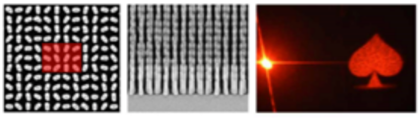
Internship project - Year 2020/2021

High order fullwave modeling and inverse design for highly efficient metasurface configurations

Inria Sophia Antipolis - Méditerranée research center
ATLANTIS project-team
2004 Route des Lucioles, BP 92, 06902 Sophia Antipolis Cedex, France



During the past few years, metasurfaces have been widely considered as ideal solutions to replace the classical optical components by manipulating the light at the subwavelength scale. Metasurfaces rely on the clever adjustment of ultrathin optical elements with spatially varying geometrical parameters and separated by subwavelength distances. These elements are often based on metallic and/or high refractive index dielectric materials. The subwavelength arrangement affords adequate control of almost all the characteristics of light such as the amplitude, the phase, and the polarization, which render full control of the incoming wavefront over a short propagation distance. Numerous optical components have been revisited based on metasurfaces such as lenses, axicons, polarization converters and waveplates [LFHB14, ZKL+17, GCA+17].

To manipulate the incoming wavefront, the subwavelength optical elements should acquire 2π phase shift with a high transmission or reflection amplitude. With the proper spatial variation of the phase across the surface, one can control the incident wavefront and realize the desired objective. Generally, in the conventional refractive elements such as lenses, the wavefront shaping is controlled by varying length of the optical path to impart a varying retardation phase [GCA+17, LFHB14]. The phase change can be achieved by changing height, length and width for a given fixed orientation direction of the subwavelength optical elements [ELD+19, ALC+98]. This type of phase retardation is generally known as the propagation or the dynamical phase.

One of the most notable features of a metasurface is the ability to modulate the polarization state of the electromagnetic wave and render the required 2π full phase control based on birefringent meta-atoms [LBZ+16, MRD+17]. The full phase control relies on the geometrical phase, or what is called the Pancharatnam-Berry (PB) phase [Ber87]. In this case, the birefringent elements need to be designed carefully to serve as half-wave plates to convert the incoming circular polarized wave to the opposite cross-polarization [LBZ+16, MRD+17] and imparting a spatially varying angular orientation to cover the 2π phase shift [Ber87]. In the case of geometrical phase, the phase retardation is not affected by the geometrical path, but it is generally influenced by the geometry of the polarization transformation path on the Poincare sphere [MRD+17]. In other words, in this case, the phase shift of cross-polarization depends on the rotation of the birefringent elements and incoming circularly polarized wave while independent of the operating wavelength [LBZ+16, MRD+17]. Numerous fascinating applications have already been proposed based on the PB phase [SKV+21, TJY+20, GGS+20]. In most of these studies, the position of the birefringent elements at the metasurface is chosen based on the required phase (by rotating the element with the required angle). However, in the majority of the above-mentioned application, the strong near field coupling between the adjacent elements is not taken into account during the phase synthesis procedure. This strong coupling may lead to a substantial decrease in system efficiency.

In our recent work [ELD+19], we have illustrated the significance of the near field coupling in enhancing the performance of the metasurface based on propagation phase. The principal aim of this internship is twofold. The first objective is the extension of our former study in Ref. [ELD+19] to numerically model and optimize metasurface devices based on geometrical phase, but taking into account the strong near field coupling between the neighbouring ridges unlike what is usually considered in the literature. This first task will be realized by optimizing different metasurface devices based on either metal or dielectric materials. The second objective is to perform a state of the art study for the broadband performance of the geometrical phase-based devices.

In order to perfor the above tasks, the candidate will use our high order fullwave time-domain Maxwell solver based on hight order Discontinuous Galerkin (DG) type methods. This solver is part of the DIOGENeS [DIO] software suite, which is dedicated of the study of light-matter interactions at the nanoscale with general structures and complex media. Thanks to the high order polynomial adaptation, this solver has been proved to be a strong asset in capturing the strong light-matter interactions, for sophisticated geometry features with strong discontinuity [ELD+19, EHBL20], compared to the classical low order approximation methods like Finite-Difference Time-Domain (FDTD).

For the optimization part, the candidate will use the Efficient Global Optimization (EGO) [Jon98]. This method is based on a surrogate modeling that replaces the complex and costly iterative electromagnetic evaluation process with a simpler and cheaper model. It has been confirmed recently that this approach is more efficient than the classical evolutionary algorithms in terms of computational cost. For more details about this method, and the comparison with other classical optimization methods in the field of nanophotonics, we refer to Refs. [SGSS+19, ELD+20]. It is worth mentioning that the coupling between the global optimization method and our rigorous electromagnetic solver has bees successfully applied in our recent works [ELD+19, EHBL20]. This internship will involve a collaboration with the group of Dr. Patrice Genevet who is a scientific researcher at the CRHEA CNRS laboratory in Sophia Antipolis. His expertise is mainly in theoretical design, nanofabrication and analysis of metasurface devices.

Scientific benefits
At the end of the internship, the student is expected to:

- Understand the physical principles of metasurfaces
- Gain experience in simulating nanophotonics devices using a high order finite element solver
- Be able to provide physical interpretation of the underlying numerical simulation and optimization outcomes
- Acquire some experience in software development (depends on his/her capacity)

Required background

- Basics of electromagnetics with sound knowledge in nanophotonics
- Basics of numerical optimization
- Sound knowledge of applied mathematics or scientific computing
- Software development skills, preferably in Fortran 200x would be a plus

Supervisors: Stéphane Lanteri and Mahmoud Elsawy

Contact: mahmoud.elsawy@inria.fr

Duration: 6 months

Monthly stipend: ≈ 600 €

References

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