Proposition de SUJET DE STAGE M2R/Ingénieur-3A

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"Artificial intelligence models for opto-mechanical silicon metamaterials"

SCIENTIFIC PROJECT:

Stimulated Brillouin scattering (SBS), mediating (THz) photons and (GHz) acoustic phonons, has an immense potential for opto-acoustic signal processing which have no analogue in conventional electro-optic or all-optic approaches. Namely, SBS has shown ultra-high-resolution filtering and remarkable low noise signal regeneration. Furthermore, the narrow linewidth and low phase noise of Brillouin lasers, make them an ideal solution for high-performance micro-wave signal generation.

SBS has been extensively developed in optical fibers, however the phonon leakage towards the cladding in conventional silicon-on-insulator (SOI) waveguides precluded the observation of SBS in Si photonics. However, **the recent development of a new generation of Si optomechanic waveguides** (see Fig. 1) **has removed this barrier, revolutionizing the field** and allowing the experimental demonstration of SBS nonlinearities surpassing Kerr and Raman effects (in 2013 [1]), complete phononic bandgap (in 2014 [2]), net amplification (in 2016 [3]), and Si Brillouin laser (in 2017 [4]). Still, **fully exploiting the potential of these Brillouin optomechanical interactions in silicon requires of novel design strategies and, and advanced design tools allowing their optimization.**

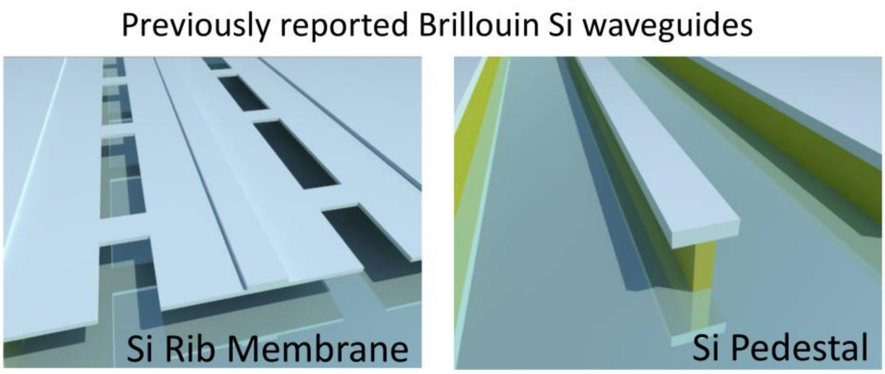

Fig. 1: *Schematic of previously reported Si Brillouin waveguides based on partial removal of the oxide cladding (left panel) and pedestal geometry (right panel).*

Patterning Si with features at the subwavelength scale (well within the capabilities of standard large volume fabrication processes) has recently been proven to be a simple and powerful tool to implement metamaterials with engineered properties [5,6,7] and to optimize optomechanical coupling [8]. Nevertheless, the field of silicon optomechanic metamaterials exploiting subwavelength nanostructuration is still in its infancy. **Optimizing optomechanic metamaterial geometries stands as a multi-physics, multi-variable and multi-target problem, ideally suited for advanced design techniques based on artificial intelligence and machine learning algorithms**, mainly gradient boosted trees [9].

The goal of this internship is to develop artificial intelligence models to harness the unique degrees of freedom of subwavelength Si nanostructures to independently tailor photonic and phononic modes, providing simultaneous tight confinement and strong overlap, thus maximizing the efficiency of the SBS effect.

The research activity will include theoretical study to understand artificial intelligence optimization methods and the key parameters governing sub-wavelength engineered waveguides, simulation work to extract main relationships between geometrical parameters and properties of the waveguide, and experimental characterizations of novel sub-wavelength structures. During the internship, the student will be actively involved in the current research activity of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities.

This project can be continued and expanded as a PhD.

METHODOLOGY OF THE STAGE

1) Bibliography study: Reading of a pre-selection of the main papers related to the topic, e.g. [5], to understand the physical principles of sub-wavelength engineering or [8] to understand artificial-intelligence-based optimization.

2) Simulation of sub-wavelength optomechanic waveguides: Optical and mechanical analysis of sub-wavelength waveguides using commercial software (Lumerical, Comsol) and numerical tools developed by MIT (MEEP, MPB).

3) Experimental characterization of sub-wavelength photonics structures: Linear and nonlinear optical and optomechanic characterizations of novel sub-wavelength waveguides.

VALUED QUALITIES IN THE STUDENT

- Curiosity for novel research experiences and fields.

- Creativity and pro-activity in the search for innovative solutions and approaches.

- Capability to communicate and share results in a multidisciplinary and multi-nationality environment.

BIBLIOGRAPHY RELATED TO THE TOPIC

[1] H. Shin et al. "Tailorable stimulated Brillouin scattering in nanoscale silicon waveguides," *Nat. Commun*. 4, 1944 (2013). https://doi.org/10.1038/ncomms2943

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[3] E. A. Kittlaus et al. "Large Brillouin amplification in silicon," *Nat. Photon.* 10, 463 (2016). https://doi.org/10.1038/nphoton.2016.112

[4] N. T. Otterstrom et al. "A silicon Brillouin laser," *Science* 360, 1113 (2018). https://doi.org/10.1126/science.aar6113

[5] R. Halir et al. "Waveguide sub-wavelength structures: a review of principles and applications," *Laser Photonics Rev.* 9 (1), 25 (2015). https://doi.org/10.1002/lpor.201400083

[6] C. Alonso-Ramos, et al. "Diffraction-less propagation beyond the sub-wavelength regime: a new type of nanophotonic waveguide," *Sci. Rep.* 9(1), 5347 (2019). https://doi.org/10.1038/s41598-019-41810-0

[7] P. Cheben et al. "Subwavelength integrated photonics," *Nature* 560, 565 (2018). https://doi.org/10.1038/s41586-018-0421-7

[8] J. Zhang et al. "Subwavelength engineering for Brillouin gain optimization in silicon optomechanical waveguides," *Opt. Lett.* 45, 3717 (2020). https://doi.org/10.1364/OL.397081

[8] D. Melati et al. "Mapping the global design space of nanophotonic components using machine learning pattern recognition," Nat. Comm. 10, 4775 (2020). https://doi.org/10.1038/s41467-019-12698-1