Position Description

1. General Information

Name of the position	**Next generation of fibers optics-based sensors for extreme environment applications**
Foreseen enrolment date	Between July and October 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • University Paris Saclay (UPSaclay) • University of New South Wales (UNSW)
Research Host	University Paris Saclay
PhD awarding institutions:	University Paris Saclay & University of New South Wales
Locations	Primary: Orsay, France Secondary: Sydney, Australia
Supervisors	Matthieu Lancry (UPSaclay) Gang-Ding Peng (UNSW)
Group of discipline	Photonics, material science, optical fibers, fiber sensors

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

Project 1: *3D microstructuring of refractory nanocrystals by IR ultrafast lasers in oxide glasses for high temperature photonic applications*

High-temperature (HT) materials are building blocks to a wide range of industries, including aviation / space (engine, launcher), manufacturing (3D laser additive manufacturing), or again photonics (optical temperature / pressure / environmental sensing etc.). In most HT applications, refractory crystalline oxide materials are selected such as Al_2O_3, ZrO_2, YAG, directionally solidified eutectic ceramics, metal alloys, carbides / nitrides, due to their high melting points, good resistance to oxidation and abrasion. **HT photonics applications** would benefit from **oxide glass-based materials**, since they bring mandatory requisites such as compactness, lightness, flexibility, high-transparency, chemical / radioactive / electromagnetic resistance, and complex manufacturing shaping. To make a HT photonic device, **the glass must be functionalized** (e.g., gratings or waveguides require stable refractive index modulations). The tool of choice for this purpose is **femtosecond laser** direct writing (FLDW). The latter enables very high light intensities (10-100s TW/cm^2) to be deposited **on (2D) and inside (3D)** a material, creating unique forces to induce oriented transformations such as **migration of chemical species, oxide dissociation, or nano-crystallization**. To date, induced modifications employed to fabricate thermally stable devices are dedicated to silica or lightly doped-silica glasses, through the **formation of porous nanogratings, limiting their use for few hours beyond 1100 °C**. The main objective of this

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proposal is to overcome this technological lock.

Conventional porous glass modifications survival at HT is dictated by the glass viscosity, and from this view silica is undoubtfully the best candidate due to its highest viscosity at HT. **To go beyond the restrictions imposed by silica glass, I will explore a novel approach where fs-laser irradiation is used to photo-precipitate refractory nanocrystals inside high-viscosity silicate glasses** (such as ZrO_2, Mullite, Sapphire, YAG). As opposed to a purely viscosity-driven erasure mechanism, I foresee that the stability of the fs-laser induced nanostructures will be dominated by other mechanisms due to the incompressible (unlike pores) and refractory nature of the photo-precipitated phases (melting points between 1600 °C and 2700°C). Therefore, we anticipate these nanocrystal/glass nanogratings to outperform nanogratings structures and enable device survival at temperatures >1200°C for months. Moreover, **we will master the size, distribution, and morphology of the nanogratings** within the focal volume (few μm^3) using a combination of light properties (polarization, phase, intensity) and thermal ones (laser heating effects).

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Project 2: *Reliable Fiber Bragg Gratings sensors for extreme environments*

Fiber Bragg grating (FBG - a spatial modulation of refractive index changes in optical fibres) based sensor technology operating in extreme temperatures is a major technological breakthrough making instrumentation for extreme environments possible. It's development and validation of innovation in a practical application will meet the new needs of the industry, particularly by designing fiber micro-sensors that will be incorporated in specific materials and processes in the areas of engine air carriers (aeronautics, SAFRAN), space (launchers, Eurocryospace) or advanced manufacturing (e.g. 3D laser additive manufacturing of metal and ceramics parts). Having innovative, reliable and robust instrumentation, based on FBGs in optical fibers for measurements of high temperature and strain (thermal measurements and / or mechanical deformations) will be an undeniable asset for industrial programs in the short and medium term. These programs are at the forefront of technological development (e.g. engines of the future, laser assisted 3D synthesis, high power lasers, nuclear plants, steel processing). They require characterization tools that can operate in harsh environments for qualification processes and products. In collaboration with CEA Saclay (focusing on nuclear applications but also fiber sensors generally for extreme environments) and Safran (aeronautic) this overall project will develop Fiber Optic sensors based on FBGs that can operate in extreme environments, especially at high temperatures (700-1500 °C). Following recent developments, these sensors are being developed to measure the temperature and strain in extreme environments. This new fiber Bragg grating technology adds extreme temperature resistance to the intrinsic advantages of FBG-based metrology such as spectral multiplexing capabilities (multiple measurement points on a single optical fiber) and electromagnetic immunity. Ultra-high temperature performance is needed across sectors such as Aerospace (aircraft engines), Advanced Manufacturing (3D laser additive manufacturing metal parts), optics (high power laser), steel and aluminium smeltering industry, nuclear (instrumentation of future reactors) and space (launchers). Two innovating FBGs to solve this high temperature problem now exist: in particular the FBG regeneration process (discovered by our Australian partner) is the only current approach that can enable photonic technologies to operate in such harsh environments at elevated temperatures (standard FBGs do not survive above 600 °C). In the simplest interpretation the regeneration process is the rebirth of a grating that is first annealed out. A second approach would be to take advantage of the selectivity in spatial and time domains that near IR femtosecond lasers offer. In this project, the technology of glass taken for granted in the macro scale will be applied on a sub-micron scale with a degree of unheralded finesse using laser patterning and writing of temperature stable submicronic structures - glass smithing with nanoscale resolution becomes feasible.

