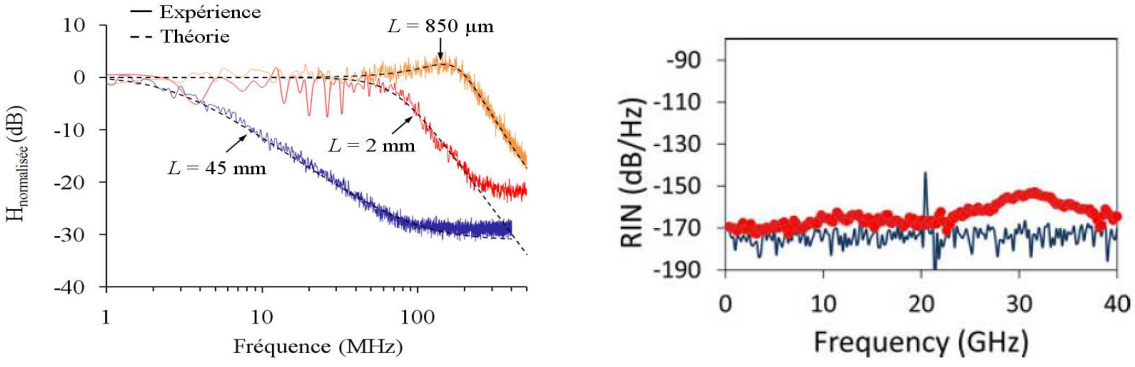
Laser dynamics

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

The main objective of this activity is to design either solid-state (Nd:YAG, Er:Yb) or semiconductor (VCSEL) laser oscillators having an intrinsically low intensity and/or low phase noise level. These self-regulated sources are useful for optical transmission of analog signals for novel radar architectures, or metrology. Recent work includes:

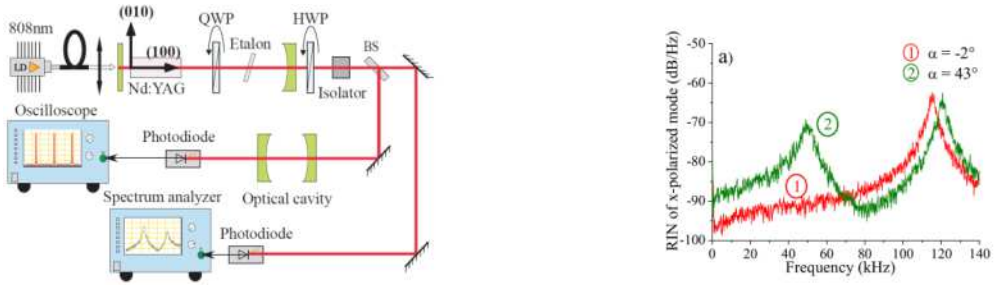
- **Realization of class-A semiconductor lasers:** It is possible to obtain class-A dynamics in Vertical External Cavity Surface Emitting Lasers (VECSELs). In this case these semiconductor lasers are free from excess intensity noise at the relaxation oscillation frequency [Bai09a]. At the same time, stable and tunable dual-frequency oscillation can be obtained [Bai09b], on a low noise optical carrier. The unusual dynamical behavior of these lasers has led to the observation of slow light effects [ElA10], or phase-locking of the amplified spontaneous emission modes on the lasing mode [ElA11]. Recently, a laser exhibiting a flat relative intensity noise spectrum of -170 dB/Hz has been realized [Bai13].These studies are conducted in collaboration with Thales-TRT, the Laboratoire Aimé Cotton (LAC) and the Laboratoire Photonique et Nanostructures (LPN).



(a) (b)

Fig. 1: (a) Observation of the transition from class-B dynamics to class-A dynamics in a semiconductor laser (VECSEL type) ; (b) Example of a class-A VECSEL exhibiting a relative intensity noise below −170 dB/Hz over a wide frequency bandwidth (300 MHz-40 GHz), except at the laser free spectral range (20.4 GHz) (blue curve).

