PhD topic proposal (2024) – open as a Joint PhD project (cotutelle)

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"Silicon nanophotonics integrating two-dimensional materials with giant nonlinear properties"

Research project description:

This thesis is in the field of silicon photonics [1]. The integration of various materials and the possibility of realising a wide range of functions through the advanced miniaturisation of guided optics offer very broad opportunities for a continuum of studies ranging from fundamental physics to applications. The elementary component of silicon photonics is, of course, the waveguide. In the near infrared at wavelengths of 1500nm, such a waveguide typically has to have dimensions of less than 200nm×500nm to remain single-mode, which leads to very large integration possibilities (hundreds of optical structures, at the very least, on 1 mm^2) (see **Fig. 1**).

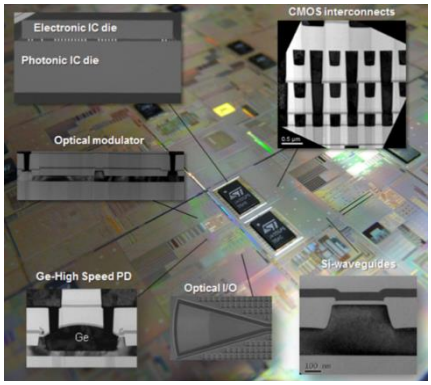

Fig. 1: Silicon photonic integrated structures
From: David Thomson, et al. Roadmap on silicon photonics. Journal of Optics, b18(7):073003, 2016. Link

The topic of this thesis is the integration of two-dimensional mono-atomic materials (graphene, MoS_2, WS_2) with a view to overcoming limitations of silicon or silicon nitride (SiN) traditionally used to make waveguiding structures. By integrating 2D materials on photonic waveguides, as illustrated in a particular configuration in **Fig. 2**, it is possible to exploit some of their exceptional physical properties to control the propagation of guided modes, whose interaction (overlap) with 2D materials can be exploited and optimised. This approach opens up a vast field of possibilities, ranging from the study of the physical properties of 2D materials to applications. The thesis will focus in particular on the study of the second order non-linear optical properties of these materials, with a view to demonstrating optical waveguides and resonators that exploit their electro-optical properties. The aim will be to develop a series of studies aimed at understanding the influence of the number of atomic monolayers and their orientation, and to propose, produce and characterise phase modulators and electro-optical modulators based on this hybrid integration approach. This work will be carried out in collaboration with Professor Zhipei Sun's group (Aalto University, Helsinki, Finland), which has internationally recognised expertise in the field of two-dimensional materials.

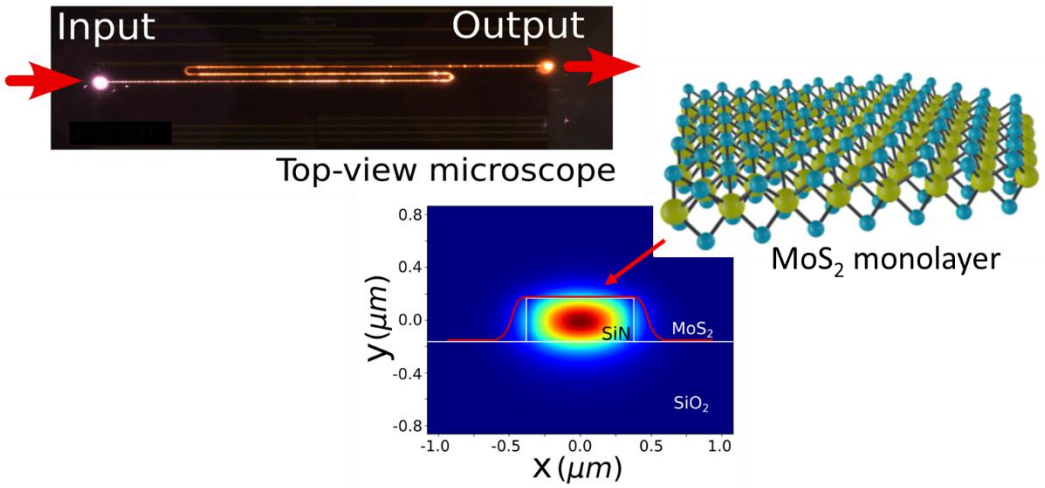

Fig. 2: General principle for the integration of nanomaterials with silicon photonic waveguides

The PhD thesis project is part of an international PhD cotutelle application and draws on the complementary expertise of two research groups:
- Paris-Saclay university (C2N - Palaiseau / France): an expert group in optics/photonics and supported by a micro-fabrication clean room **(Fig. 3)**,
- Aalto university (Helsinki / Finland): expert group in materials science.

