Proposition de SUJET DE STAGE M2R/Ingénieur-3A

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"Metamaterial optomechanic waveguides for silicon Brillouin laser"

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 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]).

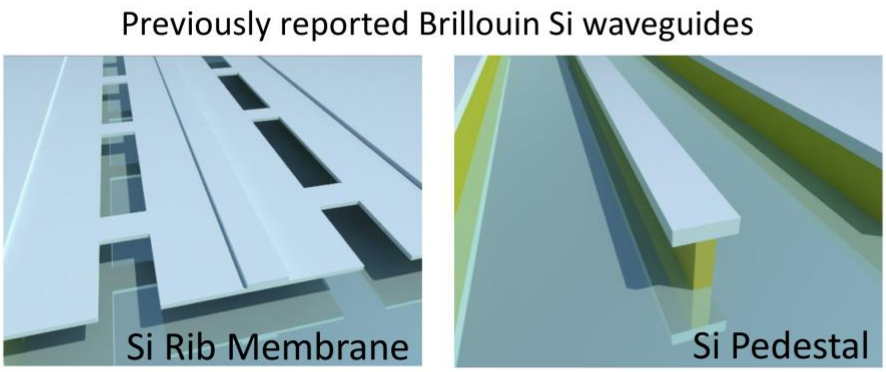

Fig. 1: *Schematic of previously reported Si Brillouin waveguides based on partial removal of the oxide cladding (left panel) and pedestal geometry (right panel).*

Although very promising, the first demonstration of Si Brillouin laser relies in fully suspended Si rib membranes with moderate SBS gain. Thus, it requires few centimeters long waveguides, which compromise the compactness and robustness of the solution. Indeed, the SBS gain is tightly related to the phonon lifetime and the overlap between photonic and phononic modes. Fully suspended Si rib membranes (see Fig. 1, left) exploit the large acoustic impedance mismatch between silicon and air to confine phonons along the Si slab, minimizing leakages (and maximizing phonon lifetime). Still, in this configuration photons are mainly confined within the central Si rib, resulting in a limited photon-phonon overlap. On the other hand, Si pedestal waveguides (see Fig. 1, right) have been demonstrated that tightly confine photons and phonons within the waveguide core, yielding an outstanding photon-phonon overlap. However, phonon lifetime is limited by leakage through the silica pillar. The trade-off between photon lifetime and photon-phonon overlap in Brillouin Si waveguides limits the SBS gain, and thus the potential of these approaches.

Concurrently, 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].

The goal of this internship is 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 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 within the frame of an JCJC ANR project, BRIGHT, on the development of Si Brillouin lasers.**

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.

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

[2] J. Gomis-Bresco et al. "A one-dimensional optomechanical crystal with a complete phononic band gap," *Nat. Commun.* 5, 4452 (2014). https://doi.org/10.1038/ncomms5452

[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