

LIGHTinPARIS		Marie Skłodowska-Curie Actions Second call for COFUND PhD fellowships
Employer	University Paris-Saclay	
Doctoral School	EOBE	
Domain	EOBE (Electrical, Optical, Bio-Physics and Engineering)	
Supervision		
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PHD THESIS PROJECT		
OSER - Optical SourcEs in silicon photonics: the Rare-earth approach (OSER)		
Summary / Abstract		
The research proposal is focused on the investigation of a specific class of light sources exploiting rare earth materials directly integrated in hybrid optical silicon (nitride) waveguides for the realization of strongly miniaturized optical amplifiers and lasers on a chip. The approach to be developed is based on an ambition to push the miniaturisation of fibre optical amplifiers and lasers to the extreme with a view to their total integration in silicon photonics, which will lead to a dramatic reduction in the light/matter interaction lengths and an increase of at least three orders of magnitude in the effective doping levels of the materials. Previous works from the collaborators (Université Paris-Saclay/C2N and Aalto University/Department of Electronics and Nanoengineering) have demonstrated the possible integration of Erbium-doped Al₂O₃ layer stacks with integrated silicon nitride waveguides. This approach will be broadly extended to account for new possibilities. Principal 3i dimension: international Keywords • Information and Communication Technologies (optoelectronics, optical fibers...) • Nanophotonics (plasmonics, metamaterials, 2D materials, surfaces and interfaces, optomechanics) • Materials (inorganic, semiconductor, organic, liquid crystal, photochromics) • Lasers		

OSER - Optical SourcEs in silicon photonics: the Rare-earth approach (OSER)

Key Objectives

- Fabrication of ultra-low loss Si₃N₄ waveguides ($\ll 1\text{dB/cm}$)
- Demonstration of the optical gain of active Si₃N₄ waveguides coated with active layers doped with rare-earth materials
- Innovative resonators design for the realization of integrated lasers in silicon photonics
- Demonstration of rare-earth doped active waveguide lasers
- Development of on-chip applications

Project

Context and state-of-the-art of Scientific Research project

The research proposal lies in the field of silicon photonics. The integration of various materials and the possibility of realising a wide range of functions through the advanced miniaturisation of guided wave optics offer very broad opportunities for a continuum of studies ranging from fundamental physics to applications. The compatibility with the silicon technological processes moreover opens up the perspectives to target large-scale applications. In this perspective, the development of integrated light sources compatible with this technological platform is of tremendous importance and has been the focus of intense research activities for years [1].

Description

In this context, the research proposal is focused on the investigation of a specific class of light sources exploiting rare earth materials directly integrated in hybrid optical silicon (nitride) waveguides for the realization of strongly miniaturized optical amplifiers and lasers on a chip. The exploited physical principle relies on the stimulated emission process in rare-earth doped materials. The approach to be developed is based on an ambition to push the miniaturisation of fibre optical amplifiers and lasers to the extreme with a view to their total integration in silicon photonics, which will lead to a dramatic reduction in the light/matter interaction lengths (from tens of meters to tens of hundreds of μm) and an increase of at least three orders of magnitude in the effective doping levels of the materials.

Methodology:

- Develop and optimize ultra-low loss optical Si₃N₄ waveguides ($\ll 1\text{dB/cm}$ and resonators with $Q > 1\text{million}$)
- Extensively investigate the active species available and the host materials available (eg Al₂O₃, TaO₂, etc) for coating silicon nitride optical waveguides
- Experimentally evidence active waveguides with a net optical gain
- Investigate possible dielectric resonators and optimize them for demonstrating on-chip lasing

Bibliography

[1] "Roadmap on silicon photonics", D. Thomson, A. Zilkie, J. E Bowers, T. Komljenovic, G. T Reed, L. Vivien, D. Marris-Morini, E. Cassan, L. Viot, J.-M. Fédéli, et al., Journal of Optics 18 (7), 073003, <https://iopscience.iop.org/article/10.1088/2040-8978/18/7/073003>

[2]“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>

[3]Zhang, Hao et al. “Atomic-Layer Engineered Erbium-Doped Waveguide Amplifier with a 14.4 dB Net Gain.” ACS Photonics (2024) – <https://pubs.acs.org/doi/10.1021/acsp Photonics.4c01466>

Facilities and quality of research environment available for the researcher

The recruited PhD student at the Centre for Nanoscience and Nanotechnology (C2N, UMR 9001) will benefit from an outstanding scientific and technical environment to carry out their research. The C2N features a large cleanroom dedicated to micro and nano-fabrication, equipped with state-of-the-art tools for the precise design, fabrication, and optimization of photonic and nanophotonic devices. This privileged access will enable the development of innovative structures using advanced lithography, etching, thin-film deposition, and other cutting-edge technologies.

