Lighting **the way**

Dr Stavros Pissadakis lifts the lid on exciting new developments using photonic crystal fibres to develop optical fibre sensors, outstanding work in the field of photonics

What is the remit of your lab based at the Foundation for Research and Technology-Hellas, Institute of Electronic Structure and Laser (FORTH-IESL)?

The objectives of the group focus on the research of materials, designs and fabrication methods for Guided Wave Photonics, with significant effort being invested in grating-based and photonic crystal fibre (PCF) devices. The knowledge accumulated on material-related problems and processes is directly transferred into the research for developing photonic devices of increased technological and scientific added value, targeting real-life applications. The strategic vision of the group refers to the development of hybrid photonic devices and related processes by engaging existing and emerging technologies in a 'disruptive' way, covering scientific and technological levels from the proof-of-principle up to the laboratory prototype.

How do you define the term 'disruptive'?

'Disruptive' describes the fusion of material and optical technologies towards the realisation of photonic devices with totally new functionalities for addressing new applications or substantially improving performance. The 'disruptive' approach includes a significant amount of research risk that we deliberately undertake, investigating ideas and processes beyond the margins of a simple feasibility study. By working in 'disruptive' mode, new challenges and questions emerge on the interface of different scientific fields, promoting multi-disciplinary research investigations. Also, the development of 'disruptive' photonic sensing devices can enhance their penetration into new applications and thus markets, strengthening further the position of Photonics as a Key Enabling Technology.

Can you describe your most recent efforts regarding optical fibre sensors and specifically those developed utilising photonic crystal fibres?

We aim to develop generic optical fibre sensing components. These exhibit versatile sensing functionalities and capabilities, and while under adaptations, are suitable for serving various application fields. We have developed optical fibre sensors for environmental monitoring, health-related applications or detection of organic vapours. In these designs, the effect of the external stimulus on a transducing material is interrogated by a customised photonic element, ie. a Bragg grating. PCFs constitute a powerful sensing platform, simultaneously combining light propagation and microfluidic functionalities. We have intensively worked during the last few years building the scientific and technical background, elaborating processes like grating inscription, infiltration, as well as theoretical simulation needed for developing PCF sensing devices. At present, we are disseminating the first PCF device examples developed in our group, referring to optofluidic actuators, shear sensing and extreme temperature monitoring, using fibres of tailored optical and fluidic characteristics.

What are the prospects that arise from the development of such photonic devices?

The principal idea is to exploit the PCF geometry for downscaling the size of the sensing and actuating elements, while in parallel increasing functionalities and improving performance. Such a transformation has already occurred in the case of the 'lab-on-chip' planar devices. The long-term target is the development of a similar technology referring to PCFs, described as 'lab-in-fibre'. The 'lab-in-fibre' sensing devices will be capable of providing in situ, point interrogation of several physical, biological or chemical parameters, offering the extra advantage of sensor size comparable to a human hair. For instance, such multi-functional photonic crystal fibre sensors can be invaluable tools in forensics, food quality tracing or gene diagnostics.

Suspensions of magnetic nanoparticles such as ferrofluids could allow the creation of new photonic devices in combination with photonic crystal fibres. Can you detail your research focus and achievements within this area?

The use of magnetic fields for manipulating the rheological, optical or even biological properties of infiltrated liquids inside PCFs and their spectral response refers to the lab-in-fibre principle. We have recently presented several different types of magneto-fluidic, in-fibre devices, including a miniature vectorial magnetometer and an efficient spectral trimmer. We are presently working on the development of magnetofective DNA biosensors and 'smart' shear stress probes, based on such magnefluidic PCFs.

What do you consider to be some of your foremost achievements to date?

Together with the ferrofluid infiltrated PCFs, the recent development of organic vapour optical fibre sensors utilising ZnO nanorods and the refractive index engineering methods invented in the past are projects that offered hybrid approaches for realistic sensing problems. Soon we will report new results on the fabrication of relief periodic structures inside the capillaries of PCFs, leading to probes with unperceived sensing capabilities in hostile environments, such as temperatures greater than 1000°C. Generally speaking, the accumulation of extensive expertise in innovative photonic device development that is available for further exploitation constitutes a valuable stepping stone.

