AUFRANDE

Position Description

1. General Information

Name of the position	**Advanced Soliton Physics in Integrated photonic circuits**
Foreseen date of enrolment	1 October 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • École Centrale de Lyon (EC Lyon) • The University of Sydney (U. Sydney)
Research Host	École Centrale de Lyon
PhD awarding institutions	École Centrale de Lyon & The University of Sydney
Locations	Primary: Écully/Lyon, France Secondary: Sydney, Australia
Supervisors	Pr. Christelle Monat (EC Lyon, INL), Dr. Christian GRILLET (CNRS, INL) Dr. Antoine Runge (U. Sydney)
Group of discipline	Physics, Photonics, Nonlinear Optics

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

Project 1: *Pure-Quartic Solitons in Integrated photonic platform for telecom band operation*
Optical solitons are wave packets that can propagate without changing shape[1]. These pulses have underpinned numerous applications, ranging from telecommunications and spectroscopy to ultrashort pulse generation. Conventionally, solitons rely on the balance between the Kerr nonlinearity and negative second-order dispersion ($\beta_2 < 0$) as it is the dominant dispersion effects in typical optical waveguides. However, the energy of such solitons is fundamentally capped by the soliton area theorem[2] leaving important high-energy, nonlinear applications out of reach. The Usyd group has recently observed and generated a novel class of optical solitons, called pure-quartic soliton (PQS)[3,4]. Unlike conventional solitons, they arise from the interplay between Kerr nonlinearity and negative fourth-order dispersion ($\beta_4 < 0$). Subsequent studies showed that PQSs can have substantially higher energy – by a few orders of magnitude, than conventional solitons, while offering the same coherence and stability. **This project aims to build on these recent discoveries, and to transfer this new physics of PQSs to integrated photonic platforms in the telecom band (~ 1.5 µm), i.e Microring resonators or dispersion engineered waveguides in Lithium Niobate or Si3N4 recently developed by INL/ CEA-Leti [5].** The direct on-chip generation of high-energy pulses, by using

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the enhancement, inherent to PQSs, instead of adding technological complexity, could unlock new nonlinear capabilities in integrated photonics.

The work will have elements of: (i) theory/waveguide design and (ii) optical characterization and device benchmarking using both experimental and numerical tools.

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).

References:

1. A. Hasegawa and F. Tappert, "Transmission of stationary nonlinear optical pulses in dispersive dielectric fibers. I. Anomalous dispersion," Appl. Phys. Lett. 23, 142-144 (1973).
2. V. E. Zakharov and A. B. Shabat, "Exact theory of two-dimensional self-focusing and one-dimensional self-modulation of waves in nonlinear media," Sov. Phys. -JETP 34, 62 (1972).
3. A. Blanco-Redondo et al., "Pure-quartic solitons," Nat. Comm. 7, 10427 (2016).
4. A. F. J. Runge et al., "The pure-quartic soliton laser," Nat. Photon. 14, 492 (2020).
5. H. El Dirani, (….) C. Monat et al. "Annealing-free Si3N4 frequency combs for monolithic integration with Si photonics" Appl. Phys. Lett. 113, 081102 (2018).

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

Project 2: *Pure-Quartic Solitons in Integrated photonic platform for Mid-Infrared applications*

Many applications such as spectroscopy, gas detection, environmental surveillance, free space communication etc require bright sources in the mid-infrared (mid-IR - in the molecular fingerprint region beyond 3 um).

The INL/CEA-Leti consortium (in collaboration with Australian Universities) has already demonstrated the ability to generate broad Mid-IR supercontinuum[1,2] based on soliton propagation (solitons generally rely on the balance between the Kerr nonlinearity and negative second-order dispersion $\beta_2 < 0$) in dispersion engineered integrated SiGe waveguides. However, the energy of such solitons is fundamentally capped by the soliton area theorem[2] leaving important high-energy, nonlinear applications out of reach.

The Usyd group has recently observed and generated a novel class of optical solitons, called pure-quartic soliton (PQS)[3,4]. Unlike conventional solitons, they arise from the interplay between Kerr nonlinearity and negative fourth-order dispersion ($\beta_4 < 0$). Subsequent studies showed that PQSs can have substantially higher energy – by a few orders of magnitude, than conventional solitons, while offering the same coherence and stability.

