Internship offer 2025-2026

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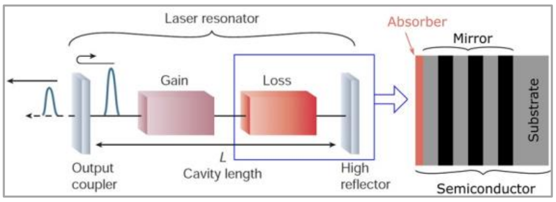
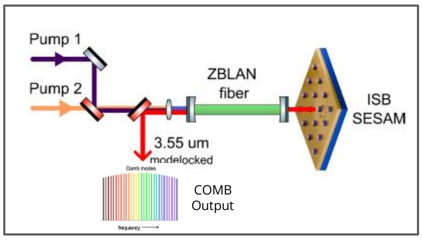
Mid-IR fiber laser frequency combs enabled by semiconductor saturable absorption mirrors

Scientific project: Saturation of the light-matter interaction is a general nonlinear feature of material systems: atoms or semiconductors [1]. A saturable absorber exhibits an absorption coefficient that depends on the incident intensity. In semiconductors, the possibility of judiciously controlling saturation phenomena is of importance for fundamental physics as well as applications. A seminal example is the semiconductor saturable absorption mirror (SESAM) [2] based on interband transitions in quantum wells, that revolutionized the field of ultra-fast lasers in the vis/near-IR spectral range, allowing ultra-fast lasers pulses (see picture on the right) that find applications in many domains.

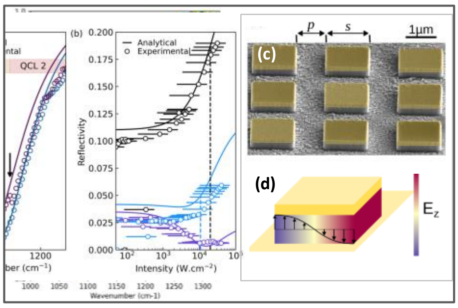


In the mid-IR (λ~3-30 μm), the intensity required to reach saturation is very high, about 1 MW/cm^2. This very high value **explains why saturable absorbers and SESAM mirrors are missing from the toolbox of mid-IR opto-electronic devices**: they could only be used with extremely high power laser sources.

The host team introduced a new concept for mid-IR SESAMs that could solve the aforementioned road-block [3][4]. The solution is to operate in the so called *strong light-matter coupling regime,* where the system response is governed by coupled light-matter states called *polaritons.* The team demonstrated SESAMs with low saturation intensities**, with the goal of generating mid-IR frequency combs with tabletop fiber lasers, as sketched on the right** (the concept is applicable to any "well behaving" mid-IR laser, such as interband cascade or solid state lasers).



The goal of the internship is to develop and optimize mid-IR low-power nonlinear mirrors, supported by recent results [4], that **specifically target comb operation of fiber lasers at λ=3.5 and 3.8 μm.** Our collaborators at CORIA/CNRS have developed such novel sources ([5] and *unpublished*), and our SESAMs will enable their mode-locking operation.



The work will proceed as follows. **First** characterizations consist in measuring the device reflectivity spectra with FTIR micro-reflectivity, to validate the design. **Second**: the devices will be measured with a tunable CW laser at different incident powers. A typical experiment is shown on the side, left panel. The low intensity spectra (full dots) show two polariton resonances. Increasing the laser intensity collapses the light-matter coupling towards the open dots curves: this is the manifestation of saturation. **Third:** The measurement of the reflectivity *phase* will be added to the setup. The candidate will participate to the development of this part. **If time permits,** time domain characterizations will be performed with a mid-IR pump/probe setup, to assess the device speed, that is a crucial figure of merit.

This project evolves in the context of a running ANR grant and of an ERC Advanced grand. It opens up exciting perspectives in the realization of ultrafast, mode-locked mid-IR fiber and semiconductor lasers.

[1] R. W. Boyd, Nonlinear Optics, 3rd ed. (Elsevier, Amsterdam, 2008).
[2] U. Keller, et al., Opt. Lett. **17**, 505 (1992); U. Keller, Nature 424, 831 (2003)
[3] M. Jeannin, JM Manceau, R. Colombelli, Phys. Rev. Lett **127**, 187401 (2021)
[4] M. Jeannin, E. Cosentino, et al., APL **122**, 241107 (2023).
[5] S. Normani et al., Optics Express **32**, 15106 (2024)

Methods and techniques: Modeling of the optical properties of the devices; quantum design of semiconductor heterostructures; use of lasers for optical pumping experiments; labview/python instrument control and data treatment; optoelectronic characterization techniques (mid-IR FTIR microscopy/spectroscopy…).

Possibility to go on with a PhD? YES

Envisaged fellowship ? Doctoral school or research grant (ANR or European *ERC Advanced Grant*)