Post-doctoral opening

Compact mid-IR frequency combs enabled by semiconductor saturable absorption mirrors (SESAMs)

Position: We have an opening for a two-year (initially) post-doctoral appointment at University Paris Saclay (France) and CNRS, with the Centre for Nanosciences and Nanotechnologies (C2N). You will integrate the *Mid-IR / THz Quantum Devices Team,* specialized in the development of novel optoelectronic devices exploiting quantum electro-dynamic effects at mid-infrared wavelengths [1] [2]. Located south of Paris, University Paris Saclay extends across a vast local area and is ranked as France's top university. The salary level can be negotiated depending on the candidate experience. The project is supported by an *ERC Advanced* Grant (project *SMART-QDEV)*.

The goal of this project is to develop self-starting passively mode-locked compact lasers with ps pulses, enabled by novel semiconductor saturable absorption mirrors (SESAM [3]) covering the whole mid-IR [4]. Compact lasers mean semiconductor-based lasers, or fiber based lasers.

Scientific project: Saturation of the light-matter interaction is a general nonlinear feature of material systems, be they atoms or semiconductors [5]. A saturable absorber exhibits an absorption coefficient that depends on the incident intensity. In semiconductors, controlling saturation phenomena is of importance for fundamental physics as well as applications. A seminal example is the semiconductor saturable absorption mirror (SESAM) [6] [3] based on interband transitions in quantum wells. **It revolutionized the ultra-fast lasers** in the vis/near-IR spectral range, allowing ultra-fast laser pulses and frequency combs (Figure 1) that find applications in many domains.

In the mid-IR ($\lambda \sim$3-30 μm), the intensity required to reach saturation is very high, about 1 MW/cm^2. This very high value explains why **effective SESAM mirrors do not exist in the mid-IR yet.**

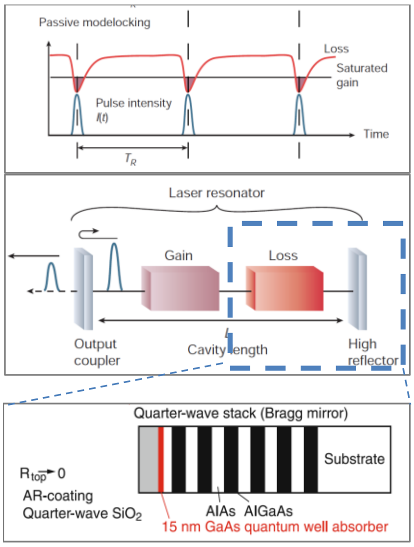

*Figure 1 – A saturable absorber - a material whose absorption decreases with the intensity of light - when inserted into a laser cavity (**middle figure**) can lead to spontaneous generation of ultra-short pulses by the laser. The principle is explained in the **top figure**: operation in pulsed mode is advantageous for the laser, as it operates when the absorption is minimum. In the 90s an invention permitted to replace this sometimes complicated system (dashed square in middle figure) with a nano-technological object: a semiconductor-based mirror whose reflectivity saturates. It enabled a revolution in ultra-fast lasers (image taken from* [3]*).*
Effective SESAMs do not exist in the mid-IR yet.

The project aims at generating mid-IR frequency combs with tabletop interband/quantum cascade lasers, relying on SESAMs with controllable figures of merit (saturation intensities, non-saturable losses…). And also developing initial applications, as sketched in Figure 2.

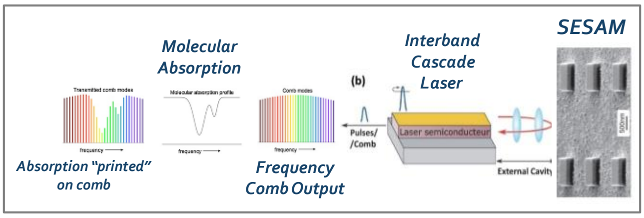

Figure 2 – Operating principle of a SESAM-based mode-locked semiconductor laser. The second laser mirror is the semiconductor saturable absorption mirror, that induces pulses and frequency comb operation (center). Operating in the mid-IR opens up applications in detection and spectroscopy, either directly or using dual comb spectroscopy. It is notable that this technique can be applied to any type of "suitable" laser, for instance fiber lasers.