Sensing the way and going FORTH

Photonics shows great promise for future technological applications, and among these are state-of-the-art sensors that meet the needs of the 21st Century. Under development is a new type of sensor that could reduce the incidence of pressure sores in the rehabilitation setting

AS A CONSTANTLY revolutionising field of technology, Photonics has already led to the creation of a huge range of applications over the last 50 years, and still shows great potential for transforming our lives in a myriad of ways. As one of the many strands of this exciting discipline, fibre optics is already ubiquitous in modern-day life, with uses that include lighting, high-speed communication and networking, sensors, imaging and spectroscopy. The proliferation of these devices shows no sign of abating, with many more applications currently in development.

PRESSURE CARE THROUGH A FIBRE

Greece is a competitive player in photonics research, with the Institute of Electronic Structure and Laser at the Foundation for Research and Technology – Hellas (FORTH-IESL) leading the way. Housed within this Institute lies the Ultraviolet Laser Facility (ULF-FORTH) member of the LaserLab-Europe consortium, a multidisciplinary European access laboratory specialising in photonics invention and innovation. Furthermore, the Photonic Materials and Devices Laboratory (PMDL) hosted at FORTH-IESL is currently investigating the use of Optical Fibre technology, and is led by Dr Stavros Pissadakis, an experienced researcher with more than 15 years experience in the field. One of the latest PMDL projects is entitled 'Intelligent Adaptable Surface with Optical Fibre Sensing for Pressure-Tension Relief' (IASIS). The FORTH-IESL team has been adapting Optical Fibre Bragg Gratings technology for use in pressure care in rehabilitation situations to develop a smart pad that is able to redistribute pressure, strain and shear applied to the skin due to prolonged periods of reduced mobility or recumbency in beds and wheelchairs. The pad acts as a skin/machine interface that detects variables related to excessive epidermal loading using a custom-designed Fibre Bragg Grating (FBG), and feeds this data back to a specialised pressure cushion or mattress, hence reducing the incidence of pressure sores.

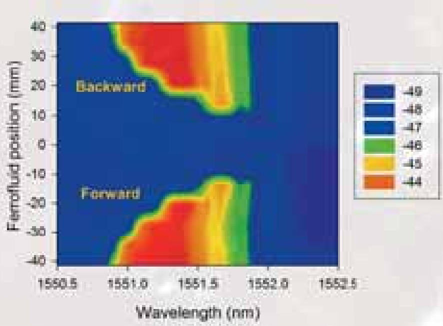


Figure 1. Spectral response of a chirped Bragg grating inscribed in a PCF that is infiltrated using ferrofluid

The ability to produce new rehabilitation-related sensing technologies relies in no small part on collaboration, both within the host institute and further afield. The FBG sensor pads were a joint effort between the IASIS partners, where the FORTH team developed a laser inscription technique that resulted in ultra-short and tailored spectra FBGs that maintained mechanical properties and durability under heavy loads. Other key role partners in the project are from external organisations, offering different expertise from both the commercial and academic sectors. These include SAFE Ltd (Cyprus), which also coordinated IASIS project; AUTH (Greece); Fujikura (UK); Bioimerosin (Greece); and MedCom (Germany).

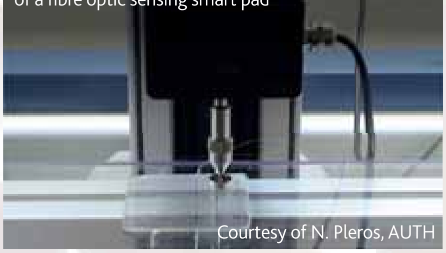
> In the near future, such smart pads may also be capable of simultaneously measuring crucial chemical or biological parameters

Fibre optic sensors, specifically FBGs, can offer fundamental advantages over traditional pressure-sensing technologies used in rehabilitation settings. Due to their remarkable properties of reflecting or transmitting particular wavelengths of light, easy analysis of changes in different variables is possible by measuring changes in light propagation over time. The optical fibres, each able to house several elements that can measure different variables such as pressure, strain, shear and temperature, are also sensitive to changes in a very small region of space, while also easily embedded into a flexible pad. Pissadakis is optimistic about the prospects of such photonic technology: "In the near future, such smart pads based on 'lab-in-fibre' photonic sensors, may also be capable of simultaneously measuring crucial biological or chemical parameters such as bacterial growth or pH, in addition to the mechanical quantities," he explains. This vision seems realistic considering the progressive standardisation of optical fibre sensing technology together with the booming of the photonic crystal fibre field, which should ensure low-cost and reliable production of such devices in the future.

