Laboratoire : Centre de Recherche sur l'Hétéro-Épitaxie et ses Applications (UPR 10)

PhD Advisor : Dr. Patrice Genevet

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DURATIONS:

The duration of the PhD is three years.

NONLINEAR WAVEFRONT CONTROL WITH METASURFACES

CONTEXT:

Unexpected and unusual effects have been recently reported in various fields of research, such as but not limited to acoustics, seismology, thermal physics, and electromagnetism. At the heart of these developments is a progressive understanding of the wave-matter interaction and our ability to artificially manipulate it, particularly at small length scales. This has in turn been largely driven by the discovery and engineering of materials at extreme limit. These "metamaterials" possess exotic properties that go beyond conventional or naturally occurring materials. The idea of manipulating light deep into the subwavelength regime can be further exploited to the extreme case where metamaterials become sufficiently thin with respect to the wavelength of light to create metasurfaces. The latter are functional interfaces covered with a collection of subwavelength nanostructures/slits or structured optical thin-films (i.e. almost 2D) to introduce abrupt modifications on the wavefront of light over the scale of the wavelength. So far most of the research on metasurfaces have been carried out in the linear regime.

RESEARCH SUBJECT, WORK PLAN:

Nonlinear phase matching is a complex problem which can be performed only with specific materials, at specific temperature and at specific angles. Several strategies have been developed to solve the phase-matching problem for nonlinear processes. The most significant solution include the use of birefringent nonlinear crystals or quasi-phase-matching in periodically poled nonlinear crystal. The latter consists in alternating the orientation of birefringent materials such that the periodic crystal can provide an additional momentum to satisfy the phase matching condition. In this thesis, the candidate will develop another approach to control and tailor the nonlinear signal. Controlling the light propagation with metasurfaces suggests an unprecedented and novel ways of achieving nonlinear phase matching in optics. The idea is to consider the phase response of nanostructures to create a new class of nonlinear optical metamaterials in which layers of carefully designed antennas would be cascaded along the propagation to perform nonlinear phase matching via local phase addressing.

Being intrinsically different from classical nonlinear metamaterials, metasurfaces will be designed to control the phase of the generated nonlinear signal according to both propagating phase delay of the pump beam and to the scattering response of the resonators. New nonlinear materials consisting of properly disposed phased-array nanoscale elements, either along a single interface or by cascading several layers of nano-patterned phased interfaces, eventually embedded or regrown in a bulk crystal can be created. This new technique, which is considerably simpler than designing the nonlinear susceptibility and the permeability of metamaterials, would open fairly wide research opportunities in the field of nonlinear optics from the mid-infrared down to the visible and eventually in the UV.

KEYWORDS:

Nanophotonics, Metamaterials, Metasurfaces, Electromagnetic Boundary Conditions, Wavefront engineering, Nano-resonators, nonlinear optics, Flat optics, Finite element methods.

APPLICANTS SKILLS:

The applicant must be highly motivated and enthusiastic student, with a Master degree either in optics and photonics, or applied mathematics, or electrical engineering. He must have good skills/understanding in electromagnetics and/or photonics. We encourage the application of candidates with strong background in applied mathematics. The applicant should also be willing to carry out nanofabrication and optical experiments.

SELECTED PUBLICATIONS:

[1] *Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction*, N. Yu, P. Genevet, M. A. Kats, F. Aieta, J.P. Tetienne, F. Capasso, and Z. Gaburro, **Science** 334, 333-337 (2011)

[2] *Holographic optical metasurfaces: a review of current progress*, P. Genevet and F. Capasso**, Reports of Progress in Physics**, 78 (2), 024401 (2015)

[3] *Flat Optics: Controlling Wavefronts with Optical Antenna Metasurfaces*, N. Yu, P. Genevet, F. Aieta, M. A. Kats, R. Blanchard, G. Aoust, J-P. Tetienne, Z. Gaburro, and F. Capasso **IEEE Journal of Selected Topics in Quantum Electronics**, DOI:10.1109/JSTQE.2013.2241399 (2013).

[4] *Multiwavelength Achromatic metasurface optical components by dispersive phase compensation,* F. Aieta, M.A. Kats, P. Genevet, and F. Capasso, **Science**, 347, 1342-1345 (2015).

[5] Recent advances in planar optics: from plasmonic to dielectric metasurfaces, P. Genevet, F. Capasso, F. Aieta, M. Khorasaninejad, and R. Devlin, **Optica** Vol. 4, Issue 1, pp. 139-152 (2017)