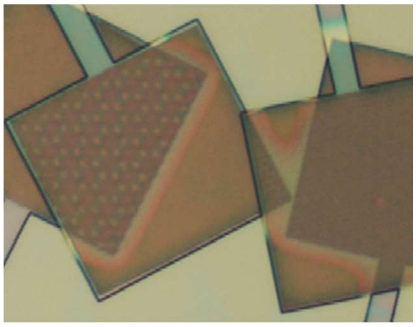
PhD Subject
Light confinement in photonic moiré

(starting september 2021 or october 2021)



Context:

In the field of Nanophotonics, we exploit technological advances to structure matter at the nanoscale to control different parameters of photons in wavelength-scale objects. This approach has been very popular over the last twenty years and has led to major advances in many fields of application such as information technology, sensors for health and the environment or energy production.

Moiré patterns are superlattice structures that appear when two gratings (with a different orientation or period) are superimposed. This phenomenon, well known in classical optics, has been recently exploited in the field of condensed matter. In particular, fascinating effects are expected when the moiré effect is obtained from two superposed and twisted graphene sheets: depending on the angle formed by the sheets, studies show that the electron transport can be completely modified and lead to a superconductivity phenomenon for "magic" angles. In the field of nanophotonics, equally amazing effects are expected from moirés formed by the superposition of photonic crystals membrane [1].

Emblematic objects of nanophotonics, photonic crystal-based structures are now a well-known platform to control the properties of light such as the ultimate confinement of electromagnetic energy, the propagation speed of photons, and non-linearity.

The i-Lum team at INL has a well-established expertise in this field. In particular, INL researchers have recently demonstrated that, in photonic crystals, the exploitation of symmetry breaking, also present in moiré crystals, enables shaping at will the dispersion relation of photons, thus opening the way to an unequalled control of optical densities of states [2].

Keywords : Photonic crystals, moiré, micro-resonators

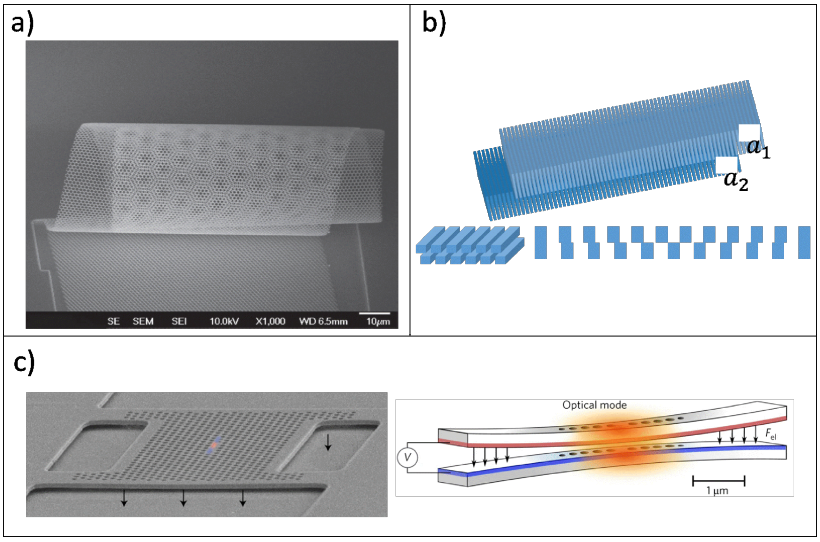
Thesis Objectives:

The main objective of this thesis is to develop and implement the concepts of photonic moirés to fabricate superlattices of micro-resonators in which photons can be efficiently "stored". These super-arrays can be used to form resonant cavities for new light sources (large area single mode lasers for example).

This objective will be achieved through the realization of periodic or aperiodic structures, of the "moirés" type, composed of two coupled photonic crystals, shifted, "tilted" or with slightly different periods (see figures below).

