PROJECT FINAL REPORT

Grant Agreement number: 224058

Project acronym: PHOSFOS

Project title: Photonic Skins for Optical Sensing

Funding Scheme: Small or Medium-Scale Focused Project

Period covered: from 01/04/2008 to 31/08/2011

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1.1. Executive summary

Photonics – the science and technology for harnessing light – has been identified as a key enabling technology (KET) by the European Union. Photonics will thus be one of the main driving forces behind the development of future goods and services. The "Second Strategic Research Agenda in Photonics" published by the European Technology Platform "Photonics21" clearly states that Europe should maintain its technological capabilities in photonic sensors through leading-edge research. This was precisely the primary endeavour of PHOSFOS "**Pho**tonic **S**kins **F**or **O**ptical **S**ensing". PHOSFOS has developed a new paradigm for optical measurement methods building on the unprecedented combination of microstructured glass and polymer optical fibre technologies, flexible optoelectronic packaging techniques and polymer material developments. The project aimed to develop a thin flexible and stretchable polymer pad in which optical sensor elements can be integrated together with the optical sources and optical detectors that are required to power and read out the sensor elements, to form an "optical sensing skin". The function of the sensor elements was to measure mechanical quantities, in particular mechanical strain or pressure applied to the sensing pad. On the way to achieve its overall objectives, PHOSFOS has developed technologies that provide solutions to essential issues that had so far prevented such optical sensors from penetrating the market.

PHOSFOS combines 4 cornerstone technologies to build application targeted proof-of-concept systems

The sensing elements developed by PHOSFOS rely on fibre Bragg gratings fabricated in dedicated microstructured glass optical fibres and polymer optical fibres. The design flexibility of the silica fibres was exploited to obtain pressure sensors that are 20 times more sensitive compared to the state-of-the art while at the same time they are almost completely insensitive to temperature changes. Polymer optical fibre sensor technology was developed so that it could be used in real applications off the optical laboratory bench for the first time. It exploited the unique advantages of polymer fibres over their glass counterparts, e.g. their ability to measure much higher strains, their safer use in medical applications and their ability to be read out with lower cost interrogation systems. The integration technologies developed by PHOSFOS allow embedding every building block of a dynamic fibre sensing system in a polymer pad: fibre sensors can be precisely positioned, optical sources and detectors can be made that thin that they become flexible and bendable while miniaturized optical coupling allows connecting sources and detectors to the fibres. PHOSFOS also developed new polymer materials that can be fabricated at lower cost than their state-of-the-art counterparts and with "on-demand" flexibility. All these technologies were combined in three demonstration set-ups that answer a clear market demand. First PHOSFOS has developed a pre-product prototype to measure downhole pressure in the field of oil and gas exploration: the sensor is capable of measuring pressures up to 1000 bar with unprecedented negligible cross-sensitivity to temperature. Second, PHOSFOS has developed a proof-of-concept medical sensor system to measure oesophageal pressure and to diagnose gastro-intestinal disorders. Third, PHOSFOS has assembled an integrated and portable proof-of-concept system capable of monitoring respiratory activity.

PHOSFOS, a collaborative effort of 41 months, has built on the unique and complementary competences of 9 European partners – of which 7 academic institutions and 2 SMEs – that are all internationally recognized in their respective fields of expertise and activity. The project received a total funding of about 1.9 million EURO and has involved a total of 27 experienced researchers and 19 PhD students. It led to 22 peer reviewed publications indexed by the ISI Web of Science.

PHOSFOS generated know-how upon which 5 new patent applications have been filed. The fibre sensor technologies developed by PHOSFOS are now being transferred to industry for pressure monitoring for oil and gas exploration and for water-in-fuel detection in the field of aeronautics. Low cost optical fibre sensor interrogation systems and polymer to silica fibre connection technology developed by PHOSFOS will be commercially available shortly after the end of the project. Total commercial revenues for the SMEs from project results are expected to grow from 100,000 EURO after one year to over 2.5 million EURO after five years of commercialization. This will create increased employment opportunities and job creation in these SMEs while contributing to strengthening the competitiveness of EU industry in innovation driven activities.

1.2. Summary description of project context and objectives

Rising to the challenges faced by the European Union in the decades to come cannot be achieved without developing novel measurement methods and sensor technologies. For example, increased demands on our healthcare systems due to an ageing population call for reduced healthcare costs while maintaining quality of life. This in turn requires the development of effective tools for early diagnosis. Exploiting and securing our energy resources in an ecological and economic manner requires using extended monitoring networks to control energy production, transport and consumption. Preserving the safety and security of the European citizens that become increasingly mobile in a global economy calls for implementing extended sensor networks that can warn against danger during transport and at work.

The use of advanced sensors and measurement systems for collecting data to monitor the influence of a myriad of physical quantities in healthcare, energy production, civil engineering, material manufacturing, aeronautics and robotics – to name a few – has therefore become increasingly important. These quantities typically include temperature, the concentration of chemical species, mechanical strain, pressure or force. In many cases conventional electromechanical sensors – such as electrical strain gauges in the case of mechanical quantities – are perfectly qualified for these tasks. Whilst the simplicity of these conventional sensors is definitely an advantage, this may also limit their effectiveness in many applications. Electrical sensors may for example experience difficulties to perform properly in the presence of sources of electromagnetic radiation such as high voltage lines or lightning strikes. Their intrinsic temperature sensitivity can also disturb the sensor signal when the physical quantity of interest is measured in transient temperature regimes. Finally electromechanical sensors can also suffer from low fatigue life or drift, which necessitates their frequent replacement or recalibrations.

The last few decades have been very productive in terms of new sensor developments, not only those based on micro-electronic technologies, but also those using optical detection methods. When traditional sensors fail optical fibre sensors (OFS), for example, have already shown their ability to provide a solution. An optical fibre sensor encodes the physical quantity that one wants to measure, the "measurand", into one (or more) properties of an optical signal that is guided within an optical fibre. The number of possible applications of optical sensors – and in particular of optical fibre sensors – is extremely large. The implementation and commercial success of OFS has therefore considerably increased in the last 25 years. Many suppliers of conventional sensors have now included OFS in their product range. However notwithstanding their well known advantages, and probably with the exception of distributed measurement systems and optical fibre gyroscopes, they have not yet succeeded in penetrating the market in numbers commensurate with their sensing capabilities. The major roadblocks depend on the application field, but a number of universal issues are well identified and listed below:

- each sensor type often needs to be tailored to the particular application resulting in high development costs;
- fibre sensors typically require compensation or correction schemes due to the cross-sensitivity of the sensors to different measurands;
- sensor packaging and the need for hermetic sealing increase the cost per sensor;
- the non-integrated aspect of the electronic and optical assembly does not favour portable solutions;
- the lack of standardization and the difficulty to integrate with mainstream technologies is a showstopper in many applications;
- the need for trained personnel to install the sensors, to operate the sensing system, to interpret the measurements and to take care of the maintenance again increases lifecycle costs.

