Position Description

1. General Information

Name of the position	**Thin film lithium niobate nonlinear photonics**
Foreseen enrolment date	1 July 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • École Centrale de Lyon (EC Lyon) • Royal Melbourne Institute of Technology (RMIT)
Research Host	École Centrale de Lyon
PhD awarding institutions	École Centrale de Lyon & Royal Melbourne Institute of Technology
Locations	Primary: Ecully, France Secondary: Melbourne, Australia
Supervisors	Christelle Monat, Christian Grillet (ECL) Arnan Mitchell, Andy Boes, Thach Nguyen, Guanghui Ren (RMIT)
Group of discipline	Physics, Photonics, Nonlinear Optics

2. Research topics (only one of these projects will be funded)

Project 1: *Efficient nonlinear broadband supercontinuum light sources in strip-loaded LNOI*
Despite the high application potential of nonlinear optics for all-optical information processing, no nonlinear material candidate has emerged as a clear choice to complement silicon photonics so far. On the one hand, wide band gap semiconductors have been investigated, but their integration onto silicon photonics is not straightforward. Glass materials have also been explored, but their relatively weak nonlinearity precludes the realization of compact devices. Lithium niobate (LiNBO3) possesses both a second-order (c(2)) and third-order (c(3)) nonlinearity, which proves useful for both electro-optical modulation and also all-optical signal processing devices. Recently, thin-film lithium niobate on insulator wafers have become commercially available and emerged as a highly promising platform for integrated nonlinear optics. Most importantly, this platform supports tightly confining waveguide geometries, a boost for nonlinearities, while additionally opening opportunities for dispersion engineering, which is key to device efficiency and broadband processes, such as supercontinuum. In this context, RMIT has developed a complementary route towards high performance thin-film lithium niobate based devices that exploits strip loading of another thin film, silicon nitride

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(Si3N4) for instance, which is patterned instead of the lithium niobate so as to support low loss guided modes. This approach elegantly alleviates the need for lithium niobate patterning, while still offering relatively tightly confining geometries (Aeff ~2µm2) and the possibility to engineer the dispersion which is key for broadband supercontinuum.

The aim of this project will be to push this approach for broadband supercontinuum generation that can reach out to the mid-IR band (5um), where many molecules of importance for the defense and environment have strong absorption fingerprint. Part of the strategy will involve quasi phase matching with periodic poling of lithium niobate to increase the efficiency of difference frequency generation processes pumped at telecom wavelengths. This will be also used as a means to increase cascaded c(2) processes and further promote spectral broadening of the pump.

A.Boes et al., Lithium niobate photonics: Unlocking the electromagnetic spectrum.Science379,eabj4396(2023).DOI:10.1126/science.abj4396
Roy, A., Ledezma, L., Costa, L. et al. Visible-to-mid-IR tunable frequency comb in nanophotonics. Nat Commun 14, 6549 (2023). https://doi.org/10.1038/s41467-023-42289-0
C. Wang, *et al.* Integrated lithium niobate electro-optic modulators operating at CMOS-compatible voltages, *Nature* **562**, 101 (2018). https://doi.org/10.1038/s41586-018-0551-y
M. Zhang *et al.* Broadband electro-optic frequency comb generation in a lithium niobate microring resonator, *Nature* **568**, 373 (2019). https://doi.org/10.1038/s41586-019-1008-7
M. Jankowski *et al*. Ultrabroadband nonlinear optics in nanophotonic periodically poled lithium niobate waveguides, *Optica* **7**, 40 (2020).
Y. Okawachi *et al*. Chip-based self-referencing using integrated lithium niobate waveguides, *Optica* **7**, 702 (2020).
D. Zhu *et al*. Integrated photonics on thin-film lithium niobate, *Adv. Opt. Photon.* **13**, 242 (2021).

Supervisors:

Pr. Christelle Monat (EC Lyon, INL), Dr. Christian GRILLET (CNRS, INL),
Pr. Arnan Mitchell (RMIT), Dr. Andy Boes, Dr. Thach Nguyen, Dr. Guanghui Ren

Research Fields: Photonics, Integrated Nonlinear Optics, Supercontinuum, Frequency COMBS

Project 2: *Efficient nonlinear integrated microcombs in thin film LNOI*

Despite the high application potential of nonlinear optics for all-optical information processing, no nonlinear material candidate has emerged as a clear choice to complement silicon photonics so far. On the one hand, wide band gap semiconductors have been investigated, but their integration onto silicon photonics is not straightforward. Glass materials have also been explored, but their relatively weak nonlinearity precludes the realization of compact devices. Lithium niobate (LiNBO3) possesses both a second-order (c(2)) and third-order (c(3)) nonlinearity, which proves useful for both electro-optical modulation and also all-optical signal processing devices. Recently, thin-film lithium niobate on insulator wafers have become commercially available and emerged as a highly promising platform for integrated nonlinear optics. Most importantly, this platform supports tightly confining waveguide geometries, a boost for nonlinearities, while additionally opening opportunities for dispersion engineering, which is key to device efficiency and broadband processes, such as optical frequency combs. The combination of both c(2)and c(3) responses can, in contrast with silicon where only c(3) does exist, provide new ways of electrically tuning all-optical nonlinear functions. Furthermore, the birefringence of lithium niobate and ferroelectric domain inversion capabilities provide opportunities for phase matching and quasi phase matching, which is critical for frequency conversion processes, such as four-wave mixing or high-order harmonic generation.

