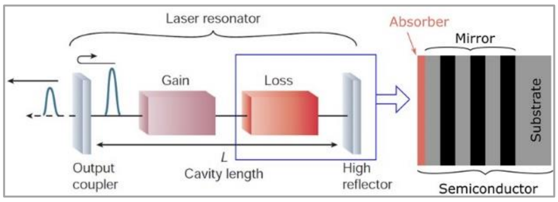
M2 Internship offer 2023/2024

Departement/Team: Photonique/ODIN
Person in charge of the internship: Raffaele Colombelli – Mathieu Jeannin
Contact: *raffaele.colombelli@universite-paris-saclay.fr* – *mathieu.jeannin@universite-paris-saclay.fr*

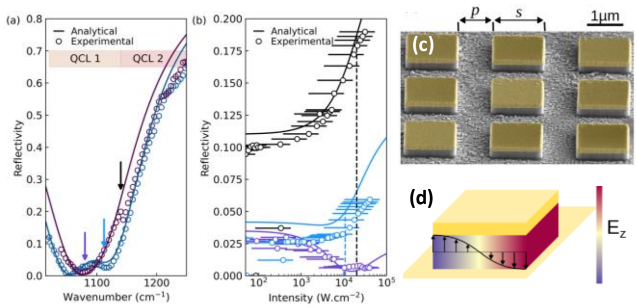
Ultra-Low power semiconductor saturable absorber mirrors in the mid-IR

Scientific project: Saturation of the light-matter interaction is a general nonlinear feature of material systems, be they 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 great importance for fundamental physics as well as applications. A seminal example is the development of 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). Ultra-fast lasers based on SESAMs find applications in several domains, and even in quantum phenomena.



In the mid-IR (λ~10 µm), the intensity required to reach saturation is very high, about 1 MW/cm^2. This very high value **explains why saturable absorbers, SESAM mirrors, bistable systems are missing from the current toolbox of mid-IR opto-electronic devices**: they could only be used with extremely high power laser sources and are incompatible with the output power levels of typical mid-IR semiconductor lasers such as quantum cascade lasers (QCLs).

The host team has recently proposed that absorption saturation can be engineered if the system operates in the so called *strong light-matter coupling regime* [3], and has also provided its experimental proof [4]. In this regime, the response is governed by coupled light-matter states called *polaritons.* In particular, they designed **a SESAM with ultra-low saturation intensities, that are compatible – for the first time – with table-top QCLs.**



The goal of this internship is to demonstrate ultra-low power nonlinear mirrors in the mid-IR, supported by the recent results obtained by the host team [4]. The experiments will be performed **by optical pumping with a tunable, commercial QCL.** Two experiments will be performed.

In the **first**, already implemented experimental configuration, the device reflectivity spectrum will be measured using the tunable QCL at different incident powers. The theoretical outcome of the experiment is shown panel (a): the low intensity spectrum (blue) shows two polariton resonances. Increasing the laser intensity leads to the collapse of the light-matter coupling towards the purple curv: this is the manifestation of saturation. In a **second** experiment, the QCL power is varied while the wavelength is fixed: a typical outcome is in panel (b). This experiment permits to gauge the saturation threshold to be compared with simulations, for further device optimization. If time permits, charac-terizations in the time domain will be performed too. This project, that evolves in the context of a running ANR grant, 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) and 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., Appl. Phys. Lett. 122, 241107 (2023)

Methods & techniques: Optical alignment, RF electronics and signal processing, instrument control (Python).
Possibility to go on a PhD: Yes
Funding: Doctoral school scholarship or research grant