REACHING OUT

The LaserLab-Europe ULF-FORTH facility, which has been operational at FORTH-IESL for almost 20 years, is also open for use to other European researchers from different institutes who seek not only the unique laser, experimental and diagnostic facilities available there, but also the niche inter-disciplinary expertise accumulated over the years by the scientists at IESL. This ensures the cross-pollination of knowledge between different individuals, institutes and disciplines. FORTH-IESL, together with the ULF scheme, constituted the first large scale laser installation in Greece, playing a seeder role in photonics research at national level. However, over the last decade the Greek photonics sector has rapidly matured, with many researchers and institutions being intimately involved in a variety of European projects and gaining a reputation for

Figure 2. Testing under pressure gauge of a fibre optic sensing smart pad



Courtesy of N. Pleros, AUTH

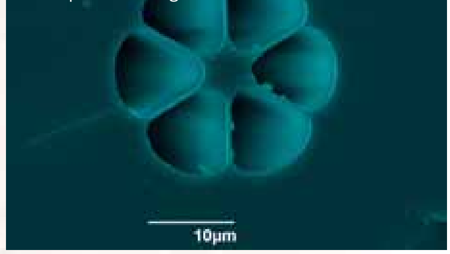
their knowledge and competency, as Pissadakis maintains: "Both academic and industrial sectors maintain continuity and high calibre academic output or service quality over several sub-fields of optics and photonics".

Pissadakis himself also coordinates the Greek National Technological Platform for Photonics (Photonics^{GR}), which is comprised of 26 members who represent major research, university and industrial institutions involved in photonics in Greece. The platform, following the success of the European Photonics21 initiative, aims to formulate a roadmap for the development of photonics at a national level in Greece through agreeing a common vision and understanding between the various institutions involved, and has spawned several collaborative ventures since its inception. It also seeks to help raising funds and the profile of Greek photonics research, and acts as a liaison between the Greek photonics community and Photonics21, ensuring market trends and associated research priorities are high on the agenda and that Greek photonics research is also recognised at a European level.

LIGHTING THE ROUTE TO DEVELOPMENT

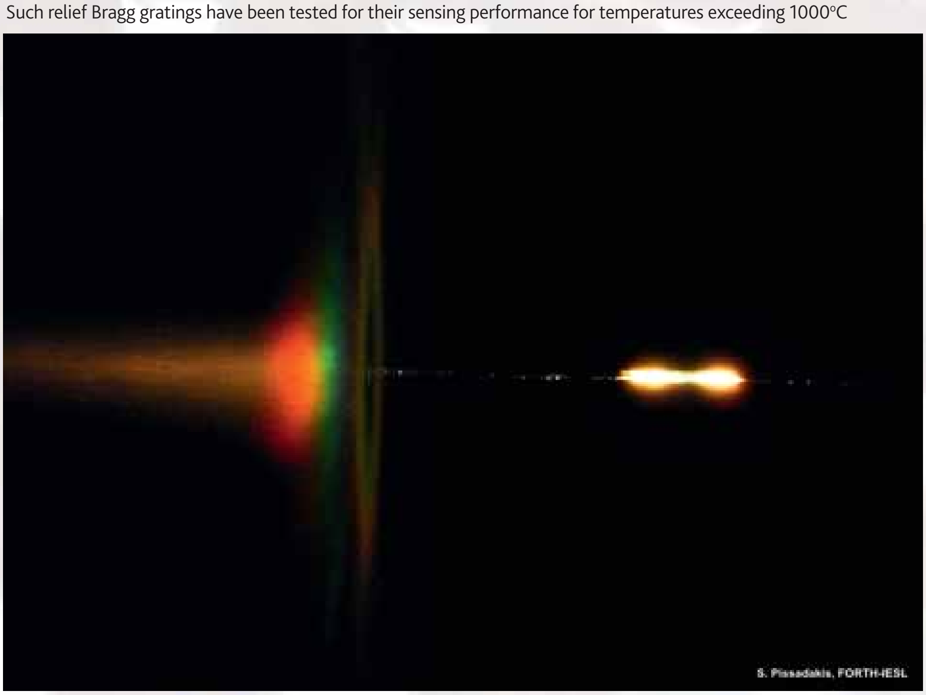
The austerity economical measures recently applied to Greece but also to several other European countries reduce public sector spending, including that of healthcare, while simultaneously prompt the optimum use of resources. Among other technologies, Photonics may help to alleviate the impact of such reductions in the future by providing efficient, low-cost diagnostics and therapy tools, such as the optical fibre sensor rehabilitation cushions developed within the IASIS project. Other photonic technology-driven innovations may also contribute to the Greek economy through the production of devices involved in solar energy conversion, seawater pollutant monitoring, and food quality screening. Furthermore, Pissadakis has a positive vision of the future for photonics and its ability to provide socio-economical benefits within the broader European Research Area: "Photonics must become a major key enabling technology which will be firstly considered by the industry when a new 'high-tech' market challenge needs to be addressed. This will secure rapid penetration into horizontal and vertical markets, while it will transform Photonic technologies into an everyday necessity".

