Master 2 : INTERNSHIP PROPOSAL

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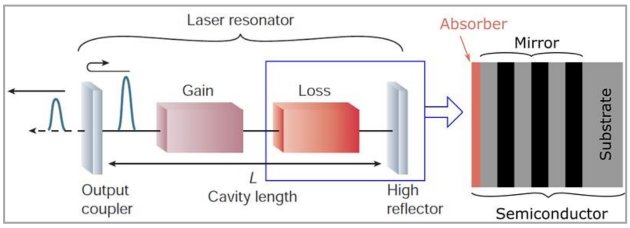
Thesis possibility after internship: YES
Funding: YES / Doctoral school or research grant

Semiconductor saturable absorber mirrors in the mid-IR

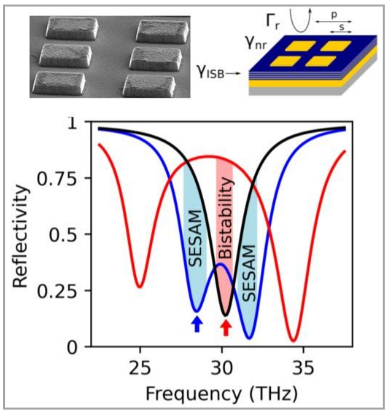
Saturation of the light-matter interaction is a general nonlinear feature of material systems, be they atoms or semiconductors [1]. A saturable absorber exhibits an absorption coefficient that depends on the incident intensity. In semiconductors, the possibility of judiciously controlling saturation 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.

The host team has recently demonstrated, in a paper to appear in Phys. Rev. Lett. [3], that absorption saturation can be engineered if the system operates in the so called *strong light-matter coupling regime.* 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 quantum cascade lasers.**

The goal of this internship is to demonstrate ultra-low power saturable absorber mirrors in the mid-IR, supported by preliminary experimental 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 on the right: the low intensity spectrum (red) shows the two polariton resonances. Increasing the laser intensity leads to the collapse of the light-matter coupling towards the black curve. This is the manifestation of saturation. A more advanced pump-probe experiment will be implemented. The QCL pump will be kept at a fixed wavelength, and the broadband reflectivity of the device will be probed with a FTIR spectrometer. Varying the QCL incident power will provide important information on the system physical parameters, allowing further optimization of the devices. This project opens up exciting perspective in the realization of ultrafast, mode-locked mid-IR 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, to appear in Phys. Review Letters (2021). https://arxiv.org/abs/2012.15633
[4] M. Jeannin, JM Manceau et al., "MIR saturable absorbers with ultra-low saturation", ESLW Workshop 2021 (France)

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