Laser dynamics

This research activity aims at understanding different aspects of laser dynamics, with a special focus on two-frequency lasers. We are interested in reducing the phase and intensity noise of solid-state or semiconductor lasers, in order to develop low-noise laser oscillators. We also study the spatial properties of laser fields, and the vectorial properties of the intracavity modes. All these activities have both a fundamental interest, and the potential for practical applications. For instance, our studies on synchronization and on laser noise are important for the implementation of ultrastable oscillators. Low intensity noise sources are mandatory in the future microwave-photonics systems, but also in cold atoms experiments and in coherent optics. The themes developed in this research domain have several connections other studies of the team in **Microwave photonics** and **TeraHertz and metrology**.

Low-noise laser sources

Synchronization in vectorial lasers

The beating between the two modes of a two-frequency laser can be used to generate a radiofrequency signal. For some applications, stabilization of this signal on a reference oscillator is required. To this end, we have shown that optical frequency-shifted reinjection is quite efficient, both in the pulsed and in the cw regime, paving the way for lidar-radar applications. Frequency-shifted optical reinjection has also allowed us to study an unusual synchronization regime, in which the average frequency of two coupled oscillators is the same, but their relative phase is not constant [The11]. This so-called “bounded phase” regime is quite generic and appears close to a Hopf bifurcation of the non linear dynamic system. We have observed that the transition from phase-locking to bounded phase does not have a noticeable effect on the low frequency part of the phase noise spectrum and that synchronization of the beatnote can be preserved even if the laser emission becomes chaotic [Tho16], or in the presence of excitable spikes [Rom16]. The dependency of the bifurcations on the sign of the frequency detuning suggests that the Nd:YAG laser medium used has a non-zero Henry factor (”α” factor), which we precisely measured using an original method [Tho17].

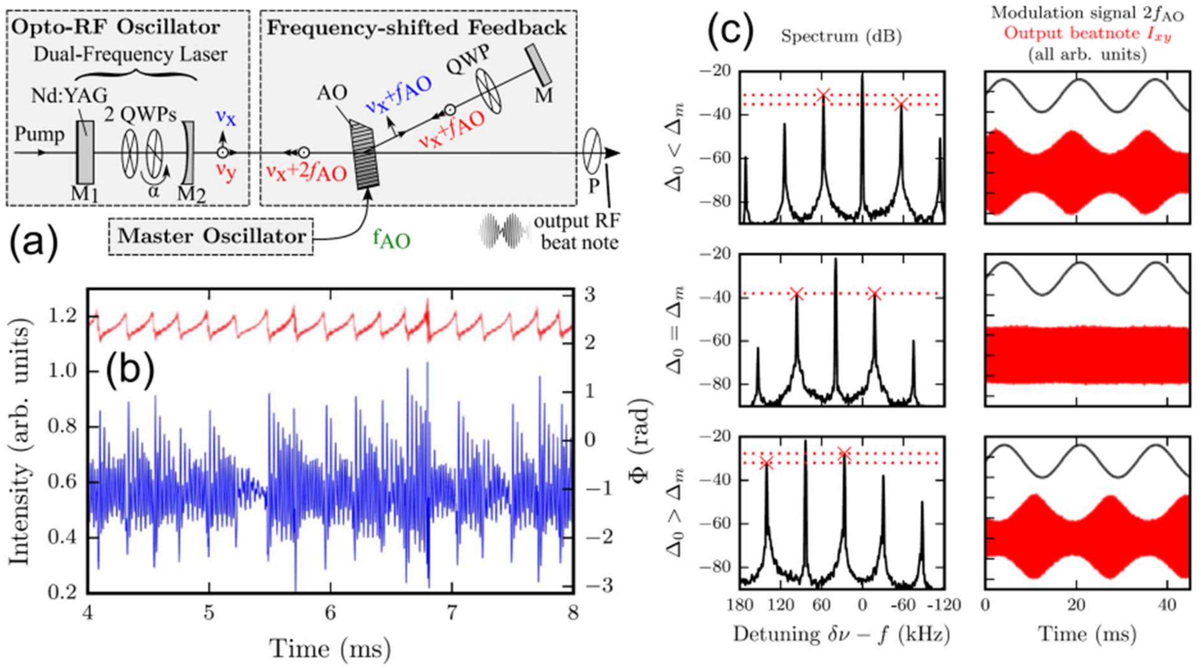

Fig. 4: a) Experimental setup allowing synchronization by frequency-shifted optical reinjection. b) Amplitude and phase of the beat-note signal in the chaotic synchronized regime [Tho16]. c) RF Spectra and time series of the beat-note signal in the case of frequency-modulated feedback, allowing the measure of "α" factor [Tho17].