This project aims to build on these recent discoveries, and to transfer this new physics of PQSs to the SiGe integrated photonic platform in the Mid-IR band (between 3 and 13 µm) developed by INL/ CEA-Leti. The direct on-chip generation of high-energy pulses, by using the enhancement, inherent to PQSs, instead of adding technological complexity, could unlock new nonlinear capabilities and applications in this wavelength range.

The work will have elements of: (i) theory/waveguide design and (ii) optical characterization and device benchmarking using both experimental and numerical tools.

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).

References:

1. A. Della Torre, et al. (…) **C. Monat**, C. Grillet, "Mid-infrared supercontinuum generation in a low-loss germanium-on-silicon waveguide" APL Photonics6 , 016102 (2021)
2. M. Sinobad, **C. Monat**, (…), C. Grillet "High-brightness mid-infrared octave spanning supercontinuum generation to 8.5µm in silicon-germanium waveguides," Optica **5**, 360 (2018)
3. A. Blanco-Redondo et al., "Pure-quartic solitons," Nat. Comm. 7, 10427 (2016).
4. A. F. J. Runge et al., "The pure-quartic soliton laser," Nat. Photon. 14, 492 (2020).

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Project 3: *Pure-Quartic Solitons in Integrated active photonic crystal structures*

Optical solitons are wave packets that can propagate without changing shape[1]. These pulses have underpinned numerous applications, ranging from telecommunications and spectroscopy to ultrashort pulse generation. Conventionally, solitons rely on the balance between the Kerr nonlinearity and negative second-order dispersion ($\beta_2 < 0$) as it is the dominant dispersion effects in typical optical waveguides. The Usyd group has recently observed and generated a novel class of optical solitons, called pure-quartic soliton (PQS)[1,2]. These arise from the interplay between Kerr nonlinearity and negative fourth-order dispersion ($\beta_4 < 0$), providing substantially higher pulse energy – by a few orders of magnitude, than conventional solitons, while offering the same coherence and stability.

This project aims to build on these recent discoveries, and to transfer this new physics of PQSs to integrated photonic platforms in the telecom band (~ 1.5 µm) that include an active gain medium. Planar III-V photonic crystals will be explored to that aim, as they allow for a fine control of the underlying photonic dispersion by simply adjusting the position of the air holes that surround the linear defect. Such structures have been used to create slow light regimes conducive to enhance optical nonlinearities[3], but could also promote the existence of these PQSs. III-V Quantum wells will be combined with these new dispersion regimes, so as to investigate the opportunities of such promising photonic design structures for the generation of short optical pulses within compact platforms[4].

The work will have elements of: (i) theory/photonic design, (ii) device fabrication in clean room environment and (iii) optical characterization and device benchmarking using both experimental and numerical tools.

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).

References:

1. A. Blanco-Redondo et al., “Pure-quartic solitons,” Nat. Comm. 7, 10427 (2016).
2. A. F. J. Runge et al., “The pure-quartic soliton laser,” Nat. Photon. 14, 492 (2020).
3. B. Corcoran et al. “Green light emission in silicon through slow-light enhanced third-harmonic generation in photonic-crystal waveguides” Nature Photonics **volume 3**, 206–210 (2009)
4. M. Kemiche et al. “Design optimization of a compact photonic crystal microcavity based on slow light and dispersion engineering for the miniaturization of integrated mode-locked lasers” AIP Advances 8, 015211 (2018).

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3. Employment Benefits and Conditions

École Centrale de 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.

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The remuneration, in line with the European Commission's rules for Marie Skłodowska-Curie fellows, will consist of a gross monthly salary of EUR 2,044 in 2023. Of this amount, the estimated net salary to be received by the researcher is EUR 1,640 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 EC Lyon (INL) and RMIT University.
- 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.
- 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 performed at a high academic standard; or an equivalent qualification that demonstrates research experience, excellence and capability.

Applicants must prove their English language proficiency equivalent to an overall IELTS score of 6.5 with no band below 6.0 (see: https://www.sydney.edu.au/study/how-to-apply/international-students/english-language-requirements.html).

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

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More information on The University of Sydney´s requirements

Meeting the minimum requirements for eligibility does not guarantee admission. Admission remains at the discretion of the Associate Dean (Higher Degree by Research) for each faculty.

Visit the website: https://www.sydney.edu.au/courses/courses/pr/doctor-of-philosophy-science0.html

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