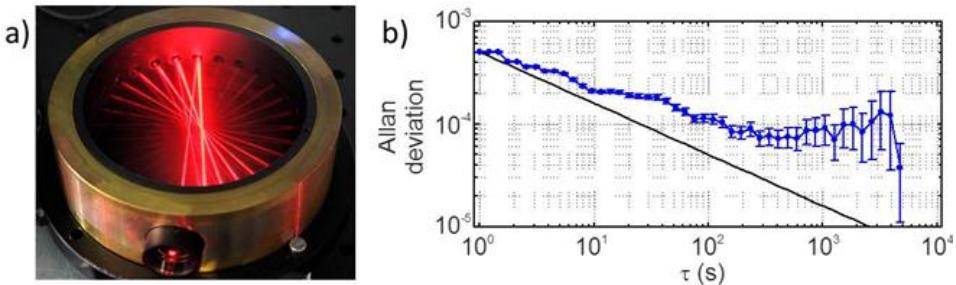


Fig. 1 a) Picture of the cylindrical mirror with the optical filter. A red laser shows the optical path used for the detection. b) Allan deviation plot of the absorption signal amplitude of the $^{16}\text{O}^{12}\text{C}^{18}\text{O}$ isotope.

For cocaine (wavelength around 1720 cm^{-1}), the laser light is injected in a Ge/Si passive waveguide and interacts through its evanescent field with the liquid flowing on top. The absorption due to the presence of cocaine molecules results in a drop of the intensity detected at the end of the waveguide. A microfluidic system is used to extract the cocaine from saliva to a solvent (PCE) transparent in the mid-infrared range. The extraction is done with diffusion process assisted by droplets generation all in the same microfluidic system. It is made of inexpensive UV glue, has a footprint of few cm^2 and is soldered on top of the wafer with the waveguide (see fig. 2a). Measurements have been successfully realized with this “on chip” configuration for a cocaine concentration in saliva of $500\mu\text{g/mL}$ as shown in fig. 2b.

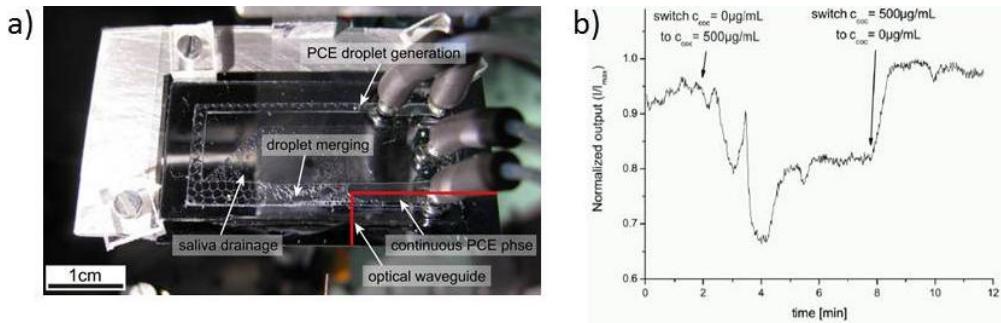


Fig. 2 a Picture of the microfluidic system soldered on the wafer with the waveguide (underlined in red) b Optical detection of cocaine extracted from saliva to PCE on chip during the measurement. The concentration of cocaine in saliva was switched between zero and 500 µg/ml.

To push further those QCL based spectroscopy systems, we are developing multi-wavelength single mode DFBs which are electrically independent. The principle is to have two or more DFB gratings with different periodicities one after the other on the same laser ridge [6] and to etch the conducting part of the top cladding between the different gratings (see fig. 3a). This gives the possibility to electrically switch between two or more wavelengths from the same optical output by pumping the desired section. It is then possible to either do spectroscopy for several molecules within the same optical path or to improve the detection stability for one molecule by using one wavelength at resonance with an absorption line and another out of resonance as a reference. Fig. 3b presents preliminary spectra at two wavelengths obtained from the same laser ridge by only changing the electrical injection conditions. Both are obtained at 293K in pulsed operation and show good single mode behavior (more than 20dB mode discrimination). The inset shows the single mode tuning of 7 cm⁻¹ for the DFB mode around 1890 cm⁻¹ for temperatures between 253K and 303K.

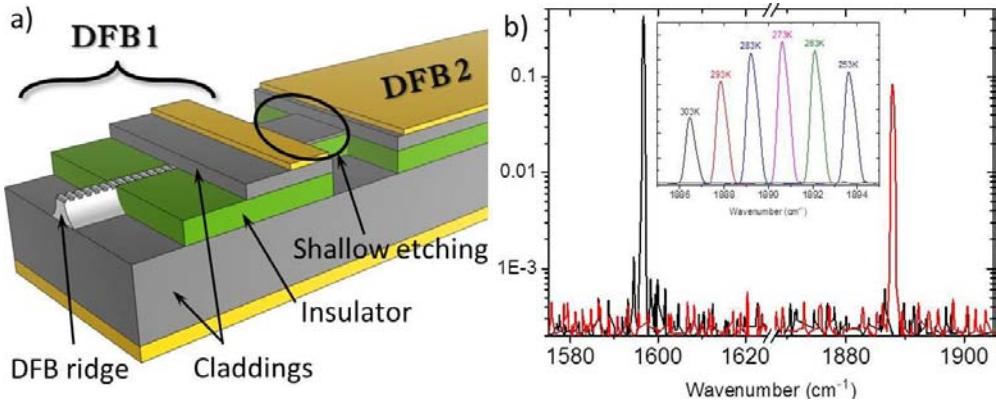


Fig. 3 a Schematic view of a two-color DFB QCL. b Spectra from a two-color DFB with either the front (black curve) or the back (red curve) section electrically pumped in pulsed mode at 293K. Inset: temperature tuning of the DFB mode at 1890 cm⁻¹ for temperatures between 253K and 303K.

By combining waveguides, microfluidic, gas cell, QCLs, QCDs and data treatment software, the consortium from the IrSens project (funded by the swiss framework Nano-Tera) have realized two demonstrators for mid-infrared spectroscopy of both gases and liquids. Detection of CO₂ isotopes and cocaine concentrations in saliva have been measured in compact systems. Among other improvements, we developed multi-color DFB QCLs with independent electrical pumping which allows switching easily between several wavelengths for the same optical output.

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