Position Description

1. General Information

Name of the position	**Mid-Infrared integrated 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	Christian Grillet, Christelle Monat, Sebastien Cueff (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: *Fully reconfigurable chip-based Mid-IR supercontinuum source*
The Mid-infrared (Mid-IR) wavelength range - from 2.5 to 13 µm - is currently experiencing a huge surge in interest for an enormous range of applications that affect almost every aspect of our society, from compact and highly sensitive biological and chemical sensors, imaging, defense and astronomy. Despite their recognized potential, Mid-IR technologies are still limited in their range of applications, largely because of the size of the Mid-IR devices and the prohibitive costs of the instruments used due to the lack of compact Mid-IR optical devices and in particular compact and broadband sources despite recent breakthrough in integrated mid-IR supercontinuum sources. The PhD's project will address the current –bulkiness and tunability– challenges of the mid-IR supercontinuum technology through realizing a robust, reliable and miniaturized broadband supercontinuum source with highly tunable performance.

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement № 101081465

The two main objectives of the PhD's project will be to (see figure 1)
Obj 1: co-integrate a compact and powerful fiber-based optical pump with a highly nonlinear photonic chip
Obj 2: exploit electrically controlled phase change materials at the core of the device.

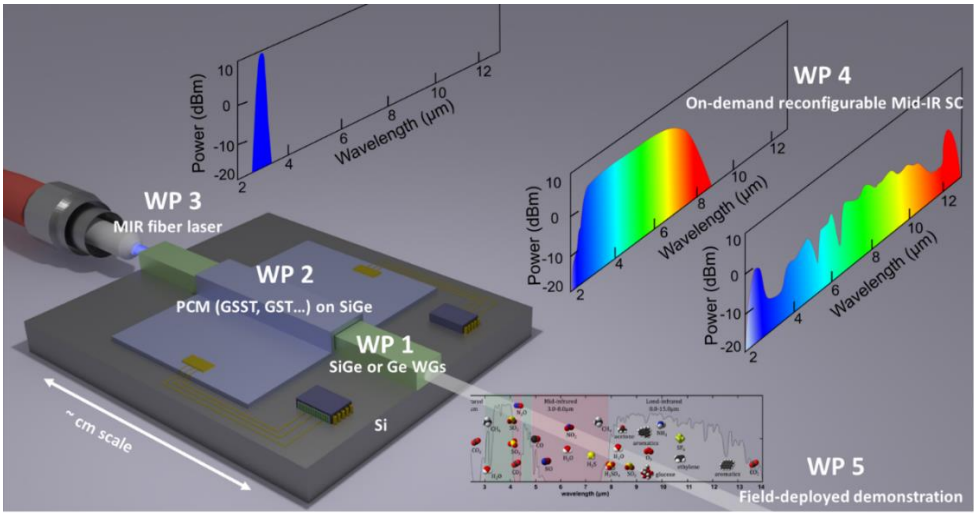

Figure 1 Scheme of the mid-IR hybrid fiber/chip architecture dynamically tuned with a PCM layer (credit A Della Torre)

[1] F. K. Tittel, D. Richter, and A. Fried, "Mid-Infrared Laser Applications in Spectroscopy," in Solid-State Mid-Infrared Laser Sources, (Springer Berlin Heidelberg, 2003).
[2] M. Sinobad, et al., Optica 5, 360 (2018).
[3] M. Sinobad, et al., J. Opt. Soc. Am. B 36, A98 (2019).
[4] M. Sinobad, et al., Opt. Lett. 45, 5008 (2020).
[5] A. Della Torre, *et al.*, "Mid-infrared supercontinuum generation in a low-loss germanium-on-silicon waveguide," APL Photonics 6, 06102 (2021), https://doi.org/10.1063/5.0033070

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

Project 2: *Mid-IR Optical Frequency Comb on a chip*

Research conducted at the beginning of the millennium on optical frequency comb generation was crowned in 2005 by the Nobel Prize in Physics awarded to John Hall and Theodore Haensch. The need for more compact, robust, and energy efficient sources offering high repetition rates (> 1 GHz) has favoured the emergence of a different approach to comb generation, based on nonlinear chip-based microresonators [1,2] that are manufactured by leveraging microelectronics processes and infrastructure. These "MicroCombs" have recently led to an explosion of record demonstrations, e.g. optical clocks on a chip [3], LIDAR [4], data transmission [5], neural networks [6], mostly using the Si3N4 or Hydex platform. INL/ CEA-Leti contributed to these efforts, with the development of Si3N4 dispersion engineered waveguides with very low loss [7], making possible the co-integration of combs with silicon optoelectronics [8] and the demonstration of an integrated Si3N4 comb source pumped by a butt-coupled DFB III-V laser (InGaAsP/InP) [9]. All these demonstrations are mainly centred around 1550 nm at telecom wavelength whereas many applications such as spectroscopy, gas