In addition, the laboratory provides a wide range of experimental facilities for the detailed characterization of samples:

- Atomic Force Microscopy (AFM) for nanoscale topographical and morphological analysis; Scanning Electron Microscopy (SEM) for high-resolution imaging; Photoluminescence spectroscopy and Raman spectroscopy for studying the optical and vibrational properties of materials;
- Comprehensive nanophotonic characterization setups, including tunable lasers, ultra-sensitive detection systems, and optical benches tailored for the study of nonlinear phenomena or light amplification.

These facilities, combined with the expertise of C2N teams, offer an ideal framework for exploring fundamental concepts and developing applications in integrated photonics, optoelectronics, and quantum information. The PhD student will thus be able to conduct ambitious experiments, from fabrication to advanced characterization, within a stimulating and collaborative ecosystem.

He/she will also benefit from the complementary expertise of the Aalto research team.

3i Dimension - international

Description and expected outcomes

International expertise of the two supervisors:

- Eric Cassan has supervised/co-supervised more than 20 PhD projects and been involved in more than 25 funded French and European project in the last 20 years. His international network extends from Canada (NRC) and MIT/USA groups to European partners (Trento, Southampton, etc). He has already supervised 3 joint PhD theses (“Cotutelles de thèses”), among which one was with Pr. Zhipei Sun.
- Zhipei Sun has developed on his side links with a large set of European and international group. As a full professor at Aalto university, he has supervised many PhD projects in the recent years. A map of his international network can be seen here: <https://research.aalto.fi/en/persons/zhipei-sun/network-map/>

The PhD candidate will interact with the two groups and will benefit from a research-training made in an international context between France and Finland.

Approximate timeline of internships / external stays corresponding to the 3i dimension

- **Year 1 (October 2026 – September 2027)**

The PhD project is structured as 36 months in France, with the timing of the visits in Finland determined based on the evolving research agenda. We favor this flexible approach over a rigid timeline, as it allows us to adapt to the scientific and technological needs of the project as they arise. Nevertheless, the PhD candidate will initially spend 6 months at Paris-Saclay University to establish the foundation of the research., and then 2 months in at Aalto, followed by 4 months at Paris-Saclay within the C2N.

- **Year 2 (October 2027 – September 2028)**

A similar schedule is foreseen for year 2: 10 months in France and 2 months in Finland

- **Year 3 (October 2028 – September 2029)**

A similar schedule is also foreseen for year 3: 10 months in France and 2 months in Finland.

Profile of PhD fellow

PhD studies and research work require curiosity, creativity, rigour, teamwork, and organisational skills. A minimum B2 level of English is mandatory. The below criteria are specific to the thesis project.

pre-requisite	Academic background should cover a deep knowledge of photonics and nonlinear optics. The applicant should be familiar with integrated waveguide design including the management of waveguide mode dispersion, field overlaps, perturbative approaches, etc
pre-requisite	He/she should also have skills to conduct lab experiments on nanophotonic optical setups, mastering the optical alignments on optical table assemblies, and being routinely able to post-process huge amounts of experimental data.
pre-requisite	He/she should be familiar with optical mode solvers, frequency domain solvers (e.g. Field mode matching) and time domain Maxwell solvers (e.g. FDTD). He/she should be familiar with the design of GDS mask of photonic waveguide structures and photonic circuits.
advantageous	Theoretical and / or experimental knowledge in semiconductor optics is welcome. Academic background should partially cover the field of material sciences
advantageous	Previous experience in clean room fabrication processes is not fully mandatory but is clearly a differentiating positive point

Ethics issues in the project as per Horizon Europe Ethics Self-assessment

Section 1. Human embryonic stem cells (hESCs) and human embryos (hEs)			No
Section 2. Humans	No	Section 3. Human cells and tissues	No
Section 4. Personal data	No	Section 5. Animals	No
Section 6. Third Countries	No	Section 7. Environment, health and safety	Yes
Section 8. Artificial Intelligence	No	Section 9. Other ethics issues	No
Section 10. Crosscutting issue: potential misuse of results			No

7. Environment, health and safety

All French labs are required to have health and safety procedures in place, which takes into account the use of high-energy light sources such as lasers of class 3 and above, and the use of hazardous / toxic chemical and biological products. The institution and the laboratory comply with the highest safety requirements and PhD fellows have mandatory health and safety training, with additional training if required.