Thesis subject

***Title* : Advanced numerical modeling of nonlinear photonic components**
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The proposed thesis aims at the development of a powerful numerical code, based on the finite element method, to model nonlinear optical phenomena in highly resonant and multi-scale 3D photonic components. The emphasis will be put on the generation of second harmonic, sum and difference frequency, in promising components to realize high-performance optical sources.
Among these components, we are particularly interested in CRIGF, for Cavity Resonator Integrated Grating Filters [1,2]. They are formed by a sub-wavelength coupler grating of a few tens of periods placed between two Bragg gratings of several hundreds of periods, etched on a stack of thin layers of dielectric materials used as a waveguide. CRIGF have the ability to generate a strong electromagnetic field concentrated on about ten wavelengths. We are currently exploiting this property in a project funded by ANR and DGA (project RESON 2020-2023) to enhance second order nonlinear optical effects, in particular second harmonic generation [3]. The main targeted application is the creation of high-performance and compact optical sources in wavelength ranges where technological solutions are rare.
However, due to their multi-scale aspect and their highly resonant character, CRIGF are difficult to model numerically, even for the 2D case (invariance of the component in one direction). The 3D case is a real challenge. We currently have 3 numerical methods developed at the Institut Fresnel (Finite Element Method - FEM, Discrete Dipole Approach - DDA, Modal Fourier Method - FMM) to model 2D CRIGFs. To treat the 3D case, we wish to develop a 3D FEM code, in particular by using high order basic functions (necessary because of the high resonant character) and domain decomposition techniques (to treat the multi-scale aspect).
The thesis will be articulated around three parts, intertwined in time.
The first part, essentially at the beginning of the thesis, will be devoted to the training of the PhD student, according to two aspects: numerical modeling, finite element method on the one hand, and non-linear optics, resonant photonic structures on the other hand.
The second part will be devoted to the development of a 3D finite element software. On the basis of an already existing source code developed in our laboratory, the PhD student will focus his work on the implementation of new functionalities such as:
- The use of basic high-order functions dedicated to the diffusion of 3D objects.
- The use of high order basic functions dedicated to the diffusion of 3D objects. The extension to the 3D case of domain decomposition techniques (FETI method [5]), and its application to anisotropic materials.
- All digital developments will be considered in a parallel environment.
For this work, the PhD student will benefit from the Institut Fresnel's expertise in numerical modeling, whether on the finite element method [5], CRIGF modeling [4] or non-linear optical effects [3,6]. Moreover, in the framework of the RESON project, our objective is to develop in parallel another software based on the DDA method for the modeling of second harmonic generation in 3D CRIGF. Although less versatile, this DDA code will allow us to validate the FEM code by comparison.

Finally, in the third part, the study of second harmonic generation in 3D CRIGF will be possible. It will allow to identify the most promising 3D CRIGF configurations, by quantitatively estimating their second harmonic generation efficiency. At the end, we will be able to conclude on the contributions of 3D structuring compared to 2D structuring, in terms of non-linear efficiency, compactness of the structure, independence to the polarization of the component...
For these studies, we will pay particular attention to the compatibility of configurations with manufacturing constraints and uncertainties. For this, the work of the PhD student will benefit from the framework of the RESON project, in particular from the collaboration with the experimenters of LAAS-CNRS (Toulouse) involved in the project. Thus, components can be manufactured and characterized at LAAS-CNRS, providing an additional means of validation of the numerical code.

References

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