PhD available position
Theory and numerical modeling of photonic resonances

Laboratory: Institut Fresnel, Marseille
Advisors: **André Nicolet** and **Philippe Lalanne** (LP2N-Bordeaux co-advisor)

Context :
This PhD thesis will take place within the framework of the ANR-16-CE24-0013 RESONANCE project (Theory and numerical modeling of optical resonance), joining Laboratoire Photonique Numérique et Nanosciences IOGS-LP2N in Bordeaux UMR 5298 (Philippe Lalanne, project coordinator), Institut Fresnel in Marseille UMR 7249 (André Nicolet, local project manager), and Laboratoire Charles Fabry IOGS-LCF in Paris UMR 8501(Christophe Sauvan, local project manager).

The PhD student will primarily work at Institut Fresnel in Marseille

Short description of the ANR RESONANCE project:
Since photons weakly interact with matter, electromagnetic resonators are ubiquitous to many science and technology developments over the entire electromagnetic spectrum. The last fifteen years have seen the emergence of completely novel micro/nano resonators for operation at optical frequencies. Two emblematic examples are high-Q photonic-crystal resonators with wavelength-cube mode volumes and more recently low-Q plasmonic nanoresonators, which offer deep subwavelength mode volumes and represent a promising route to interface optics and nanosciences/technologies.
However, optical resonators are open systems that are often made of absorbing and dispersive materials. Their rigorous electromagnetic modeling remains immature. Indeed, their analysis and design should essentially rely on the concept of resonance modes, the natural modes of the resonator that are also called quasi-normal modes (QNMs) with a complex frequency, but in practice one uses classical Maxwell's equations solvers that are operating at real frequencies or time domain. They are extremely demanding in computational resources and are not helping much getting intuition, other than through the analysis of the computed results. **In sharp contrast with waveguides for instance, for which a modal theory is well-established, there is a large gap between our way to conceptualize resonators and our numerical tools to design them.**
The objective of the RESONANCE project is to radically change this perspective and to close the gap between concepts and modeling tools in a lasting way.

PhD work in ANR RESONANCE project:
The thesis work will encompass:
A theoretical contribution: we will try to answer fundamental questions about the nature of the radiation QNMs belonging to the continuum, understand mathematically under what condition leaky and radiation QNMs may form a complete set, and explore the critical factors limiting their calculation by discretizing finite-dimensional spaces. This study will lay the foundations to the domain.
A numerical contribution: we will elaborate rigorous formulations based on finite-element methods (FEM) to calculate and normalize QNMs for arbitrary geometries. The entire effect of material dispersion will be taken into account by auxiliary fields (or by an alternative method such as a direct numerical linearization) and all the QNMs will be calculated with a single diagonalization, just like for non-dispersive media. We will implement the FEM formulations and release an efficient open-access Computational Code to calculate QNMs for the most general case of materials with absorption, anisotropy, chirality... This work will

rely on the open source software OneLab/Gmsh/GetDP environment (see onelab.info, gmsh.info, getdp.info). The software development itself will not require a large amount of coding since the software environment provides high level script languages and only limited modifications of source codes will be necessary.

A benchmarking: Finally, we will promote the software by benchmarking it against classical approaches on modern examples of photonics. We expect to reach computational speeds that are several orders of magnitude faster than those of current solvers, while maintaining a very good accuracy. The benchmarks will provide an opportunity to develop post-processing toolboxes for helping potential users to efficiently use the software in the study of advanced photonic problems.

On the whole, we will show that the proposed numerical tool is intrinsically elegant/helpful since it sticks to the physics of resonant systems and is perfectly suited for both the initial design and optimization of resonant devices. We expect this unique combination to lastly impact the methodology and the conceptualization of electromagnetic resonators.

Requested knowledge and skills:

Electrodynamics, Numerical Modelling (experience in Finite Element Modelling with Maxwell's equations and/or in numerical computation of eigenvalues is an asset), Nanophotonics, Applied Mathematics, Computer Programming (C++, Python…) and use of numerical linear algebra libraries (PETSc, SLEPc…).

Some important references are in the PhD context are

"Theory of the spontaneous optical emission of nanosize photonic and plasmon resonators"
C. Sauvan, J.P. Hugonin, I.S. Maksymov and P. Lalanne, Phys. Rev. Lett **110**, 237401 (2013).
"Quasimodal expansion of electromagnetic fields in open two-dimensional structures"
B. Vial, A. Nicolet, F. Zolla, M. Commandré, Phys. Rev. A **89**, 023829 (2014)