Master 2 – ICFP & Quantum Engineering / Offre de stage

Ultra-fast mid-IR modulators for applications to frequency combs and spectroscopy

Date de la proposition : 11/10/2024

Responsable du stage : Raffaele Colombelli and Adel Bousseksou

E-mail : raffaele.colombelli@c2n.upsaclay.fr adel.bousseksou@c2n.upsaclay.fr

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

Electrically reconfigurable surfaces are artificial components whose optical properties, in reflection/ absorption, can be addressed electrically. In particular, surfaces whose complex reflectivity (real/imaginary parts of the S11 parameter, in electronic scattering terms) is electrically tunable are particularly useful as amplitude or phase modulators [1]. In the mid-infrared (MIR, 3um < λ < 30um), these functionalities are useful for applications such as laser phase stabilization, spectroscopy, **EO frequency comb generation** [2], mode-locking, optical communications.

The ultrafast (10–40GHz) modulation of mid-IR radiation is still a missing device functionality. **The Host Team is at the forefront of this research with a far-reaching approach**: the development of electrically reconfigurable surfaces for the mid-IR, where they are not as developed as in the visible/telecom spectral regions or as in the radio frequency (RF) domain [3].

After a proof-of-principle demonstration [4], the Host Team has recently demonstrated (see picture on the side) ultra-fast (10 GHz speed) **MIR modulators with performances that are compatible with real world applications** [5]. The specificity (and the beauty) of the concept is that it relies on a fundamental physics phenomenon: the strong-coupling regime between light and matter.

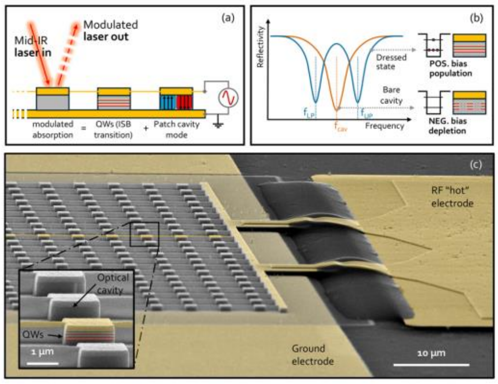
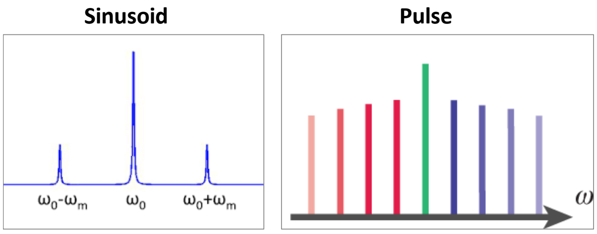


Figure 1 - (a) Scheme of modulator architecture: the active region embedded in metal–metal cavities that are electrically connected. The amplitude of the optical reflected beam is modulated by the application of an external RF signal. (b) Intuitive view of modulator operating principle in an ideal configuration. (c) SEM images of a typical fabricated device.

The goal of this internship is twofold. **First**, employing the currently existing modulators to generate EO frequency combs, that is a crucial step for applications. **Secondly**, participate in the full characterization, and result interpretation, of a new generation of modulators (currently being fabricated) with improved functionalities. The experiments will be performed with the currently existing setup, **built around a tunable, commercial quantum cascade laser.** The perspective intern will also have the possibility to add improvements to the setup (for instance the measurement of the modulation phase).

The **first experiment** works as follows. In general, a modulator is fed a GHz-frequency sinusoidal signal: as a consequence, the reflected laser is sinusoidally amplitude modulated. In the frequency domain, this means creating two laser sidebands around the main laser line (figure on the right). If instead a **short RF pulse** is fed to the modulator, several Fourier components will be present and many sidebands will be generated around the main laser line: that is a frequency comb (see sketch on the side). This comb can be employed to perform spectroscopy experiments.



The **second experiment** will deal with full device characterizations, similar to the ones performed in Ref. [5]. A part of the activity will be device design/simulation to compare with the measurements.

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

[1] I.-C. Benea-Chelmus, M. L. Meretska, D. L. Elder, M. Tamagnone, L. R. Dalton, and F. Capasso, Nat. Commun. 12, 5928 (2021).
[2] N. Picqué, T. W. Hänsch, and P. Natale, Nat. Photonics 13, 146 (2019).
[3] C. Balanis, *Antenna Theory: Analysis and Design* (Wiley-VCH Verlag GmbH, 2005).
[4] S. Pirotta, N.-L. Tran, A. Jollivet, G. Biasiol, P. Crozat, J.-M. Manceau, A. Bousseksou, R. Colombelli, Nat. Commun. 12, 799 (2021).
[5] M. Malerba, S. Pirotta, et al., Appl. Phys. Lett. 125, (2024).

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 (European)

Financement acquis / *Secured funding*		*Type of funding*	European and Maturation
Condensed Matter Physics: YES		**Quantum Physics: YES/**	