On-chip particle accelerators: studies of photonic structures

Internship in photonics. Master 2 level. Start from March 2021

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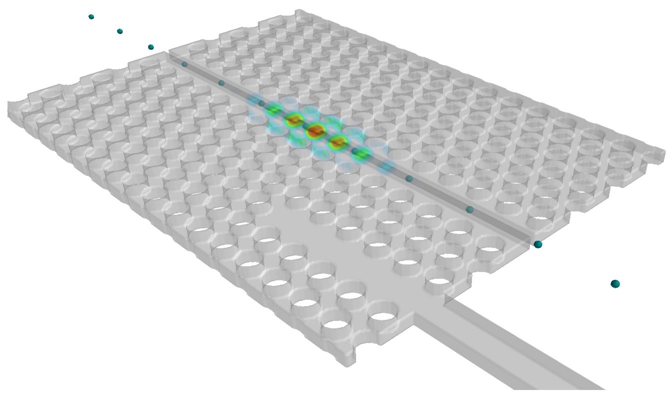
Recent advances in nanophotonics provide new opportunities for studying the interactions between an electron beam and optical modes confined in microcavities or waveguides. In this context, several designs of dielectric laser accelerators on chip have been developed [1-2]. This type of accelerators has many potential applications, for example in physics with the realization of compact accelerators and in medicine with the generation of particle beams for oncology treatments, advanced imaging or isotope production.

During this internship, we will focus on the study of optical modes confined in an optical microstructure able of accelerating an electron beam, such as a slot waveguide or a photonic crystal (PhC) cavity. These structures, which can be made in silicon [3] or in diamond [4], make it possible to obtain extremely intense fields because of their low modal volume (of the order of a few wavelengths to the cube) and offer a strong potential for acceleration. Thus, for an energy corresponding to a single photon stored in a photonic crystal cavity in the state of the art, the electric field can reach the MV/m.



Schematic diagram of a photonic crystal accelerator. Electrons enter the PhC through the trench. They interact with the optical mode in the center of the PhC which measures here 10 microns. The light can be injected thanks to the guide coupled to the cavity (bottom)

A first part of the work will consist of a bibliographic study in order to become familiar with the different necessary concepts of this rapidly evolving field. The electromagnetic modes propagating in a typical photonic structure will then be simulated using the tools available in the laboratory. In particular, the acceleration capacities of the structures will be evaluated by semi-analytical and numerical methods. Optical characterizations of previously realized photonic structures will be carried out in order to compare, by imaging, the simulated optical modes and the modes obtained in the sample produced as well as their dispersion relation. Finally, new designs of photonic structures will be proposed with enhanced acceleration properties. Acceleration tests will be done with our collaborators from the Laboratory of Solid Physics (LPS).

The student will acquire skills in advanced electromagnetism and photonics: i) in simulation and analysis of complex micro-structures (finite difference in the time domain (FDTD) spectral method, coupled modes theory, …) and ii) in Optical characterization of nano-devices (measurement of resonances, mode imaging, ...).

This internship can continue with a PhD thesis, where the aspects of fabrication and systematic characterization of the accelerators will be studied (fundings : doctoral school EOBE, ANR project, ...).

[1] R. Joel England et al. « Dielectric laser accelerators », Review of Modern Physics 86(4):1337-1389 · (2014)
[2] N. V. Sapra et al., “On-chip integrated laser-driven particle accelerator”, Science 367(6473), pp. 79-83 (2020)
[3] Z. Han, X. Checoury, D. Néel, S. David, M. El Kurdi, and P. Boucaud, Optics Communications 283, 4387 (2010).
[4] C. Blin, X. Checoury, et al., Advanced Optical Materials,1: 963-970 (2013)