Half of the thesis will be carried out on each site according to a schedule to be defined later in the service of the scientific project. The person recruited will therefore evolve in an international context and will be trained in contact to two French and Finnish teams which know each other very well **[2-4]** as well as through the cultures and methods of doctoral trainings at the two universities. A final single PhD defense and a single manuscript will lead the PhD candidate to get the PhD degrees of the two universities.

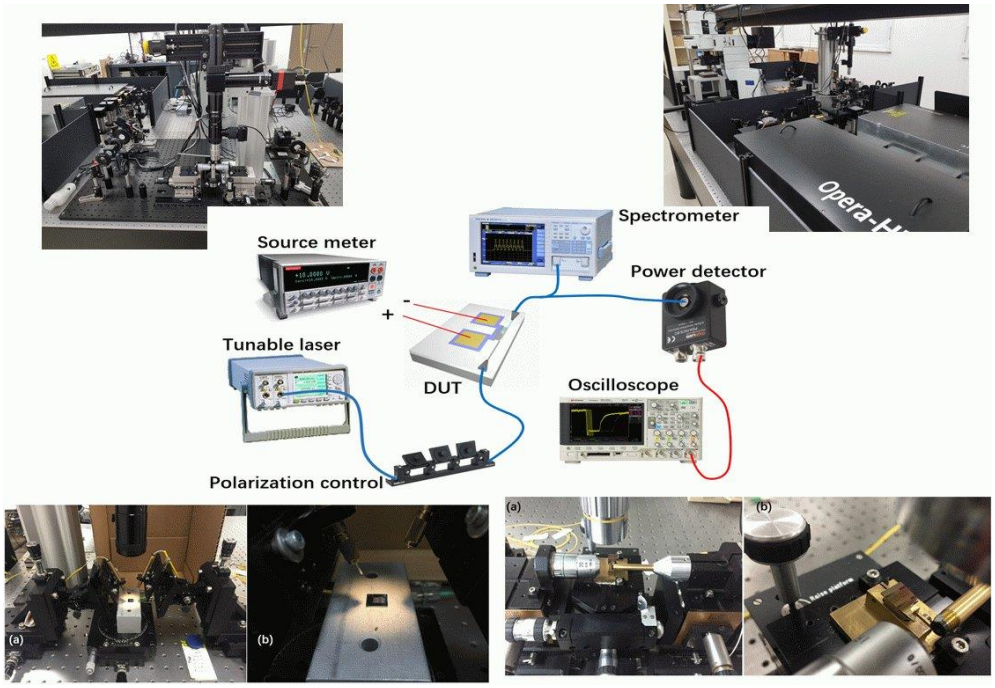

Fig.3: Some illustrations of the experimental facilities available at the C2N laboratory host team / UPSaclay-CNRS.

We expect from you:

- Enthusiasm and strong involvement in your project, a growing autonomy, and the ability to address your topic as a project with milestones and deliverables
- Taste for **Material Science** and **Optics&Photonics**, including experiments and simulation
- Ability to communicate and work in a group, an open-minded attitude and an ability to conduct a project by addressing questions to relevant people around you

For any questions, to ask for references, and to apply:

eric.cassan@universite-paris-saclay.fr

References:

[1] **"Roadmap on silicon photonics"**
David Thomson, Aaron Zilkie, John E Bowers, Tin Komljenovic, Graham T Reed, Laurent Vivien, Delphine Marris-Morini, Eric Cassan, Léopold Virot, Jean-Marc Fédéli, et al.
Journal of Optics, Volume 18 (7), 073003, https://iopscience.iop.org/article/10.1088/2040-8978/18/7/073003

[2] **"Hybrid integration of 2D materials for on-chip nonlinear photonics"**
Vincent Pelgrin, Hoon Hahn Yoon, Eric Cassan, Zhipei Sun
Light: Advanced Manufacturing (2023), 4:14 - https://doi.org/10.37188/lam.2023.014

[3] **"Ultra-high on-chip optical gain in erbium-based hybrid slot waveguides"**
J. Rönn, W. Zhang, A. Autere, X. Le Roux, L. Pakarinen, C. Alonso-Ramos, A. Säynätjoki, H. Lipsanen, L. Vivien, E. Cassan, Z. Sun, **Nature Communications**, 10:432 (2019), https://doi.org/10.1038/s41467-019-08369-w

[4] **"Erbium-doped hybrid waveguide amplifiers with net optical gain on a fully industrial 300 mm silicon nitride photonic platform"**
John Rönn, J. Zhang, W. Zhang, Zhengrui Tu, Antti Matikainen, X. Leroux, E. Durán-Valdeiglesias, N. Vulliet, F. Boeuf, C. Alonso-Ramos, H. Lipsanen, L. Vivien, Z. Sun, E. Cassan, **Optics Express**, 28 (19), pp. 27919-27926 (2020) - https://doi.org/10.1364/OE.399257