The overall objective of PHOSFOS was to develop an integrated technology that is sufficiently generic to overcome or alleviate some of the roadblocks stated above, in particular the need for compensation schemes, the packaging difficulties and the non-integrated aspects. PHOSFOS aimed to pave the way towards quasi distributed sensing, flexible sensing pads, lower cost integrated solutions that do not require the intervention of specialized personnel during installation and use. The output of the sensor modules developed in PHOSFOS can come in an electrical form and through conventional electrical wires, while the more fragile parts including the sensing fibres would be embedded in a flexible material.

To achieve this overall objective PHOSFOS has pursued the development of two optical fibre sensor technologies and has built on the combination of these with new optoelectronic integration technologies. The approach consisted first in developing the actual sensor devices with very particular features tailored to the intended applications and second in developing the technologies required to package the sensor probes, to read out the sensor signals and to embed the sensing systems into flexible polymer structures. This approach was translated into two specific objectives.

1. The **first specific target** of PHOSFOS was **to develop sensing structures consisting of fibre Bragg grating (FBG) sensors in two types of optical fibres**. A FBG is a type of distributed reflector constructed in a short segment of optical fibre that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fibre core, which generates a wavelength specific mirror. The reflected wavelength is sensitive to external perturbations such as mechanical strain applied to the fibre and temperature. Detecting the reflected wavelength hence allows measuring the applied strain and/or the temperature. The two types of optical fibres considered each come with their specific advantages that justify the choice for these two complementary routes.
   The **first fibre type** is glass **micro-structured fibre** (MSFs). An MSF is an optical fibre that contains microscopic air channels running along its entire length. The lay-out, the size and the position of these channels in the cross-section of the fibre govern the optical guiding properties of the fibre. Modifying the topology of the air channels therefore allows tailoring the characteristics of the fibre with unprecedented flexibility and hence adapting the sensing features to very specific needs. When correctly designed the fibre should allow the measurement of a single measurand, without cross-sensitivity to other physical quantities, and hence without requiring any complex cross-sensitivity compensation schemes. This is the **first breakthrough feature** introduced by PHOSFOS. The use of these special fibres will result in a lower complexity of the electronic circuitry and consequently in up to 20% lower cost compared to modules with present-day technology offering inferior performances. The sensing principle that PHOSFOS intended to exploit is very schematically illustrated in Figure 1.
   The **second fibre type** is **polymer optical fibre** (POF). Polymer fibre sensors offer unique challenges but have some distinct advantages over glass fibre for certain sensing applications. First a POF can survive much higher strains and is far less stiff than a glass fibre. Second, because of its organic composition and low drawing temperature, POF can be processed using a wide range of organic chemical techniques. Third, for medical applications polymers are intrinsically more biocompatible than silica. Fourth and depending on the POF pre-processing, polymer fibre gratings can have temperature sensitivity an order of magnitude larger than those in glass fibre. Whereas this temperature sensitivity limits the range of applications, it can nevertheless be turned into an asset for others. At the start of PHOSFOS POF sensors had only been demonstrated to operate in a laboratory environment. PHOSFOS intended to take this technology to the level of practical use, out of the lab and into the field. This is the **second breakthrough feature** presented by PHOSFOS.
   Although the field of fibre Bragg grating sensing using conventional optical fibres is already very well established, the integration of Bragg gratings in the new types of fibres used in PHOSFOS was far from straightforward and posed a number of technological challenges. At the start of PHOSFOS early attempts had been made at manufacturing gratings in MSF and in POF with various levels of success. PHOSFOS intended to bring this technology to the level of practical use by developing the methods that allowed reliable and repeatable fabrication of Bragg gratings adapted to sensor applications in both MSF and POF, which brings along the **third breakthrough** feature of PHOSFOS.

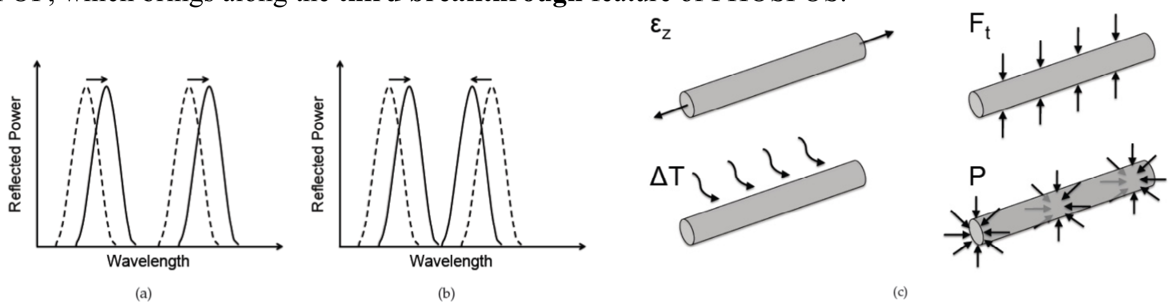

Figure 1. Illustration of the sensing principle exploited in PHOSFOS with FBGs in highly birefringent glass MSF. The measurand (pressure or a load applied transversally to the fibre) is encoded in the spacing Δλ between the two Bragg peaks reflected by a FBG. (a) Response of the sensor to temperature changes or longitudinal strain as common mode signal – both peaks move is the same way and Δλ remains unchanged. (b) Response of the sensor to transverse perturbations as differential signal – the peaks move in opposite direction and Δλ changes. (c) Temperature changes and axial strain are not considered as measurands and will lead to common mode signals. Transverse load or hydrostatic pressure are the perturbations of interest and should thus appear as a differential signal.