The activity builds on recent results of the Host Team that elucidated how absorption saturation (and also coherent/incoherent non-linearities) can be engineered if the system operates in the *strong light-matter coupling regime* [7]. The Team also provided initial experimental proof of the validity of the concept [8]. The key is that in the strong coupling regime, the response of the system is governed by coupled light-matter states called *polaritons* [9] [10]*.* Operating in the strong coupling regime is crucial to the device functionality: the intrinsic speed of intersubband polaritons [11] [12] and their enhanced non-linearities make them an **ideal platform to implement ultra-fast devices for the mid-IR, that is an underlying research thrust in the Host Team.**

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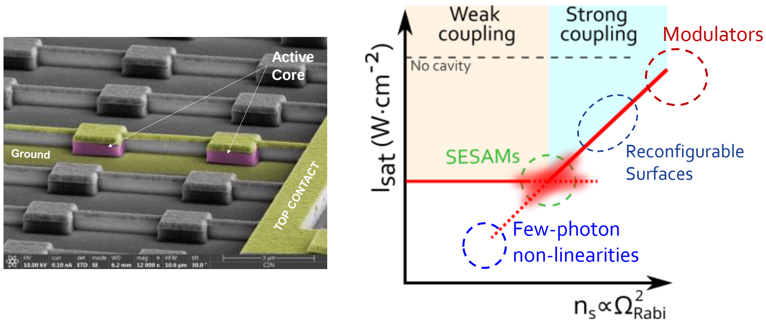

Figure 3 – Right panel: Tailorable saturation intensity (I_{sat}) as a function of the light-matter coupling strength, and potential devices for each regime. The SESAM regime suits the onset of the strong coupling (green circle). Ultrafast modulators [13], *as well as reconfigurable surfaces, better operate in regions where saturation is difficult. Left panel: SEM of a modulator sample, to highlight the type of technology involved* [14]

This rich physics permits the development of several device families, as summarized in Figure 3, even beyond this post-doc proposal, but all in development in the Host Team.

The post-doctoral project will evolve in this context. **As a post-doc,** you will first identify suitable target laser systems (QCL and ICL mainly). After this you will focus on developing and validating SESAMs with figure of merits adapted to such lasers. In particular, the various figures of merit of the devices (saturation fluence, non-saturable losses, speed…) will be carefully gauged. Finally, the laser + SESAM system will be implemented in order to study/achieve/demonstrate mode-locking, and related applications (dual comb spectroscopy for instance) will be explored. Some effort will be also devoted to the implementation of tools and measurement benches for frequency combs characterization in the mid-infrared. Such tools will be also shared with other research lines in the team.

Consortium and Funding: This project will benefit from collaborations with the laboratories IES (Montpellier), LPA/ENS (France), TU Wien (Austria), Laboratory CORIA/CNRS (Rouen), Le Verre Fluoré. Funding is provided by an ERC Advanced Grant.

Applicant profile and how to apply: The work is experimental, but with an important part devoted to quantum/ electromagnetic simulations for device design. We are looking for highly motivated candidates with experience in some (not necessarily all) of the following fields: physics and technology of semiconductor devices; electromagnetic modeling; cleanroom manufacturing; laser physics; optoelectronic characterization techniques; design of quantum hetero-structures.

The successful applicant will have completed an experimental PhD program in Physics, Optics or Engineering. The position is available immediately.

Applications, including cover letter and a CV, should be sent by email to Raffaele Colombelli (E-mail: raffaele.colombelli@c2n.upsaclay.fr or r.colombelli@gmail.com).

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