INTERNSHIP PROPOSAL
Internship offer 2026-2027

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

Scientific project: Electrically reconfigurable surfaces are artificial components whose optical properties, in reflection/absorption, can be addressed electrically, and they are especially useful as as amplitude or phase modulators [1]. In the mid-infrared (MIR, 3um < λ < 30um), these functionalities are crucial 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 highly sought and **the Host Team is at the forefront of this research with a broad and long-term approach**: the development of electrically reconfigurable surfaces for the mid-IR, as they are not as developed as in the visible/telecom or as in the radio frequency (RF) domain [3]. After a proof-of-principle demonstration [4], the Host Team has demonstrated (see picture on the side) ultra-fast (10 GHz) **MIR modulators with performances compatible with real world applications** [5], and is using them now to generate electro-optic (EO) combs [6]. 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.

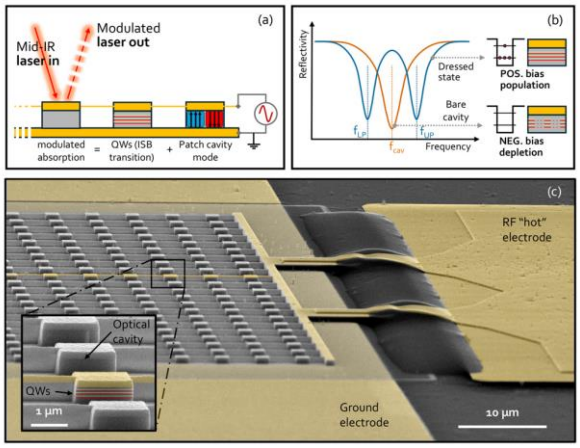
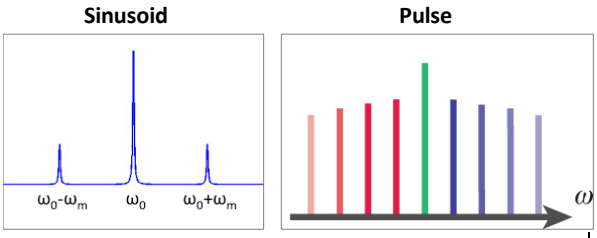


Figure 1 - (a) Scheme of modulator architecture: the active region embedded in metal–metal cavities that are electrically connected. The amplitude of the optical reflected beam is modulated by the application of an external RF signal. (b) Intuitive view of modulator operating principle in an ideal configuration.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

The goal of the internship is twofold. **First**, rely on the current modulators to generate and employ EO frequency combs for applications. **Second**, participate in the full characterization, and result interpretation of two modulators concepts (currently being fabricated) with improved functionalities. The experiments will be performed with the existing setup, **built around a tunable, commercial quantum cascade laser.** The perspective intern will also work on a crucial setup improvement that will permit to measure **the phase of the modulated signal.**



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 modulated. In the frequency domain, this means creating two laser sidebands around the main laser line. If instead a **short RF pulse** is fed to the modulator, many 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.

[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, and R. Colombelli, Nat. Commun. 12, 799 (2021).
[5] M. Malerba, S. Pirotta, et al., Appl. Phys. Lett. 125, 041101 (2024).
[6] Mid-IR single-and dual-electro-optic comb generation with an ultrafast modulator, G-L. Ngo, L. Lucia, S. Pirotta, …, A. Bousseksou, R. Colombelli, arxiv 2607.03317 (2026).

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; optoelectronic characterization techniques (mid-IR FTIR microscopy/spectroscopy….).

Possibility to go on with a PhD ? YES
Envisaged fellowship? Doctoral school or research grant (ANR / European ERC Advanced)