2. The **second specific target** of PHOSFOS was **to integrate and to embed the sensor elements and the peripheral optoelectronic components and optical fibre waveguides in a flexible functional package.** This has been inspired by the current trend in packaging of electronic components and the recent advances in embedding active electronic circuitry in flexible foils. Embedding of optoelectronic components (on rigid substrates) had already proven to be a possible route to overcome the packaging and alignment problem, but had never been tried on flexible circuits prior to PHOSFOS. Integrating thinned optoelectronic components into the optical layers of a flexible pad is a **fourth breakthrough** introduced by PHOSFOS. This requires dedicated processing and handling of low-cost optical sources such as LEDs or vertical-cavity surface-emitting laser diodes (VCSELs) and photodetectors, in order to thin these devices down to a thickness of a few tens of microns. Owing to the reduced thickness these devices become flexible while remaining fully operational, i.e. they do still emit and detect light according to their initial specifications but they are now mechanically compliant and can be embedded in thin flexible polymer material pads. These optoelectronic devices also need to be connected to the optical fibre sensors mentioned above that have been embedded within the same polymer pad by means of optical coupling structures, which represents the **fifth breakthrough** element of PHOSFOS. Finally, the nature of the polymer material used for the packaging plays an essential role. Ideally, the polymers need to be compatible with the technological embedding processes, should exhibit an on-demand level of flexibility depending on the application and have to provide excellent adhesion properties for the mechanical forces acting on the pad to be transferred in a reliable manner to the actual optical fibre sensor elements. PHOSFOS intended to develop such materials and by doing so achieve its **sixth breakthrough** result.

All the technological deliverables of PHOSFOS are articulated around the specific central concept which is schematically depicted in Figure 2.

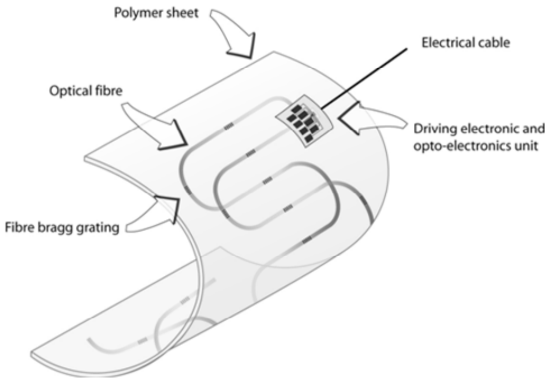

Figure 2. Sensor pad concept of PHOSFOS. Sensor elements in optical fibres are embedded in a flexible polymer pad and connected to the optical sources and optical detectors to power the sensors and to read out the measurements.

The final objective of PHOSFOS was to develop three proof-of-concept systems based on the technologies described above. These systems had to be chosen to match with the markets targeted by the two Small and Medium Enterprises (SMEs) involved in PHOSFOS. The proof-of-concept systems had to answer a clear market demand with potential to contribute to economic growth and job creation within the SMEs.

1. The first proof-of-concept is a sensor device that uses FBGs in glass MSF and targets the application domain of oil and gas exploration. The unique selling point here is the ultralow cross-sensitivity to temperature that allows carrying out high pressure measurements in the presence of significant temperature variations and which cannot be achieved using conventional technologies. The ambition was to develop this system to the level of pre-product prototype. The first SME involved in PHOSFOS is active in the field of structural health monitoring and will continue the development up to the product level and commercialize the sensor systems with commercial revenue of 84,000 EURO in the first year of commercialization to 2.3 million EURO after five years.
2. The second proof-of-concept system uses an array of FBGs in POF and addresses medical applications which require embedded sensors in a polymer sensing tube with exceptional flexibility connected to a separate low-cost read-out unit. This system will pave the way towards comfortable diagnosis of

oesophageal or intestinal disorders that appear following a stroke or due to cancer. This proof-of-concept system will require additional development beyond PHOSFOS followed by approval of official healthcare administrations prior to use. The second SME involved in PHOSFOS and active in the field of optical medical instrumentation will nevertheless immediately commercialize the low-cost read-out unit as well as the POF to glass fibre connection technology which are universally deployable in many other applications with commercial revenues increasing from 15,000 EURO in the first year of commercialization to 60,000 EURO after three years. The lower return here compared to the glass fibre technology is due to the lower technology readiness level of the POF sensors.

3. The third proof-of-concept system uses individual FBGs in POF and also addresses the medical need to provide comfortable measurement of the effectiveness of someone's breathing function in order to allow distinguishing between obstructive and central apnea, measuring the triggers and treatment of asthma and monitoring cardiac activity. Potentially the market opportunities here are large but again the technology readiness level is still lower that the MSF sensors. Consequently modest 20,000 EURO revenue after 3 years is anticipated. Further research funding opportunities are currently being explored for this concept.

With these expected revenues and by tackling essential issues such as packaging, fully-fledged system integration, optical coupling and interfacing, dependable strain transfer and reliability, PHOSFOS will support wide deployment of optical fibre sensor technologies. This will support the European Union in facing the challenges that lie ahead of us in the coming decades and beyond, strengthen the competitiveness of European industry in this field and at the same time ensure job creation in the involved SMEs.

1.3. A description of the main S&T results/foregrounds

In this section we describe the main scientific and technological results obtained by PHOSFOS over its entire duration of 41 months. We emphasize the breakthroughs and those developments that provide true advancement beyond the state-of-the-art.
The section is organised in accordance with the structure of the project and aligns with the different individual technologies that had to be developed before bringing these together to realize the proof-of-concept systems targeted by the project. The first four paragraphs relate to these technologies:

1. microstructured optical fibre sensors;
2. polymer optical fibre sensors;
3. polymer materials;
4. flexible embedding and packaging techniques.

The final paragraph then deals with the actual proof-of-concept systems and builds on the information provided in the first four subsections.

Microstructured Optical Fibre Sensor Technology

Optical fibre sensors are part of the field of optical metrology, which is the science and technology of measuring physical quantities, to which we refer as measurands, by means of light. In this field one can make a distinction between methods that are based on free space optics, such as full field interferometric techniques, particle image velocimetry, Doppler velocimetry, infrared thermography, LIDAR (LIght Detection And Ranging), etc. and those that use optical fibres to guide the optical signal that carries the measurand information, such as fibre interferometers and fibre gratings.

Most optical fibres are composed of silica (glass). In 1979 it was discovered that the cores of such fibres displayed photosensitivity to UV light. This phenomenon remained a curiosity for about a decade until it was realised that a spatially periodic modification to the refractive index along the core of the fibre could be induced by exposing a short section of the fibre to a spatially varying intensity pattern of UV light, usually produced by interfering two beams of coherent UV light incident on the side of the fibre.

