Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes the PhD subject and supervisor proposed by the French Polytech network of 14 university engineering schools. Please contact the PhD supervisor by email or Skype for further information regarding your application.

Supervisor information	
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PhD information	
Title	Reliable Fiber Bragg Gratings sensors for extreme environments
Main topics regards to CSC list (3 topics at maximum)	VI-2. Prevention of serious engineering breakdowns and system safety IV-11. Information, storage and sensor materials
Required skills in science and engineering	Optical science, glasses, laser-matter interaction, optical fibers

Subject description (two pages maximum)

Harsh environmental sensing using Fiber Bragg Gratings (FBGs) technologies is a rapidly growing field of research. A new generation of devices that operate in extreme environments (particularly those operating above 700°C and up to 1800°C), including environments with additional challenges such as radiation and intense optical fields (e.g. high power lasers), must be capable of withstanding gradual annealing and degradation, or aging, over time while preserving their intrinsic advantages (multiplexing capabilities, electromagnetic immunity, low intrusivity, mechanical reliability) with regard to thermocouples. Of particular local relevance these include live diagnostics with optical sensor embedded into high-temperature composites for aircraft, helicopters and space infrastructure, temperature and pressure sensing in increasingly deeper and hotter oil bores, and the monitoring and mapping of temperature distribution at power plants, furnaces and chemical reactors. Much of the answer is related to inherent glass structure and properties, particularly viscous flow/chemical migration and stress relaxation. It therefore may be overcome by judicious application of glass preparation and glass annealing.

Two innovating FBGs to solve this high temperature problem: In particular the FBG regeneration process 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. In this PhD 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.

As it is proposed here, regenerated Fiber Bragg Gratings form an excellent test bed for understanding and optimizing much of this; their centrality to a new generation of sensors that can be integrated with relatively low loss into coming intelligent optical SmartGrids means they are of immense practical importance as well. Despite this early success, the general feedback is that these two writing technologies are still too early and requires improvement in material performance. Indeed deployment of such regenerated FBG temperature sensors arrays to real life application requires fulfilling stringent requirements from the end-users. Moreover efficient solutions have to be developed in order to propose regenerated FBGs as a reliable and mature industrial solution with regard to well-established techniques such as thermocouples. Among the key issues for the deployment of calibrated arrays of regenerated FBGs, let mention: i) the availability of collective and standardized temperature calibration methods, ii) an efficient process for the regeneration of FBG sensing lines with an arbitrary topology (currently limited by the use of conventional furnace), iii) better understanding of the regeneration process itself in order to draw silica optical fibres optimizing the regeneration ratio and the thermal stability of the Bragg wavelengths (together with their tolerance to radiation in case of nuclear projects) and also iv) improvements in both stability and v) high temperature coatings able to protect and package the regenerated FBGs.

This project will study the physical basis for this in more detail. A connection between changes in optical properties, structural relaxation and viscous flow will be study and used to optimize and predict the thermal and optical resistance of glass technologies in the all-critical industrial 700-1500°C window. Fundamental and FBG sensors devices studies will enable photonic technologies to operate in such harsh environments at elevated temperatures. The project therefore brings together a number of key objectives:

(1) Studying and maximising regenerated FBG temperature performance through material control
(2) Studying and maximising regenerated FBG mechanical endurance
(3) Regenerated FBG lifetime mastering to get drift-less photonic sensors
(4) Femtosecond laser written FBG lifetime mastering to get drift-less photonic sensors
(5) Demonstrating and applying the outcomes to practical sensing systems in high T environment

Methodology: For reaching the objectives, we have decided to divide our work plan into 5 **key tasks** with flows between them that can be separated into basic and application oriented actions. Firstly we need Studying and maximizing FBG temperature performance through material control (Task 1). For example this task will explore the impact of Al_2O_3 and ZrO_2 in the fibre core that increase the processing temperature to equal or surpass that of the cladding. While controlling the high T regime is at the heart of the project, demonstrations of reliable FBGs require also addressing their packaging (Task 2). Indeed one of the most critical risk, early so identified, is that after high T annealing, the fibre segment becomes brittle. We need thus a packaging technique to encapsulate the high Temperature FBG to withstand the demanding vibration and shock conditions during measurements, and the interface method fibers to attach the sensor element once packaged to the hot area in a reliable way, which could be either metallic or ceramic, materials that are common in thermal protection systems. A significant manpower will be focus on this topic. In Task 3 we will extend the high temperature regime potentially up to 1800°C using femtosecond laser direct writing in Sapphire optical fibers. Here our partner will realize some specific tapers and fiber connector in such a way we can feed only the LP01 mode of these initially multimodes sapphire fibers whereas fs-FBGs will be written and their properties studied by ICMMO. Then results from investigation will be collected, sorted and eventually completed etc… After completion, all results will be collected for rationalizing (Task 4). For such 800-1800ºC temperatures, actual implementation of the technologies is crucial to properly understand this environment and its demands as much understanding the component glass performance. To emphasize this point, long-term assessment will be study deeply. In this task, a connection between changes in optical properties, structural relaxation and viscous flow will be studied and used to optimize and predict the thermal and optical resistance of glass technologies in the all-critical industrial 800-1800°C window. This study will lead to drift-less optical fiber sensors for Task 5 that is a major issue for their adoption and deployment to major industrial players. Following this step, few tests would be considered to secure consistency. This is the first flow oriented scientific knowledge for reaching a rational. A second flow will be application oriented. Based on the specifications for targeted FBG sensors applications, optical fiber design, laser and thermal treatments and packaging procedure will be specified to demonstrate and applying the outcomes to practical sensing (Task 5). In particular we will perform demonstrators in practical sensing systems and high-end applications (aircraft engines, Additive Laser Manufacturing, in-service thermal monitoring of next generation of sodium-cooled nulear Fast Reactor).

Scientific Impact: Bragg grating sensors technology operating in extreme temperatures is a major technological breakthrough within the instrumentation for extreme environment. Its development and validation of innovation will meet the new needs of the industry by designing fiber micro-sensors that will be incorporated in particular materials and processes in the areas of engine air carriers (aeronautics, engines, turbines), space (launchers reusable space launcher) or the advanced manufacturing (e.g. 3D laser additive manufacturing of metal and ceramics parts). Having an innovative, reliable and robust instrumentation, based on Bragg gratings in optical fibers, for measurements in high temperatures (thermal measurements and/or mechanical deformations) will be an undeniable asset for industrial in the short and medium words, at the forefront of technological developments (engines, laser assisted 3D synthesis, high power lasers, nuclear plants, steel) and requiring characterization tools in harsh environments for qualification processes and products.