Master 2 – ICFP & Quantum Engineering / Offre de stage

Semiconductor saturable absorber mirrors for mid-IR fiber and cascade laser combs

Date de la proposition : 11/10/2024

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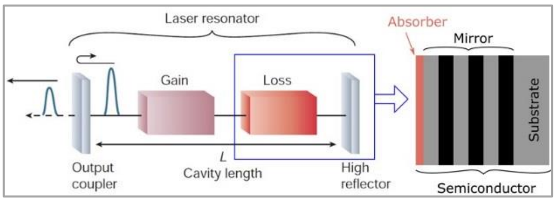
Nom du Laboratoire / *laboratory name*: **Centre de Nanosciences et Nanotechnologies (C2N)**

Etablissement / *institution* : CNRS et UPSaclay Code d'identification : UMR9001

Adresse / *address:* 10 Boulevard Thomas Gobert - 91120 Palaiseau – France

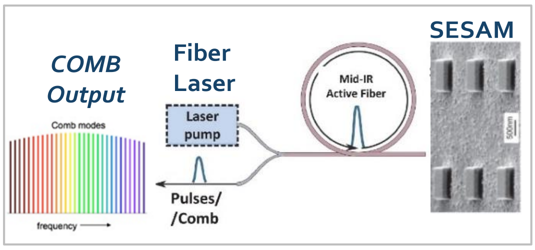
Lieu du stage / *internship place*: C2N

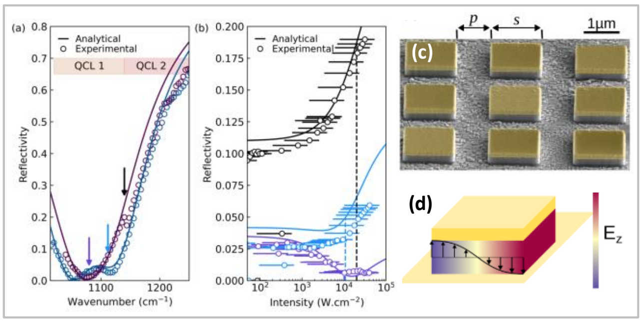
Scientific project: Saturation of the light-matter interaction is a general nonlinear feature of material systems: atoms or semiconductors [1]. A saturable absorber exhibits an absorption coefficient that depends on the incident intensity. In semiconductors, the possibility of judiciously controlling 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 has proposed that absorption saturation can be engineered if the system operates in the so called *strong light-matter coupling regime* [3], and also provided its experimental proof [4]. In this regime, the response is governed by coupled light-matter states called *polaritons.* The team designed SESAMs with low saturation intensities**, with the goal of generating mid-IR frequency combs with tabletop fiber or ICLs as sketched on the right.**





<u>The goal of the internship</u> is to develop low-power nonlinear mirrors in the mid-IR, supported by the recent results obtained [4] (figure on the left), that fit the comb application with fiber and/or ICL lasers. Most of the experiments will be performed **by optical pumping with a tunable, commercial QCL** in an experimental setup already in place**. <u>A first</u>** characterization consists in measuring the device reflectivity spectrum using the tunable QCL at different incident powers. A typical outcome of the experiment is shown panel (a): the low intensity spectrum (blue) shows two polariton resonances. Increasing the laser intensity collapses the light-matter coupling towards the purple curve: this is the manifestation of saturation. These spectra allow to determine the wavelengths for SESAM operation. **<u>In a subsequent</u>** experiment, the saturation threshold will be gauged by measuring the reflectivity at a fixed wavelength while varying the QCL power (panel (b)) and compared with simulations, for device optimization. If time permits, time domain characterizations will be also performed with a mid-IR pump/probe setup. 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.

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

[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)

Ce stage pourra-t-il se prolonger en thèse ? *Possibility of a PhD* **? : Yes**

Si oui, financement de thèse envisagé ou acquis : Doctoral school or research grant (ANR / European)

Financement acquis / *Secured funding*		Nature du financement */Type of funding*	European
Condensed Matter Physics: YES		**Quantum Physics: YES/**	