Such a device is known as a fibre Bragg grating (FBG), and it has the property of reflecting light of essentially one wavelength, while allowing all other wavelengths to pass. The precise reflected wavelength is initially set by the period of the inscribing UV light pattern, but once the grating is recorded the reflected wavelength is also influenced by the strain or temperature to which that region of fibre is subjected and this process offers the possibility of monitoring strain entirely optically. The main advantage of FBGs for sensing is that these devices perform a direct transformation of the sensed parameter into optical wavelength, independent of optical power level, connector or fibre losses, or other FBGs at different wavelengths.

Since the early nineties, considerable effort world-wide has been devoted to developing this technology, the basic aspects of which are now quite mature, and the technology has been commercialised for more than 10 years. FBGs have become one of the most established types of optical fibre sensors and importantly, Europe has several innovative and leading companies exploiting this technology, which offers the following advantages over conventional piezo-resistive strain gauge technology:

- Immunity to electromagnetic interference
- Multiple sensors possible on one fibre, e.g. working in different wavelength regions
- Light weight
- Small size
- Operation at high temperature (>500 °C) possible

These FBGs are commonly fabricated in conventional telecommunication grade optical fibres. PHOSFOS intended to innovate in this field by considering **FBG sensors in microstructured optical fibres (MSF). The first objective was to design, fabricate and characterize FBG-based sensors in silica MSFs that allow accurate measurements of hydrostatic pressure independent of temperature changes with a single sensor element.** This was not achievable prior to PHOSFOS.

The activities started off with the design of a dedicated microstructured fibre. Initially we believed that the temperature insensitivity target could not be reached with FBG compatible fibre designs because of the inclusion of a doped core. However a rigorous investigation of the sensor sensitivity showed that the temperature sensitivity could not be straightforwardly modelled without taking the dispersion of the birefringence into account. After doing so **we showed for the first time that the inclusion of the doped region in the core of the MSF was counter-intuitively required to make the final sensor temperature insensitive.** Simultaneously the fibre birefringence is close to 10^{-3} which allowed obtaining a sufficiently large Bragg peak separation in the reflection spectrum of a FBG inscribed in the core of such a MSF. Finally the confinement losses had to be sufficiently low for both straight and bent fibre. The optimized designs of the fibre geometries that were selected for fabrication are shown in Figure 3.

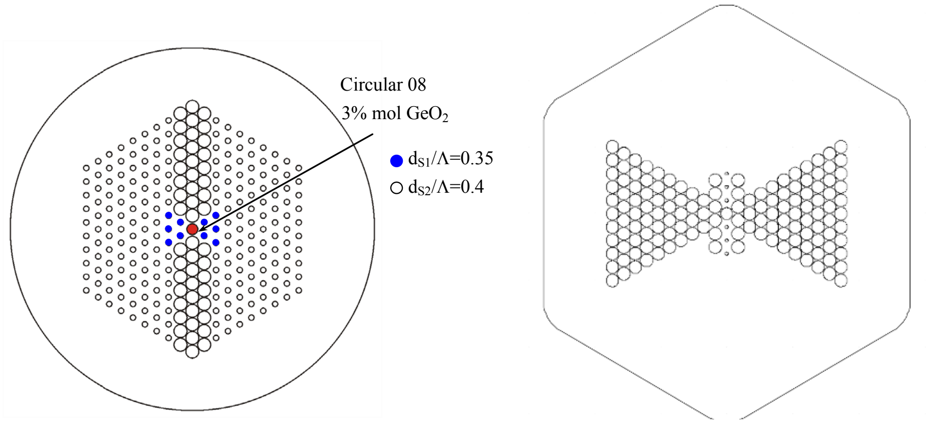

Figure 3. PHOSFOS microstructured fibre designs exhibiting increased pressure sensitivity and low temperature sensitivity. Left: Type I – Right: Type II or "Butterfly" type

Second we established a stable and well-controlled technological process for drawing micro-structured fibres with a high birefringence. The development of the MSF drawing technology for highly birefringent fibres was based on the technology for low birefringent fibres, but requires greater knowledge of the deformation of the microstructure during the drawing process, since airholes with more than one specified diameter need to be accurately realized. These MSFs were fabricated via a stack-and-draw process. This technique consists of creating a preform which contains the structure of interest, but on a macroscopic scale. This preform is obtained by stacking a number of glass capillaries and rods by hand to form the desired air–silica structure. After the stacking process the capillaries and rods are held and fused together during an intermediate drawing process. Finally the preform is drawn down on a conventional optical fibre drawing tower to obtain the reduced cross-section with diameters on the order of 80 to 125 µm. The germanium doped core was prepared via a Modified Chemical Vapour Deposition (MCVD) method. Finding the correct stable drawing conditions for such fibres was a technological challenge because these conditions are specific for each microstructure. **In comparison with the state-of-the-art, the developed MSF drawing technology allows fabricating microstructures that combine different hole diameters, a doped core region and a high number of included airholes.**

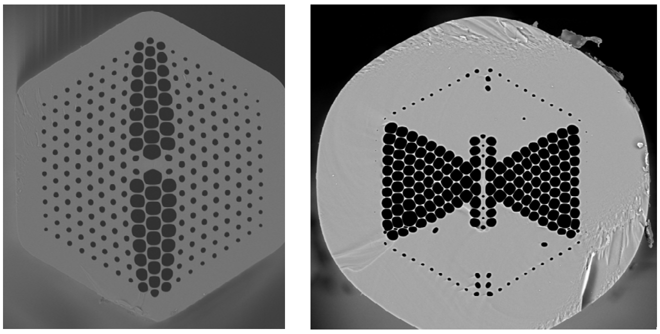

Figure 4. Cross-sections of the final PHOSFOS MSFs based on the MSF designs shown in Figure 3. Left: Type I – Right: Type II or "Butterfly" type

More than 23 fibre batches were delivered in the development process. The MSFs that show the best performance out of the complete set of fabricated fibres for both designs are shown in Figure 4.

In a next step our specialty fibres have been experimentally characterized in a broad wavelength range for both their basic guiding properties and for their mechanical and thermal sensitivities. SEM micrographs of the fibre cross-sections provided detailed insight in the shape of the microstructure and the shape of the GeO_2 doped core region. The geometry of the fabricated fibres could then be used in the same simulation models that we used in the design phase of the fibres.