The specific objectives of this PhD study will be (1) to exploit strip-loaded lithium niobate on insulator resonators to design and realize highly efficient c(3) nonlinear devices with anomalous dispersion for comb generation, (2) to experimentally demonstrate the integration of electro-optical modulators with c(3) ring resonators on a single chip, where the modulation frequency of the modulator can be tuned to match the free spectral range of the ring resonator, which will enable the efficient generation of optical frequency combs, (3) explore the alternative path offered by c(2) nonlinear optics via quasi-phase matching in lithium niobate for the generation of optical frequency combs and (4) use the c(2) response of lithium niobate to realize tunable nonlinear functions.

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Research Fields: Photonics, Integrated Nonlinear Optics, Frequency COMBS

Project 3: *Ultra-high Q factor lithium niobate resonators for mid-IR Kerr combs*

Despite the high application potential of nonlinear optics for all-optical information processing, no nonlinear material candidate has emerged as a clear choice to complement silicon photonics so far. On the one hand, wide band gap semiconductors have been investigated, but their integration onto silicon photonics is not straightforward. Glass materials have also been explored, but their relatively weak nonlinearity precludes the realization of compact devices. Lithium niobate (LiNBO3) possesses both a second-order (c(2)) and third-order (c(3)) nonlinearity, which proves useful for both electro-optical modulation and also all-optical signal processing devices [1]. Recently, thin-film lithium niobate on insulator wafers [2] have become commercially available and emerged as a highly promising platform for integrated nonlinear optics [3]. Most importantly, this platform supports tightly confining waveguide geometries, a boost for nonlinearities, while additionally opening opportunities for dispersion engineering, which is key to device efficiency and broadband processes, such as optical frequency combs [4,5]. In this context, RMIT has developed a complementary route towards high performance thin-film lithium niobate based devices that exploits strip loading of another thin film, silicon nitride (Si3N4) for instance, which is patterned instead of the lithium niobate so as to support low loss guided modes. This approach elegantly alleviates the need for lithium niobate patterning, while still offering relatively tightly confining geometries (Aeff ~2µm2) and the possibility to engineer the dispersion which is key for the generation of frequency combs.

While much has been done with the lithium niobate on insulator (LNOI) platform in the telecom band, this material is transparent up to the mid-IR and could support low loss modes up to about 5um, reaching out the spectral window where many biomolecules of importance for defence and environmental applications have strong molecular fingerprints. The aim of this PhD will be to design and fabricate high quality factor microresonators (microrings, microdisks or photonic crystal cavities) that can support low loss confined modes at these long wavelengths. These will be specifically engineered, using for instance photonic molecules consisting of coupled cavities, and adequate coupling strategies (e.g. using pulley waveguides) will be deployed to sustain optical Kerr microcombs in the mid-IR.

A.Boes et al., Lithium niobate photonics: Unlocking the electromagnetic spectrum.Science379,eabj4396(2023).DOI:10.1126/science.abj4396
Roy, A., Ledezma, L., Costa, L. et al. Visible-to-mid-IR tunable frequency comb in nanophotonics. Nat Commun 14, 6549 (2023). https://doi.org/10.1038/s41467-023-42289-0
C. Wang, *et al.* Integrated lithium niobate electro-optic modulators operating at CMOS-compatible voltages, *Nature* **562**, 101 (2018). https://doi.org/10.1038/s41586-018-0551-y
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Research Fields: Photonics, Integrated Nonlinear Optics, Mid-IR photonics	

3. Employment Benefits and Conditions

Ecole Centrale Lyon offers a 36-months full-time work contract (with the option to extend up to a maximum of 42 months). The employment contract includes a probation period of one month, which may be renewed once for a period not exceeding the initial duration. The total working hours per week is 35h.

The remuneration, in line with the European Commission's rules for Marie Skłodowska-Curie fellows, will consist of a gross monthly salary of EUR 2,142 in 2024. Of this amount, the estimated net salary to be received by the researcher is EUR 1,720 per month. However, the final amount to be received by the Researcher is subject to national tax legislation (approximately EUR 100 /month). This salary will increase during the thesis and should reach, on average, EUR 2,340 gross (i.e. EUR 1,870 net) per month.

Benefits include

- Becoming a Marie Skłodowska-Curie fellow and be invited to join the Marie Curie Alumni Association.
- Access to all the necessary facilities and laboratories at Ecole Centrale Lyon and RMIT, including potential access to other French research laboratories.
- Tuition fees exemption at both PhD awarding institutions.
- Yearly travel allowance to cover flights and accommodation for participating in AUFRANDE events.
- 10,000 EUR allowance to cover flights and living expenses for up to 12 months in Australia.
- 27 days paid holiday leave.
- French Social security coverage.
- Sick leave.
- Parental leave.

4. PhD enrolment

Successful candidates for this position will be enrolled by the following institutions and must comply with their specific entry requirements, in addition to AUFRANDE's conditions.

Applicants must hold a Master's degree that includes a research component comprised of at least 25% of a full-time academic year (or part-time equivalent) with an overall high distinction or a master degree without a research component with at least a high distinction average.

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Applicants will also need to meet English proficiency requirements: https://www.rmit.edu.au/study-with-us/international-students/apply-to-rmit-international-students/entry-requirements/english-requirements.

More information on EC Lyon's requirements

Foreign degrees are examined by the doctoral schools to determine whether they are equivalent to a Master's.

Important: the authorisation of the Defence Security Officer may be required before admission. In case of denial, the enrolment will not be carried out.

Visit the website: https://www.ec-lyon.fr/en/research/doctorate/admission-enrolment-doctorate

More information on RMIT University's requirements

Visit the website: https://www.rmit.edu.au/research/research-degrees/how-to-apply

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