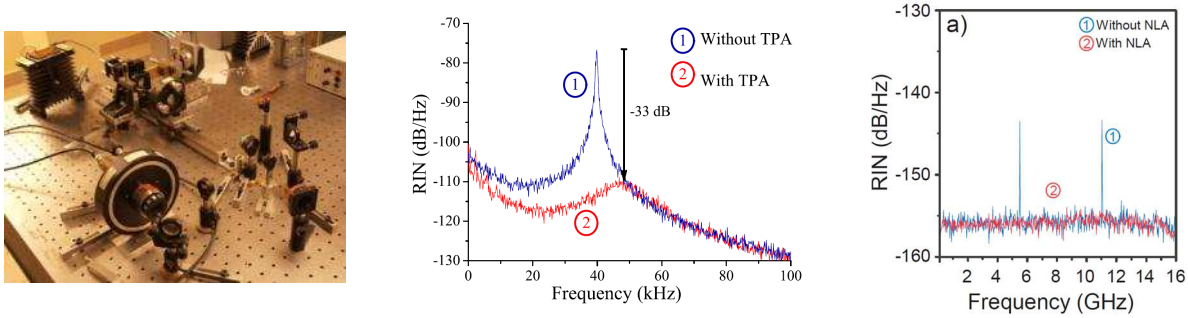
- **Two-frequency Nd:YAG laser free from antiphase noise:** In two-frequency lasers, anticorrelated energy exchange between the two oscillating polarization modes results in the so-called antiphase noise peak at a specific frequency. We have recently shown that this mode partition noise can be suppressed by orienting conveniently the cristallographic axes of the gain medium, in order to decouple the populations feeding each polarization mode [ElA12]. These works are conducted in collaboration with LAC.



(a) (b)

F ig. 2 : a) Schematic of the laser cavity and measurement setup ; b) Observation of antiphase noise suppression (red curve) when the polarization modes of the dual-frequency laser are oriented along the crystallographic axes of the (100)-cut Nd:YAG active medium.

- **Intensity-noise self-regulated solid-state laser:** These studies aim at modifying the intrinsic dynamics of solid-state lasers, in order to reduce their noise. This is obtained by exploiting some nonlinear absorption mechanisms (two-photon absorption, ineffective frequency doubling) inside the laser cavity [ElA13]. We have shown that the intensity noise of a solid-state laser can be self-regulated on an extremely broad frequency spectrum. In particular, we have demonstrated the complete suppression of the excess noise peaks due to the relaxation oscillations, and to the beating between the lasing and the neighboring non-lasing cavity modes [ElA14]. These features had never been obtained in any laser.



(a) (b) (c)

Fig. 3: (a) Photograph of the experimental setup. (b-c) Experimental observation of resonant intensity noise suppression at the relaxation oscillations frequency (b) and at very high frequencies (c) due to the insertion of an intra-cavity two photons absorber (TPA).

Selected publications:

[Bai09a] Baïli G., Alouini M., Malherbe T., Dolfi D., Sagnes I., Bretenaker F., "Direct observation of the class-B to class-A transition in the dynamical behavior of a semiconductor laser," Europhysics Letters 87, 44005 (2009).

[Bai09b] Baïli G., Morvan L., Alouini M., Dolfi D., Bretenaker F., Sagnes I., Garnache A., "Experimental demonstration of a tunable dual-frequency semiconductor laser free of relaxation oscillations", Optics Letters 34, 3421 (2009).

[ElA10] A. El Amili, B.-X. Miranda, F. Goldfarb, G. Baili, G. Beaudoin, I. Sagnes, F. Bretenaker and M. Alouini, "Observation of slow light in the noise spectrum of a vertical external cavity surface-emitting laser," Phys. Rev. Lett. 105, 223902 (2010).

[ElA11] A. El Amili, V. Pal, F. Goldfarb, R. Ghosh, M. Alouini, I. Sagnes, and F. Bretenaker, "Observation of noise phase locking in a single-frequency VECSEL," Opt. Express 19, 17250 (2011).

[Bai13] G. Baili, L. Morvan, G. Pillet, D. Dolfi, S. Bouchoule, Z. Zhao, J-L. Oudar, M. Alouini, L. Ménager, S. Formont, F. Bretenaker, "High power and ultra-low noise VECSEL for high dynamic range and wideband microwave optical links," International Topical Meeting on Microwave Photonics (MWP), Alexandria, Virginia USA (2013).

[ElA12] A. El Amili, G. Loas, S. De, S. Schwartz, G. Feugnet, J. P. Pocholle, F. Bretenaker, and M. Alouini, "Experimental demonstration of a dual-frequency laser free from antiphase noise, " Optics Letters 37, 4901 (2012)

[ElA13] A. El Amili, G. Kervalla and M. Alouini, "Experimental evidence and theoretical modeling of two-photon absorption dynamics in the reduction of intensity noise of solid-state Er:Yb lasers, " Optics Express 21 (7), 8773-8780 (2013).

[ElA14] A. El Amili, G. Loas, L. Pouget, and M. Alouini, "Buffer reservoir approach for cancellation of laser resonant noises," Optics Letters, Vol. 39, 5014-5017 (2014)

Synchronization in vectorial lasers

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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Laboratoire de Photonique et Nanostructures LPN (Marcoussis)

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