For most MSFs, the polarimetric pressure sensitivity was negative and smaller than the project target value of 100 rad/m·MPa, as expected from the design simulations. The maximum polarimetric pressure sensitivity in SME-grade fibre was 82 rad/m·MPa. Only for 2 MSFs with a so-called "butterfly" design (right pictures in Figure 3 and Figure 4) for which the fabrication technology was pushed to its limits (outside the drawing conditions that allow SME-grade fibre fabrication), was the sensitivity positive (as a result of the interchanged orientation of the slow and fast axis) and it **exceeded the project target value up to 120 rad/m·MPa. This is more than 20 times larger than for commercially available step-index birefringent optical fibres**.

The delivered MSFs were then prepared for the inscription of the fibre gratings. First we investigated Bragg grating inscription in a very large set of MSFs to explore the limitations of our MSF designs to maintain compatibility with conventional UV FBG fabrication technology. **Our findings showed that the MSFs with dopant concentrations as low as 0.45 mol% still allowed FBG inscription, with reflection levels that are relevant for sensing purposes.** As expected, higher doping concentrations yielded stronger gratings and shorter fabrication times. **In addition, the influence of the angular fibre orientation in the FBG fabrication setup was shown to play little role on the reflection strength of the fabricated FBGs, which drastically eases the practical realization of the FBG inscription since no accurate control over the MSF orientation is required in the inscription setup.** Finally, the limited role of the airhole diameter and the airhole pitch allowed us to conclude that the MSF designs could be freely adapted as long as the core region contained a germanium concentration above 3 mol% to guarantee reasonable inscription times. Figure 5 shows a reflection and transmission spectrum of a FBG inscribed in a Butterfly type MSF and evidences that high quality sensor gratings can be fabricated in such fibres.

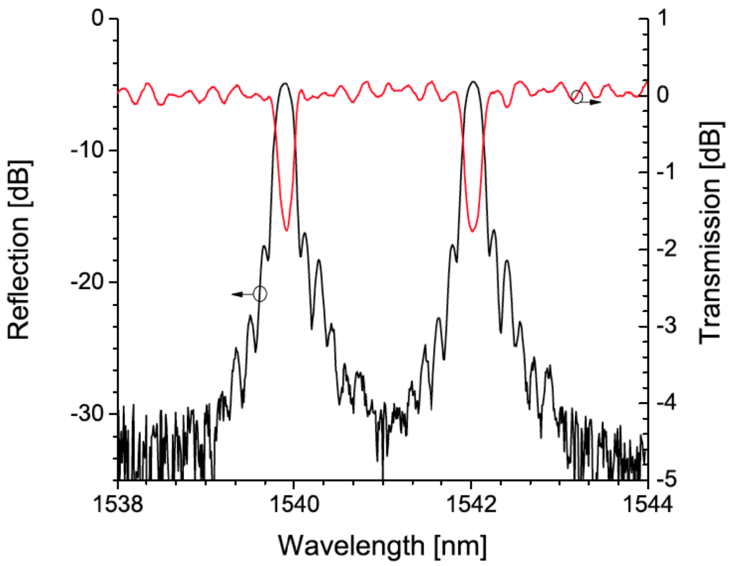

Figure 5. Reflection and Transmission spectrum for an UV-written FBG in Type II or "Butterfly" MSF, showing a double Bragg reflection.

We also demonstrated the future potential of unconventional femtosecond laser based FBG fabrication techniques by showing, for the first to our knowledge, an infrared femtosecond point-by-point Bragg grating inscription in a MSF. In femtosecond point-by-point FBGs each period of the grating is fabricated with one femtosecond laser pulse that is focused into (or near to) the core of an optical fibre. By moving the focal point along the length of the optical fibre with a well chosen translation speed, one grating period is inscribed after the other at the laser pulse repetition rate. This technique has several advantages over conventional UV inscription. First the grating period Λ_{FBG} and therefore its resonance wavelength can be tailored by tuning the ratio of the translation speed to the laser pulse repetition rate. Second, the refractive index changing mechanism for infrared femtosecond pulses is based on nonlinear absorption – multi-photon processes – and thus requires high power densities that surpass material dependent thresholds. This allows overcoming the diffraction limit and inscribing fine periodic structures in the sub beam waist size domain that would not be achievable with linear absorption processes at the same laser wavelength. Finally fibres no longer need to be photosensitized with doping materials or by hydrogenation to permit FBG writing and the typical inscription time is shortened to the range of tens of seconds instead of tens of minutes as for other femtosecond inscription techniques. As a result of these advantages femtosecond point-by-point grating fabrication is no longer limited to silica. Indeed this technique can be used in almost every waveguide material, such as polymer optical fibres, as long as there is a wavelength transparency window in the fibre cladding that allows the light accessing the waveguide core. For the femtosecond point-by-point FBGs in our MSFs the transmission valleys are about 0.2 dB deep. The successful fabrication of this grating in a MSF contributes to the anticipated flexibility of fibre types that are compatible with this FBG fabrication technique and brings the potential of a universal inscription setup within closer range.

We have then characterized the sensitivity to temperature and pressure of several FBGs in the fabricated MSFs. The differential Bragg peak sensitivity to temperature appeared to be very low and a precise determination of its value was not possible since the measured values were in the range of the measurement error. Therefore we cannot unambiguously demonstrate that we reached the project target of $d(\Delta\lambda_B)/dT < 10^{-2}$ pm/°C. However, the very low temperature sensitivity on the level of the measurement error evidences that our achievement is **more than satisfactory for practical applications.**

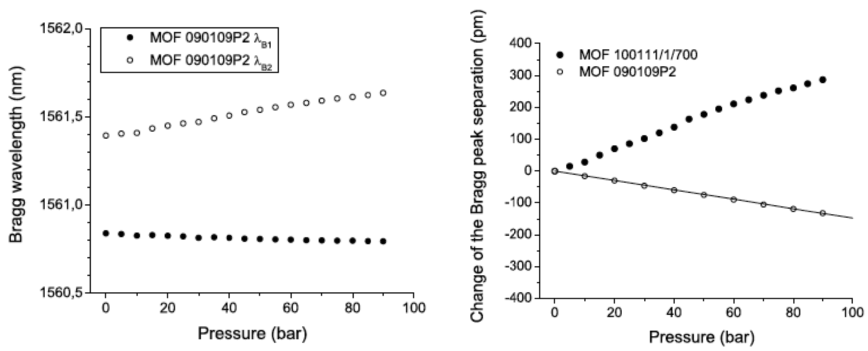

Figure 6. Left: Wavelength shift of the Bragg wavelengths versus hydrostatic pressure. Right: Change of the Bragg peak separation versus hydrostatic pressure in two PHOSFOS MSFs with sensitivities of -1.47pm/bar and 3.1 pm/bar.