Figure 3. Scanning electron microscope picture of a microstructured optical fibre endface used in the development of magnetofluidic devices



Through the work of Pissadakis and his peers at both institutional and national level, the prospects for Greek photonics seem encouraging. There is a certain momentum that has been gained through their diligence and outstanding research, but its ultimate success lies on the ability to translate from the laboratory to the marketplace. Needless to say, this will require a mixture of continued collaboration and cooperation, in tandem with targeted dissemination of their research and proof of its commercial viability. By meeting these standards, the future of Greek photonics may well be bright.

Figure 4. White light scattering out from a relief Bragg grating inscribed in a photonic crystal fibre (PCF). Such relief Bragg gratings have been tested for their sensing performance for temperatures exceeding 1000°C



INTELLIGENCE

IASIS

INTELLIGENT ADAPTABLE SURFACE WITH OPTICAL FIBRE SENSING FOR PRESSURE-TENSION RELIEF

OBJECTIVES

IASIS aims to demonstrate a smart pad for serving as the skin/machine interface in therapy beds and wheelchairs, capable of redistributing the pressure applied on the skin, preventing the onset of pressure ulcers. Diagnosis relies on optical fibre Bragg grating sensors that can identify the values and coordinates of excessive epidermal loadings, and provide feedback information to an adaptable mattress or seat mechanism.

KEY PARTNERS

Professor G Papaioannou, S.S.F. Safe Smart Fabric Adaptable Surface Ltd (SAFE), Cyprus-SME (Project Coordinator) • **Foundation for Research and Technology-Hellas (FORTH)**, Greece- RTD • **Aristotelio Panepistimio Thessalonikis (AUTH)**, Greece-RTD • **FUZIKURA**, UK- RTD • **BIOIMEROSIN LABORATORIES S.A. (BIOIMEROSIN)**, Greece- SME • **MEDCOM GESELLSCHAFT FUER MEDIZINISCHE BILDVERARBEITUNG MBH (MedCom)**, Germany- SME • **COMITECH S.A. (CMT)**, Greece - SME • **Nicosia General Hospital (NGH)**, Cyprus - EndUser • **FILOKTITIS S.A. - Center for Rehabilitation**, Greece _ EndUser

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DR STAVROS PISSADAKIS obtained his BSc degree in Physics from the University of Crete, Greece in 1994 and his DPhil in Integrated Optics from the Optoelectronics Research Centre, University of Southampton, UK in 2000. He joined IESL-FORTH, Greece in 2003, where he is now a Principal Researcher. His interests include development of optical fibre devices for switching and sensing applications, photonic crystal fibres, and the study of photosensitivity in optical fibres and materials using high intensity lasers. He has been heavily involved in the activities European Technological Platform Photonics21, while he has coordinated the formation of a similar National Technological Platform for Photonics in Greece (Photonics^{GR}).