M2 Internship offer:

Holographic metasurfaces for sensor applications

Research team: i-Lum, light engineering and conversion

Main location: La Doua campus

Keywords: Nanophotonics, metasurfaces, phase sensors, dispersion diagrams

Profile: Physics/engineering, Optics/Photonics

Duration: 4-6 month.

Context:
In Nanophotonics, light can be controlled by structuring matter at a subwavelength scale, as in photonic crystals (or metasurfaces). By trapping light at a given wavelength that gives rise to a resonant effect, the photonic crystal becomes a photonic sensor highly sensitive to its environment. The presence of objects (such as molecules) at the photonic crystal-liquid interface modifies the resonance, inducing a wavelength shift. This variation makes it possible to detect the presence of biomolecules. For early disease diagnosis, the detection of these molecules in small quantities remains a current challenge. Therefore, there is still a need to improve the sensitivity and detection limits of photonic sensors.
To characterize the light-controlling properties of a photonic crystal, spectroscopic measurements and/or dispersion diagrams are usually carried out. These provide information on the mode of reflection, transmission or emission, depending on the wavelength and on the excitation direction of the photonic crystal. In general, dispersion measurements are intensity measurements. At INL, we are adding phase measurement to the dispersion diagram, as this provides additional information that is little explored in Nanophotonics. For example, metasurfaces can possess special phase properties, such as a phase singularity. A phase singularity is characterized by a reflectivity that tends towards zero in intensity and exhibits a sharp phase jump at resonance. Under certain conditions of angular phase distribution, these photonic crystals could boost the phase sensitivity and reduce the detection limit in sensor applications. Hence, the study of phase and amplitude dispersion diagrams will pave the way to understanding the behavior of these photonic crystals when used as sensors.
In this context, we have developed a new approach for sensor applications, i.e., a holographic micro-reflectivity measurement system that provides access to the complex reflectivity of the photonic crystal (amplitude and phase) [1]. Our aim is to extend the functions of our measurement system, from a reflectivity measurement for a given angle and wavelength, to a system that measures the reflected light for a range of wavelengths and a range of angles in both the x and y directions of space. In other words, a system able to measure 3D amplitude and phase dispersion diagrams.
For sensor applications, it will enable us to study the evolution of resonance in the dispersion diagram. The phase dispersion measurements will provide a better understanding of the behavior of the phase singularities when the resonance is modified by the presence of molecules in the near-field of the photonic crystal. Obtaining complex 3D dispersion diagrams (amplitude and phase) and their evolution in a sensor application is highly original, and to our knowledge has never been done before.

Objectives and workplan:
The aim of this experimental internship is to study photonic crystals by measuring their 3D dispersion diagram and to see how it evolves when the refractive index of the liquid medium changes above the photonic crystal.
The first step will be to reproduce reflectivity measurements at a given wavelength for an angle distribution in the x,y plane, and then to obtain a 3D dispersion diagram by varying the laser

wavelength. More particularly, we will study photonic structures with ultra-flat bands, meaning that the reflectivity spectrum evolves very slowly as a function of angle. The purpose of this first step will be to calibrate the holographic phase measurement setup and to compare it with the theoretical band diagram.
In a second step, we will apply the setup to sensing. For this purpose, we will vary the liquid environment in contact with the photonic crystal by injecting glucose solutions of different concentrations with a micro-fluidic system. The effect of the refractive index variation on the dispersion pattern will be studied, with particular emphasis on its phase.

Scientific profile and competences:
The nature of the proposed work being mainly experimental, the candidate must have an engineering degree or a Master's degree in physics or engineering science. A strong interest in experimentation is required to successfully complete this internship. Basic knowledge of optics and photonics is required. During the internship, the student will become familiar with the concept of nanophotonics, optical and holographic experimental techniques and the methods used in photonic sensors. If the student so wishes, he/she could also acquire skills in photonic numerical simulation. The student will have the opportunity to evolve within the i-Lum team in an environment that integrates different facets with theoretical, technological and experimental aspects.

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[1] Théo Girerd, Fabien Mandorlo, Cécile Jamois, Taha Benyattou, Lydie Ferrier, and Lotfi Berguiga, “Optical sensing based on phase interrogation with a Young’s interference hologram using a digital micromirror device”, Optics Express 32.3 (2024), pp. 3647. DOI 10.1364/oe.507643.