The measured differential sensitivities of FBGs to pressure are in very good agreement with the polarimetric sensitivities (see Figure 6). They are sufficiently large and even exceed the target value for some fibres. Fibres with slightly lower sensitivity to pressure but with good manufacturing repeatability have therefore been chosen as elements of choice for the PHOSFOS pre-product prototype targeting temperature insensitive pressure measurements in the field of oil and gas exploration. **The sensitivity of the FBGs in these MSFs is sufficiently large for industrial use.** The final sensor elements were then fabricated and transferred for assembly and validation. Achievements versus specific target values are summarized in Table 1 and Table 2.

With this work on microstructured optical fibre technology PHOSFOS has brought new momentum to the field of optical fibre based metrology in general and fibre Bragg grating sensors in particular. The delivered fibres already meet industrial requirements. In the coming years we predict that many more novel optical fibre sensors relying on microstructured optical fibre technology will allow leapfrogging the performance of conventional technologies.

Specification	Target	Achievement	
		Type I MSF	Type II MSF
Loss	< 20 dB/km at 1.5 μm	43	23
Birefringence	> 10^{-3} at 1.5 μm	1.48 x 10^{-3}	0.72 x 10^{-3}
Temperature sensitivity	$d\Delta\lambda/dT$<0.01 pm/K for λ = 1.5 μm to 1.6 μm	Achieved	Achieved
Pressure sensitivity	K_P = 100 rad/MPa·m	43.3	63.9
Number of modes	1 or 2	Achieved	Achieved
Core doping	Up to 10 %	3.1%	2.4%
Number of hole rings	Allowing FBG inscription	9 (Achieved)	10 (Achieved)

Table 1. PHOSFOS detailed targets and achievements for the MSFs.

Specification	Target	Achievement	
		Type I MSF	Type II MSF
Characteristic wavelength	1550 nm	Achieved	Achieved
Reflectivity	A few dB suffices for sensing applications. The more the better.	Achieved	Achieved
Peak wavelength spacing	2 nm, depending on fibre birefringence	Achieved	Achieved
Particular requirements	Reproducible writing, preferably independent of fibre orientation	Achieved	Achieved
Stability	Peak wavelength stability	Achieved	Achieved

Table 2. PHOSFOS detailed targets and achievements for the MSF based final sensors.

Polymer Optical Fibre Technology

In many ways silica is a very good material from which to construct strain sensors, however it does have some significant limitations:

- silica is a stiff material and so when silica fibre sensors are used to monitor compliant or elastic structures, the silica fibre can act to reinforce the structure, so that the local strain experienced by the fibre is much smaller than the true background strain;
- the breaking strain of silica (especially under repeated strain cycling) is much less than some structures of interest (e.g. some composite materials), limiting its range of applicability.

Both these deficiencies can be overcome through the use of polymer (plastic) optical fibre (POF) which offers some additional potential advantages:

- there is a huge range of polymeric materials that could be used to create POF providing different physical and chemical properties;
- the tools of organic chemistry may be used to modify POF, either by adding functional groups directly to the polymer or doping the fibre with organic compounds. This offers access to a wide range of possibilities for realising specific chemical sensitivity, enhancing non-linear effects or providing optical amplification.
- POF is attractive for medical applications, particularly in-vivo, where the dangers associated with a potentially broken sharp silica fibre are significant.

Most POF is based on a well-known polymer: poly (methyl methacrylate), commonly abbreviated as PMMA. The photosensitivity of bulk samples of this material was recognised as early as 1970, however it was not until 1999, following the development of single mode POF, that the first polymer optical fibre Bragg grating (POFBG) was demonstrated. By the time that PHOSFOS was being conceived, FBGs had been recorded in step index fibre with various dopants (targeted at speeding up the recording process) and in microstructured[2] POF (by Aston University). The basic strain and temperature sensitivity of these devices had been measured but beyond using a POFBG as the mirror in a widely tuneable fibre laser, there had been no applications or systems development work. Indeed all experiments to that time had been carried out on the optical bench.

There were two fundamental reasons behind this lack of development. Firstly, all POFBGS reported up to that time were fabricated in the 1550 nm spectral region often exploited for telecommunications purposes. This wavelength region is used because silica fibre has its lowest loss here, however it is a very poor choice for POF because the attenuation of plastic fibre rises rapidly as the wavelength increases beyond the visible such that at 1550 nm the fibre loss is around 1dB/cm, which is to say that half of the light is lost in travelling through just 3 cm of fibre. Such high losses limit the practical length of POF that can be used at this wavelength to less than 10 cm. The second issue is that, regardless of the length of the POF that could be used, at some stage there needs to be a connection to silica fibre. This is because the fibre related technology that needs to be integrated with a POFBG to make it useful (pigtailed sources and detectors, couplers, circulators) all tends to be based on silica fibre. The fact that only a short length of POF can be used exacerbates this problem, requiring a silica connecting lead to be used unless the sensor is mounted right next to the measurement unit.

At the start of PHOSFOS, the only way of connecting silica and POF fibre was to mount both fibres on high precision 3-axis translations stages and carefully align them on the optical bench[3].The overall aim of PHOSFOS was to take this very immature technology and make it into something usable in the real world by developing a means to connect small cored silica and plastic fibre, realising gratings at much shorter wavelengths where the attenuation of POF is less and demonstrating applications of the sensors away from the optical bench.

