Proposition de SUJET DE STAGE M2R/Ingénieur-3A

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"Subwavelength nanostructured Si photonic devices enabled by advanced immersion lithography"

SCIENTIFIC PROJECT:

Driven by the impressive development in the nanofabrication technologies and the nanoscale engineering, **silicon photonics has rapidly become the platform of choice for on-chip integration of high performing photonic devices**. At the beginning, these photonic circuits mainly targeted the realization of ultra-wideband transceivers for datacom applications, e.g. in big datacenters. However, this enormous technology development has opened new opportunities for Si photonics beyond datacom, with a growing interest in sensing [1], microwave photonics [2] and quantum photonics [3] applications. In this context, **metamaterial photonics has seen an outstanding progress**, particularly in nanostructured engineered materials: metamaterials, metallic and dielectric subwavelength structures and subwavelength engineered waveguides. **The novel optical properties found in these structures, along with the capability to control their optical responses, has opened new prospects for controlling and manipulating light in planar waveguide circuits** [4-6]. Since the early demonstrations of a silicon wire waveguide with subwavelength grating (SWG) metamaterial core, metamaterial SWG waveguides have attracted a strong research interest in academia and industry because of their unique potential to control light propagation in planar waveguides. Periodically patterned silicon waveguides with a pitch smaller than half of the propagating wavelength effectively suppress diffraction, enabling development of metamaterials with properties that are between those of the Si and the cladding material.

The new degrees of freedom in tailoring dispersion and confinement, released by subwavelength nanostructuring allowed the demonstration of various devices with unprecedented performance, including fiber-to-chip couplers, ultra-wideband power splitters and mode converters, and narrowband wavelength filters, to name a few. Still, the flexibility in engineering of these metamaterial devices has been restricted by the limitations of current lithography processes, namely minimum feature size and propagation losses arising from fabrication imperfections. **The recent development of advanced immersion lithography techniques enables substantially smaller feature sizes in silicon with unprecedented precision**. This technological advancement has opened a unique opportunity to fully exploit the potential of subwavelength engineering, releasing new degrees of freedom to engineer optical properties in silicon devices.

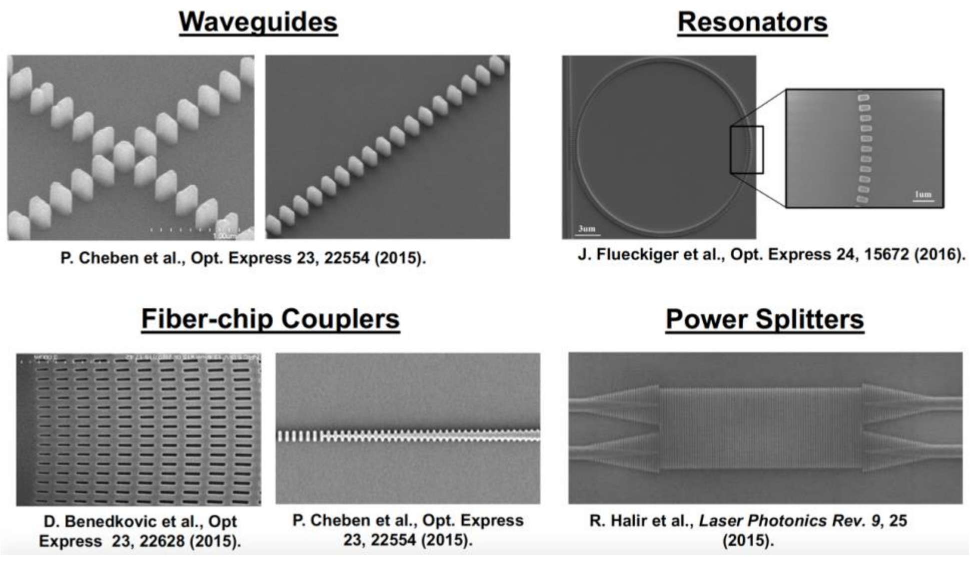

Fig. 1: Examples of key building blocks based on sub-wavelength engineering, with performances and functionalities that go far beyond what is possible with standard approaches.

The goal of this stage will be to design and experimentally characterize different subwavelength engineered photonics components leveraging advanced immersion lithography fabrication.

The research activity will realized in close collaboration with CEA Leti and can be extended in the form of a PhD. The work 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.

METHODOLOGY OF THE STAGE

1) Bibliography study: Reading of a pre-selection of the main papers related to the topic, e.g. [4], to understand the physical principles of sub-wavelength engineering.

2) Simulation of sub-wavelength waveguide structures: 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 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] M.-C. Estevez et al. “Integrated optical devices for lab-on-a-chip biosensing applications,” *Laser Photonics Rev.* 6, 463–487 (2012). https://doi.org/10.1002/lpor.201100025

[2] J. Capmany and D. Novak, “Microwave photonics combines two worlds,” *Nature Photon.* 1, 319–330 (2007). https://doi.org/10.1038/nphoton.2007.89

[3] J. W. Silverstone et al. "On-chip quantum interference between silicon photon-pair sources," *Nat. Photon.* 8, 104–108 (2014). https://doi.org/10.1038/nphoton.2013.339

[4] R. Halir et al. “Waveguide sub-wavelength structures: a review of principles and applications,” *Laser Photonics Rev.* 9(1), 25-49 (2015). https://doi.org/10.1002/lpor.201400083

[5] 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

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