



PhD Thesis Proposal

Title : Global polarizability approach for designing multi-functional metalens fiber endoscopes on micro- to macroscales

Host Institution : Hubert Curien Laboratory (LabHC) & Jean Monnet University – in collaboration with the Institute for Research in Surface Engineering (IREIS, HEF group) within COMETA.

The Hubert Curien laboratory is a joint research unit (UMR CNRS 5516) of the Jean Monnet University, Saint-Etienne, the National Research Centre "CNRS" and the Institut d'Optique Graduate School. It is composed of 90 researchers, professors & assistant professors, 25 engineers & administrative staff, and around 110 PhD & post-PhD students. This total of approximately 230 staff makes the Hubert Curien laboratory the most important research structure in Saint-Etienne. Our activities are organized around two scientific departments: Optics, Photonics & Surfaces and Computer Science, Security & Image, and scientific projects are carried out by 6 main teams: Functional Materials and Surfaces, Materials for Optics and Photonics in Extreme Radiative Environments, Laser-Matter Interaction, Image Science & Computer Vision, Data Intelligence, and Secure Embedded Systems & Hardware Architectures. <https://laboratoirehubertcurien.univ-st-etienne.fr/en/the-lab/edito.html>

This PhD project is embedded within the broader scope of the **Laboratoire commun COMETA**, which aims to create new designs for optical components with optimal performance and novel functionality using the properties of nanostructures and by applying the concept of metasurfaces. COMETA combines the resources and the expertise of the Institute for Research in Surface Engineering (IREIS, HEF group) and the Hubert Curien Laboratory (LabHC), affiliated with Jean Monnet University, CNRS and Institut d'Optique Graduate School. <https://www.rhone-auvergne.cnrs.fr/fr/cnrsinfo/laboratoire-commun-cometa-revolutionner-loptique-avec-les-metasurfaces>

Funding: Institute for Research in Surface Engineering (IREIS, HEF group)

Subject :

Metasurfaces, consisting of an arrangement of resonant nanostructures – meta-atoms, can boost significantly the multi-functionality of optical components, providing precise and compact spatial control of the optical wavefront. Designing the complex optical response of meta-atoms, arranged non-periodically, remains challenging and requires the development of novel efficient methods, applicable both to complex focused light sources and confined modes relevant at small spatial scales and extendable to large industrial scales. Recently, a global polarizability matrix (GPM) method [1] has been proposed to tackle these challenges, consisting in learning the individual optical response of each meta-atom to arbitrary light sources to construct the polarizability tensor, and using the electromagnetic Green's tensor to account for multiple scattering and confined modes to obtain the optical response of the complex arrangements. In contrast to optimization techniques mimicking a global phase profile by individual meta-atoms, GPM approach takes account additionally for strong coupling between meta-atoms, essential for enabling sharp focusing and sharp spectral features, as well as multi-functionality of optical device.

We propose to develop, apply and validate the GPM method for a metalens in two extreme regimes: a micrometric metafacet of the optical fiber and a millimetric metasurface at the tip of endoscope. A metasurface on the fiber facet sees a non-planar field launching out of the fiber, so designing a proper phase profile for tight focusing requires accounting for the curvature of the incident field and longitudinal modes in the fiber, caused by the finite size of the fiber. Therefore, the Green's tensor formalism should also include these modes. We aim to design metasurfaces made of a silica metalens consisting of silicon sub-wavelength meta-atoms with multi-mode functionality, enabling to focus the output light at different focal planes depending on the wavelength of light in the near-infrared spectral range. At microscale, the developed approach will be validated by comparing the optical response of the identical structure with full-vector Maxwell simulations. With the increasing size of the metasurface, the computational expense of direct computational methods increases (not feasible to compute accurately the field distributions for a fiber diameter > 100 microns). As a result, only GPM-like methods are feasible for the modeling of larger scale devices, such as millimeter-sized endoscope probe with a metasurface tip, requiring simultaneous focusing, spectral filtering and polarization control for optical coherence tomography and contrast imaging performance in clinical diagnostics. Such multi-functional design could be realized with the help of strongly coupled hybridized modes in the meta-atoms, which are fully taken into account by GPM approach.

In summary, this project will tackle the problem of modeling and designing of large-scale metasurfaces with strongly coupled non-periodic meta-atoms. The insights and tools developed within this project will help to predict the optical response, to optimize and to propose fabrication friendly design of a multi-mode metalens from the microscale to millimetric dimensions for emerging applications in telecommunications, biomedical imaging, and clinical diagnostics.

[1] M. Bertrand, A. Devilez, J.-P. Hugonin, Ph. Lalanne, and K. Vynck, "Global polarizability matrix method for efficient modeling of light scattering by dense ensembles of non-spherical particles in stratified media", *JOSA A*, Vol. 37, No. 1 (2020).

Keywords :

Optics; Metasurface; Computational Electromagnetics; Global polarizability matrix; Green tensor; Metalens; Imaging; Endoscopy

Candidate Profile :

The ideal candidate holds a Master's degree (MSc or equivalent) in Physics, Optics, Photonics, Materials Science, or related fields. The following skills and background are expected:

- Strong knowledge in electromagnetics & optics
- Experience with numerical modeling (Python, MATLAB, or C++) and computational electromagnetics codes (Finite-Difference Time-Domain (FDTD), or Discrete Dipole Approximation (DDA), or Rigorous Coupled Wave Analysis (RCWA))
- Proficiency in written and spoken English; proficiency in French is a plus
- Familiarity with Green's functions, inverse design strategies, machine learning and parallel programming (OpenMP, MPI, or GPU) is a plus
- Motivated to work in a multidisciplinary environment and to collaborate with industrial partners

The candidate is expected to demonstrate initiative and autonomy in order to successfully complete his/her thesis.

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The interested candidates should provide (1) an updated CV with the detailed education background, work experience and professional skills, (2) an optional short motivation letter, (3) a transcript with the detailed courses taken and grades received for a Bachelor's/Master's degrees.