Two approaches to connection were pursued: using a demountable mechanical connector and creating a permanent glued connection. It did not prove possible to achieve sufficient positional tolerance to make the former approach useable; however it did prove possible to use UV curable glue to make a permanent connection early in the PHOSFOS project. The precise procedure depends on the type of POF being used, but good success was achieved with both single mode step-index fibre and 50 micron cored few-moded mPOF, where the gluing process typically adds rather less than 1 dB to the joint loss. Single mode mPOF proved to be less tractable and additional losses of about 5 dB were obtained (though later in the project the additional loss was reduced to close to 1 dB in the best case). This important technological development has enabled the POF gratings to be taken off the optical bench and applied for the first time. **Permanent glued connections to silica fibre could thus be fabricated repeatably.**

A POFBG with a reflecting wavelength of 850 nm has a refractive index modulation with a spatial period of almost half that of a grating reflecting at 1550 nm. This means that the stability of the optical set-up must be twice as good and in addition it requires that the fibre material has a recording resolution of around 250 nm. Initial attempts at producing gratings in the 850 nm region by two different approaches were not successful leading to some concern that the material might not be suitable for such a high spatial resolution. However, improvements to the stability of the set-up and careful adjustments to the position of the recording phase mask eventually met with success and gratings were recorded at both 827 nm (see Figure 7 Left) and 860 nm using two different phase masks. The loss of some of the PMMA fibre has been measured at 850 nm and 1550 nm, revealing that at the lower wavelength the loss is more than 10 times less than at the higher (8 dB/m vs almost 100 dB/m). As a result of this development it became possible to record gratings in the ~25 cm lengths of fibre required for the POF based proof-of-concept systems. **The first POFBGs in the lower loss 850 nm spectral region have therefore been demonstrated by PHOSFOS.**

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[2] Microstructured POF (mPOF) is the same as photonic crystal POF – the former terminology has become commonplace in the POF world.

[3] To be more precise it was possible to connect multimode silica fibre with the large core POF typically used for short range communications using mechanical connectors, however such large cored fibre (up to 1mm) cannot be used for POFBGs as the reflected spectral peak would cover an enormous wavelength range and could not be monitored with useful precision.

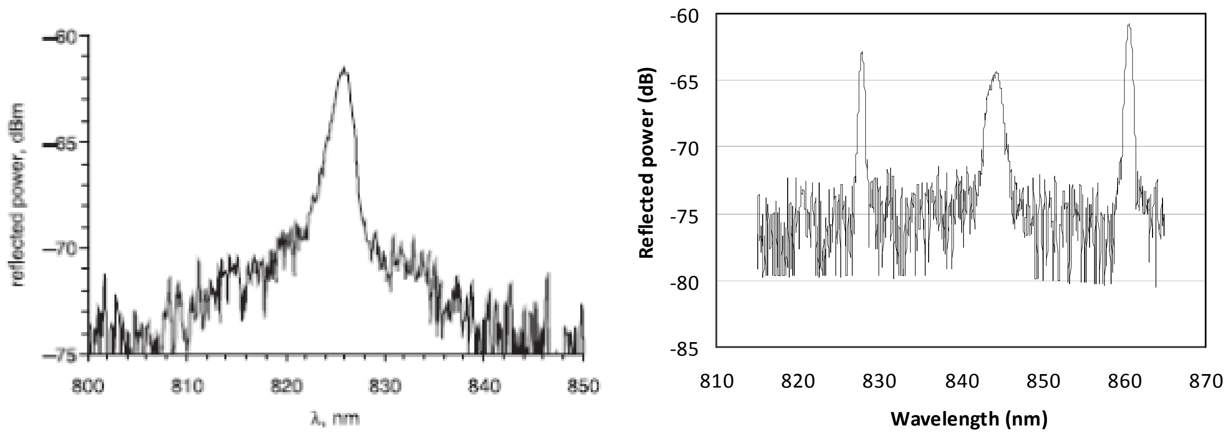


Figure 7. Left: Reflection spectrum of first POFBG in the 850 nm spectral region. Right: 3 grating multiplexed sensor array.

Prior to the start of PHOSFOS, no-one had ever produced a sensor incorporating more than a single POFBG. **Within PHOSFOS we succeeded in fabricating multiplexed sensors with up to 3 gratings for the very first time** (see Figure 7 Right) **in both 800 nm and 1550 nm spectral regions**. The recording of multiple gratings can either be carried out using several phase masks or, we discovered, using the annealing approach described below.

When a polymer such as PMMA is polymerised, the long molecules tend to be randomly oriented and intertwined in a fashion analogous to a plate of spaghetti. When the fibre is made it is drawn under tension from a cylindrical preform and during this process the molecules become preferentially aligned along the fibre axis. When the fibre is heated above a temperature of about 55 °C for PMMA, the fibre is able to relax back towards its initial disordered state and this causes a slight shrinkage of the fibre along its axis.

Prior to PHOSFOS, experiments at Aston University had shown that to obtain stable POFBG behaviour at temperatures above 55 °C the fibre had to be annealed, allowing the shrinkage to take place. In the course of the PHOSFOS project, we realised that this process could be utilised to impart a well defined wavelength shift on a POFBG recorded in the fibre prior to annealing (see Figure 8). This shift can either be used to create wavelength multiplexed POFBG sensors or it can be used to tune the wavelength of one sensor to accurately match a desired wavelength, for which no dedicated phase mask was available. Within PHOSFOS this was used to match gratings to specific laser diodes, for example.

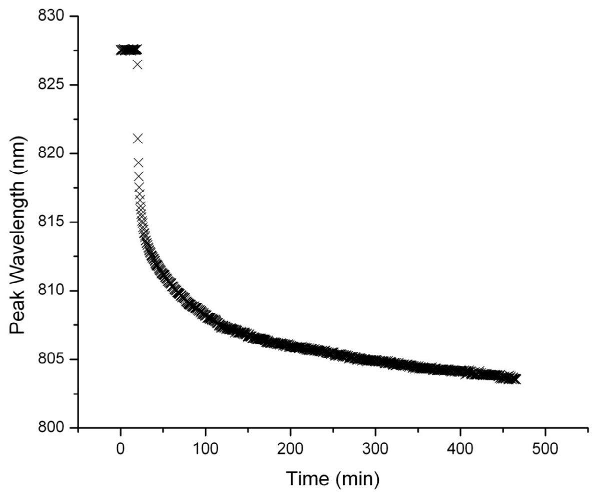


Figure 8. Annealing curve at 80 °C for grating recorded at 828 nm in multimode mPOF.