Another issue related to synchronization in lasers is the realization of vectorial mode-locked lasers for the generation of short pulses. Indeed, in common ultra-fast lasers, polarization is fixed by strong intracavity anisotropies (Brewster windows, gain medium anisotropies, etc.). We have shown that, if such anisotropies are lifted, a mode-locked laser can emit simultaneously two frequency combs along two orthogonal polarizations. A saturable transmission mirror (SESAM) enforces synchronization of the two combs. The laser then emits a pulse train whose polarization switches from one pulse to the other, as shown in the figure below. The first experiments have been performed using a Nd:YAG laser delivering picosecond pulses. A peculiar behavior was observed when the frequency detuning between the two combs is close to c/4L = $f_{rep}/2$: all the emitted frequencies locks their phases, so that the overall stability of the combs is increased [The12].

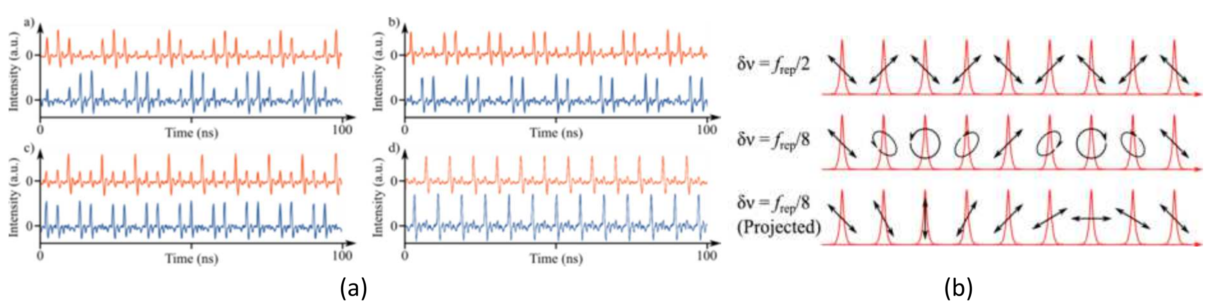

Fig. 5: (a) Experimentally observed pulse trains for several detunings between the two combs: (a) $f_{rep}/5$, (b) $f_{rep}/4$, (c) $f_{rep}/3$, and (d) frep/2 (f_{rep} = 271 MHz). The intensity is detected after a polarizing beam-splitter. The traces correspond to +45° (red) and –45° (blue) polarization directions (with respect to the laser cavity eigenpolarizations) ; (b) Illustration of the pulse-to-pulse switching of polarization state at the laser output.

Selected publications:

[The11] J. Thévenin, M. Romanelli, M. Vallet, M. Brunel, and T. Erneux, "Resonance Assisted Synchronization of Coupled Oscillators: Frequency Locking without Phase Locking," Phys. Rev. Lett. 107, 104101 (2011).

[Rom14] M. Romanelli, L. Wang, M. Brunel, and M. Vallet, "Measuring the universal synchronization properties of driven oscillators across a Hopf instability," Optics express, 22, 7364-7373 (2014).

[Tho16] A. Thorette, M. Romanelli, M. Brunel, and M. Vallet, "Frequency-locked chaotic opto-RF oscillator," Optics Letters, 41, 2839 (2016).

[Rom16] M. Romanelli, A. Thorette, M. Brunel, T. Erneux, and M. Vallet, "Excitable-like chaotic pulses in the bounded-phase regime of an opto-rf oscillator," Phys. Rev. A, 94, 043820 (2016).

[Tho17] A. Thorette, M. Romanelli, and M. Vallet, "Linewidth enhancement factor measurement based on FM-modulated optical injection: application to rare-earth doped active medium," Optics Letters, *in press*.

[The12] J. Thévenin, M. Vallet, and M. Brunel, "Dual-polarization mode-locked Nd:YAG laser," Opt. Lett. 37, 2859 (2012).

Transverse effects

Laser control by electronic spin injection

PhD theses (*past* / ongoing) **:**

Jérémy Thévenin, « Accrochages de fréquences dans les lasers vectoriels à état solide : étude du verrouillage de modes passif et de la réinjection décalée en fréquence », 2012.

Nicolas Barré, « Étude de la sélection des structures transverses stationnaires dans les lasers », 2014.

Kevin Audo, *« Lasers solides bifréquences auto-régulés en bruit d'intensité »*

Aurélien Thorette, *«Structures de polarisation dans les lasers et réinjection : application à la génération de faisceaux opto-hyper »*

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