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detection, environmental surveillance, free space communication etc require combs in the mid-infrared (mid-IR - in the molecular fingerprint region beyond 3 µm).

Our first objective is to demonstrate **the first "Micro-comb" on a CMOS compatible platform to cover the actual mid-IR region.** We will exploit the SiGe and Ge platform to create highly nonlinear resonators in the mid-IR with high Q-factor, suitable dispersion and repetition rate (from tens GHz to few GHz FSR as required for direct gas sensing). **We will also explore other platforms like LNOI, LNOS or GaP.**

Our **second objective** is to demonstrate an on-chip dual-comb spectrometer operating in the mid-IR. We will aim at demonstrating the usefulness of these compact spectrometers for sensing applications such as pollution monitoring, breath analysis.

There will be opportunities to travel and interact with our partners on a national and international level (both Europe/France and Australia).

1. L. Razzari, et al. "CMOS-compatible integrated optical hyper-parametric oscillator," Nat. Photonics 4, 41-45 (2010).
2. T. J. Kippemberg, R. Holzwarth and S.A. Diddams, "Microresonators-based optical frequency combs," Science 332, 555-559 (2011)
3. S. A. Diddams, K. Vahala, T. Udem, *Science*, vol. 369, p. 267, 2020.
4.J. Riemensberger, A. Lukashchuk, M. Karpov, W. Weng, E. Lucas, J. Liu, T. J.Kippenberg, *Nature*, vol. 581, p. 164, 2020.
5.B. Corcoran, et al., *Nat. Commun.*, vol. 11, p. 2568, 2020.
6. X. Xu, et al., *Nature*, vol. 589, p. 44, 2021.
7. H. El Dirani, et al. Opt. Express 27, 30726-30740 (2019)
8.H. El Dirani, et al., Appl. Phys. Lett. 113, 081102 (2018); https://doi.org/10.1063/1.5038795
9. Sylvain Boust, Houssein El Dirani, et al., J. Lightwave Technol. 38, 5517-5525 (2020)

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Research Fields: Photonics, Integrated Nonlinear Optics, Frequency COMBS

Project 3: *Mid-IR Integrated Nonlinear Optics*

The Mid-infrared (Mid-IR) wavelength range - from 2.5 to 13 µm - is currently experiencing a huge surge of interest for an enormous range of applications that affect almost every aspect of our society, from compact and highly sensitive biological and chemical sensors, to imaging, defence and astronomy.

Despite their recognized potential, Mid-IR technologies are still limited in their range of applications, largely because of the bulky size of the Mid-IR devices and the prohibitive costs of the instruments used. Compact Mid-IR optical devices are indeed currently lacking and despite recent breakthroughs related to integrated mid-IR supercontinuum sources, compact and broadband sources in particular are critically missing.

Our strategy is therefore based on the development of an integrated hybrid Mid-IR platform, involving the miniaturization of optical components and their integration on a planar substrate made of materials with remarkable optical properties (particularly in terms of transparency and non-linearities) at MIR wavelengths like SiGe alloys, LiNbO3 or emerging III-V semi-conductors like GaP.
The student's project will focus on one of the fundamental issues of integrated Mid-IR, namely efficient and broadband MIR sources and their integration into an optical circuit. In this thesis, we will exploit nonlinear-phenomena over an unprecedented wavelength range (from visible to Mid-IR). The aim will be to develop an on-chip supercontinuum (and potentially combs) that can cover a broad wavelength span, from the visible to the mid-IR.
There will be opportunities to travel and interact with our partners on a national and international level (both Europe/France and Australia) including European industry (CEA-LETI and others).

[1] F. K. Tittel, D. Richter, and A. Fried, "Mid-Infrared Laser Applications in Spectroscopy," in Solid-State Mid-Infrared Laser Sources, (Springer Berlin Heidelberg, 2003).

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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.

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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.

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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