Scientific and Technological objectives:

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(1) Studying and maximizing FBG temperature performance through material control
(2) FBG lifetime mastering to get drift-less photonic sensors
(3) Demonstrating and applying the outcomes to practical sensing systems

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Project 3: *Investigation and development of high temperature operating optical fibers and optical components imprinted by femtosecond laser*

The project brings together a number of key objectives, which can be summarized as follows: (1) Studying and maximizing FBG temperature performance through material control: The usual dopants like Germanium, Fluorine or Boron in the silica fiber core determine the high temperature processing. Therefore, most commercial optical fibers are not designed for operation above 1000 °C. However, if one examines the melting point of compatible oxides, there is at least one common oxide that raises silica melting point - Al_2O_3, which melts above 2000 °C. Alumina doping in the core of a fibre helps to harden the core making it resistant to fibre fuse effects. This task will explore mainly the impact of Al_2O_3 and ZrO_2 in SiO_2 glasses on increasing the processing temperature to equal or surpass that of the pure silica cladding. Recent work has already identified 3 glass vitrification regions for SiO_2-Al_2O_3 glasses: 0-15% Al_2O_3, $50Al_2O_3$-$50SiO_2$ and 60-$70Al_2O_3$. Following this idea, multiphoton FBG writing will also be undertaken by the internship using femtosecond laser facilities at CEA and ICMMO. Our Australian partner from UNSW has demonstrated the possibility to do high quality 3D printed fibers and these already have their own high temperature performance. A part of the project aims to undertake a detailed comparison and study between femtosecond IR writing of Bragg gratings and some FBG based on a local crystallization. (2) FBG Lifetime mastering to get drift-less photonic sensors: For such 800-1500 ºC temperatures, actual implementation of the technologies is crucial to properly understand this environment and its demands as much as understanding the component glass performance. To emphasise this point, a long-term assessment of an early regenerated grating has been recently done during 9000h at 800°C. This reveals that much has to progress before the technology is considered for this regime. Accelerated aging experiments will be done during this internship to ensure (lifetime prediction in a reliable manner) long-term operation above 1000 ºC - the aluminosilicate (including Al_2O_3 fiber) approach may offer the best solution. A connection between changes in optical properties, structural relaxation and viscous flow will be studied by ICMMO-UTS and used to optimize and predict the thermal and optical resistance of glass technologies in the all-critical industrial 800-1500 °C window. Additionally, we will have to consider the combination of aging and viscous flow, which is an area that demands both fundamental and applied research. (3) We will perform genuine long-term tests that evaluate and validate structures in actual working environments. This study may lead to drift-less optical fiber sensors, removing detuning of the sensors that is a major issue for their adoption and deployment by major industrial players and especially in collaboration with some company.

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3. Employment Benefits and Conditions

University Paris Saclay offers a 36-months full-time work contract (with the option to extend up to a maximum of 42 months). The total working hours per week is 35h.

The remuneration, in line with the European Commission rules for Marie Skłodowska-Curie grant holders, will consist of a gross annual salary of 27,816 EUR. Of this amount, the estimated net salary to be perceived by the Researcher is 1,850 EUR per month. However, the definite amount to be received by the Researcher is subject to national tax legislation.

Benefits include

- Access to all the necessary facilities and laboratories at University of Paris Saclay and UNSW (optics, spectroscopy and electrons microscopy facilities), to sport and training activities.
- Tuition fee waiver 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 12 months in Australia.
- 25 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 should hold a master in science or in engineering (physics, chemistry, optics, materials science, ...) with a substantial research component and demonstrated capacity for timely completion of a high-quality research thesis.
Applicants must demonstrate an English language proficiency equivalent to an overall IELTS score above 6.5 and no band below 6. Note that the test needs to be completed no more than two years before enrolment.
For more information about the tests accepted and scores required, visit UNSW website.

More information on UPSaclay’s requirements

The successful Applicant to AUFRANDE selection process will be required to submit his/her application on ADUM and be accepted by the 2MIB doctoral school.

Approval of the French Authorities may be required before the starting of employment. In case of denial, the employment will not be carried out.

More information: https://www.universite-paris-saclay.fr/recherche/doctorat-et-hdr/cotutelle-de-doctorat

More information on UNSW’ requirements

Visit the website: https://research.unsw.edu.au/higher-degree-research-programs