Proposal of a PhD thesis

2020-2023

Title of the project: Coherent dual-combs for gas sensing

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Laboratory: Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB), UMR 6303 CNRS/ UBFC

Collaborations: SLCO and OSNC research groups within the Photonic department

Summary: Dual-comb spectroscopy (DCS) is well recognized as an innovative analytical technique for rapidly identifying molecular species with high resolution, high signal-to-noise ratio, wide spectral coverage, and fast acquisition rate. It has been successfully applied to precision metrology, remote monitoring of greenhouse gases and coherent Raman scattering. This powerful spectroscopic tool can be implemented under different schemes but most require complex phase-locking systems, which greatly limit outside laboratory applications. Various methods have been proposed to reduce the complexity of dual-comb spectrometers, the common idea is to generate the two combs from the same laser source so as to ensure intrinsic mutual coherence between them without active stabilization.

We thus find coherent dual-comb sources without optical cavity based on the electro-optic modulation of a single continuous wave laser or single-cavity mode-locked fiber lasers where the two combs are generated in opposite directions or with orthogonal polarizations. In the case of free-running single-cavity lasers, different mode-locking mechanisms have been widely exploited, such as the nonlinear polarization rotation, the semiconductor saturable absorber mirrors (SESAMs), the carbon nanotube saturable absorbers, or also the nonlinear loop mirrors (NOLMs). Another original mode-locking mechanism based on nonlinear multimodal interferences (NLMMIs) has recently been proposed.

Most coherent dual-comb sources have been operated in the erbium or thulium near-infrared (NIR) bands of 1.55 μm and 2 μm, respectively. However, an operation at higher wavelengths in the mid-infrared (MIR) domain is possible via wavelength conversion based on four-wave mixing (FWM) processes in nonlinear Kerr media (such as optical fibers and semiconductor coupled waveguides) or by difference frequency generation (DFG) in quadratic PPLN-like crystals. We have already achieved significant results in this multifaceted field, particularly on electro-optic DCS. Our objective is to continue research in this field in particular by targeting applications, such as the measurement of the isotopic ratio 13C/12C for the analysis of exhaled air and the measurements of CO2 concentration for the environmental and agronomic sectors. Another objective is to contribute to new innovations in this promising field by exploiting our expertise on NOLM-based systems and nonlinear effects in multimode fibers.

In summary the aim of the doctoral thesis is to develop coherent dual-comb sources for gas sensing, based on electro-optic modulators and on fiber cavities exploiting two types of mode-locking with either NOLM or multimode fibers (NLMMI). This rapidly developing multidisciplinary project is technically and scientifically challenging.

<u>Main publications of the supervisors related to the topic:</u>

1. A. Labruyere, P. Tchofo-Dinda, Opt. Comm. 266, 676 (2006): Analytical design of nonlinear optical loop mirrors for fiber-optic communication systems.
2. G. Millot *et al*, Nat. Photon. 10, 27 (2016): Frequency-agile dual-comb spectroscopy.
3. K. Krupa *et al*, Nat. Photon. 11, 237 (2017): Spatial beam self-cleaning in multimode fibres.
4. R. Dupiol *et al*, Opt. Lett. 42, 1293 (2017): Far-detuned cascaded intermodal four-wave mixing in a multimode fiber.
5. K. Krupa *et al*, Phys. Rev. Lett. 118, 243901 (2017): Real-Time Observation of Internal Motion within Ultrafast Dissipative Optical Soliton Molecules.
6. A. Parriaux, K. Hammani, G. Millot, Comm. Phys. 1, 17 (2018): Two-micron all-fibered dual-comb spectrometer based on electro-optic modulators and wavelength conversion.
7. J. Igbonacho *et al*, Phys. Rev. A 99, 063824 (2019): Dynamics of distorted and undistorted soliton molecules in a mode-locked fiber laser.

Type of project (theory / experiment): Theory and experiment

Required skills: Optical fibers, Matlab, scientific writing