[1] P. Wang et al., Nature 577, 42–46 (2020). Voir aussi : G. Hu et al., Nano Lett. 20, 5, 3217–3224 (2020) et G. Hu. Et al., Nature 582, 209-213 (2020)

[2] H.S. Nguyen et al., Phys. Rev. Lett. 120, 066102 (2018)



Different technological routes to fabricate "Photonic Moiré": a) 2D "tilted" moiré obtained by self-winding of a CP membrane at INL [3], b) schematic views of a 1D moiré obtained by double nanostructuring with alignment c) NOEMS (Nano Opto-Electro-Mechanical Systems) technologies can also be used to couple CPs [4]

Scientific challenges

The main challenge lies in the fabrication of the structures, which requires going beyond the usual planar technologies of micro-opto-electronics, by combining know-how in micro-nanostructuring and in selective micromachining of thin semiconductor layers. The fabrication of these objects will consist in associating two photonic crystal membranes. Hence, it will be necessary to develop processes to superimpose two photonic crystals and to adjust their respective vertical and lateral positions. The realization of photonic crystals being mastered at INL, various tracks are considered in the thesis in order to control their superposition:

1. Successive fabrication of two 2D silicon photonic crystals, separated by planarized silicon oxide layer to finely tune their spacing. The lateral offset between the two photonic structures will be controlled during the lithography steps.
2. Exploitation of selective undercut processes to realize deformable membrane photonic crystals. In a first phase of the study, the positioning of the superimposed membranes will be controlled by exploiting the effects of displacement induced by the relaxation of mechanical stresses in the thin films, according to self-rolling processes developed in a previous project. In a second and more exploratory phase, the feasibility to achieve active control of the respective positions of the photonic membrane crystals will be studied (in particular by means of a NOEMS-type process, Nano Opto-Electro-Mechanical Systems).

Expected original contributions

The objectives of this thesis are primarily to experimentally demonstrate the fundamental phenomena predicted by theoretical studies on moirés formed by 1D photonic crystals. This will set the ground work to demonstrate new ways to confine light and to control the dispersion relation of devices. The experimental results obtained in terms of device fabrication will open up a generic technology platform for original optoelectronic devices

[3] A Danescu et al., Nanotechnology 29, 285301 (2018)

[4] L. Midolo et al., Nature Nanotechnology 13, 11-18 (2018)

In particular, the project will focus on two promising outcomes predicted by the remarkable properties of moiré-like structures:
- Natural and "spontaneous" generation of photonic devices with extraordinary properties together with very low design cost in terms of adjustable parameters, (e.g. production of miniaturized and highly resonant photon traps). As a corollary, it is expected that the technology for the elaboration of these devices will be particularly robust.
- Ability of the moiré-based devices to be tunable/switchable in the spatial, angular and frequency domains, with a very high efficiency in terms of the energy cost of their actuation.

Among the expected results we can mention:
- The implementation of technological processes allowing the fabrication of three-dimensional micro-objects, which may lead to interesting impacts well beyond photonics.
- The demonstration of new photon confinement mechanisms.
- The realization of microsources of light with original properties.

Research program and proposed scientific approach
The PhD student will be hosted in the i-Lum team of the INL. A first part of the thesis will be devoted to the bibliographic study, the comprehension of the photonic concepts, as well as the training on various experimental tools crucial for the project. Then the PhD student will specifically be in charge of optimizing the various technological stages necessary to the fabrication of the moiré structures. He/she will test and evaluate the different 3D fabrication methods in order to select the one(s) that will allow to obtain functional photonic structures. This evaluation will involve optical characterization of the structures, both in the far and near field, on various optical setups available in the laboratory. The PhD student will be able to rely on the recognized expertise of the i-Lum team in the field of photonic crystal-based structures, as well as on the Nanolyon technology platform.

The candidate
Desired profile (prerequisites)
The candidate must have a strong background in material science and/or electromagnetism, with a strong motivation for technological and experimental work.
Skills developed during the PhD
This thesis will mainly focus on fabrication and characterization aspects. The PhD student will thus receive a solid technological training in clean room environment on equipment such as electron lithography, dry etching, electron microscopy,... Similarly, he/she will develop skills in electromagnetic simulations and optical characterizations of nanophotonic devices (micro-photoluminescence at room temperature and cold, Fourier spectroscopy, optical near field microscopy,...)
Professional perspectives after the PhD :
These skills acquired during the thesis will allow him/her to pursue an academic career, or to work in the industry (microelectronics, R&D, engineering and management).

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Laboratory: Institute of Nanotechnologies of Lyon, site of the École Centrale de Lyon
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Documents to send : CV, Motivation letter, Master (or equivalent) transcript