Within PHOSFOS we have also identified a design of mPOF which combines a large core (50 microns) with a few fibre modes of similar propagation constant. Such fibre produces a rather broader reflection spectrum than is the case with single mode fibre (for example, in the 1550 nm region a 4 nm width versus about 0.5 nm for a similar grating in single mode fibre) however the large core size simplifies connection to a multimode silica fibre pigtail opening up the possible use of broad area and low cost sources such as LEDs. Furthermore, beyond PHOSFOS it should allow the possibility of demountable mechanical connection to silica fibre. The penalty to be paid for using such fibre is that the larger bandwidth reflection peak compromises the achievable strain measurement resolution to somewhere around 20-30 μstrain versus just a few με for a single mode fibre. However, a main motivation for using POF is its ability to monitor very large strains of 10000 to 100000 μstrain in which case the highest resolution will not be important. Figure 7 illustrates gratings recorded in the large cored mPOF in the 850 nm spectral region.

The much lower elastic modulus of POF allows the fibre to respond much more to stresses within the material being sensed, as contrasted with silica which tends to act as a reinforcing element, thus masking the true background strain. This is illustrated in Figure 9, which shows the results of straining a sheet of highly elastic polydimethylsiloxane (PDMS) in which were embedded a POFBG and a silica FBG. This rubber-like material is very elastic and it can be seen that the response of the two sensors is dramatically different. The POFBG wavelength exhibits a near linear response to the applied strain, while the silica FBG response is characterised by large amounts of non-linearity and hysteresis, which probably involves the fibre locally pulling away from the PDMS. Note also that despite the sensitivity to strain of POF and silica FBGs being similar to with 10% of each other, the wavelength shift experienced by the silica FBG is roughly 50 times less than that of the POFBG, showing that it is locally stiffening the PDMS. **This demonstrates the advantages of POFBGs when embedded in compliant materials.**

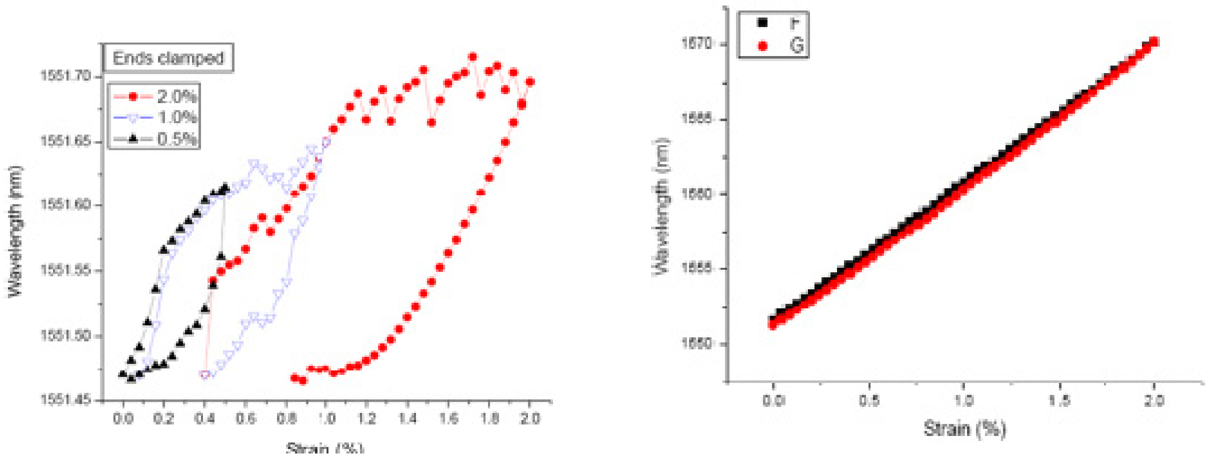


Figure 9. Strain response of FBG sensors embedded in PDMS. (left) silica FBG; (right) POFBG.

Achievements versus specific target values are summarized in Table 3 and Table 4.

To conclude, within the project more than two hundred grating fabrication experiments have taken place in approximately twenty fibre types. Fourteen single grating sensors, four 2-sensor and three 3-sensor multiplexed devices were supplied to partners for embedding trials and final proof-of-concept system assembly. The main technological achievements resulting from this work are:

- permanent glued connections to silica fibre;
- the first POFBGs in the lower loss 800 nm spectral region;
- the first multiplexed POFBG sensors in both 800 nm and 1550 nm spectral regions;
- the use of fibre annealing to shift the Bragg wavelength of a sensor;
- the first useful multimode fibre POFBGs;
- demonstration of the advantages of POFBGs when embedded in compliant materials;
- a determination of the effects of fibre drawing on the anisotropy of the fibre.

Beyond PHOSFOS, these developments have permitted applications of POFBGs in tapestry monitoring, humidity sensing, water-in-fuel detection and high-strain sensing for aerospace.

Specification	Target	Achievement
Connection between silica and polymer fibre	Not pre-defined	Glued connection
FBGs in low loss fibre	Loss < 10 dB/m	8 dB/m @ 850 nm
Grating reflectivity	Reflectivity > 50%	• 97% with step-index fibre @ 1550 nm • 20% routinely with mPOF @1550 nm • 10-20% likely with mPOF @ 850 nm
Large strain sensing	5% repeatable, 10% single use	Recoverable strain measured to 5%, range limited by optical source bandwidth

Table 3. PHOSFOS detailed targets and achievements for the POFBGs.

Specification	Target	Achievement
No. of multiplexed sensors	Up to 3 separated by 10 mm	Achieved
Operating wavelength	820-870 nm	Achieved. Multiplexed sensors at 827, 844 and 860 nm
Grating reflectivity	50%	Likely 10-20%, though more than sufficient for operation with commercial silica FBG interrogation systems at 1550 nm or 850 nm.
Operating temperature	Body temperature	Gratings can operate up to 55 ºC without annealing and > 90 ºC after fibre annealing
Connector	FC/APC	Achieved by gluing to silica fibre pigtail.
Wavelength range	< 3 nm	Achieved. Gratings tested to 65 nm, limited by bandwidth of optical source.

Table 4. PHOSFOS detailed targets and achievements for the final POF based sensors.

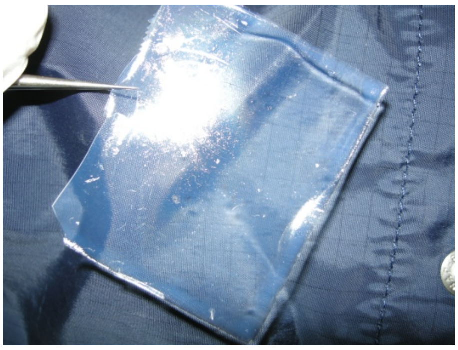
Polymer materials

To achieve its objectives PHOSFOS needed to develop dedicated polymer materials that were adapted to the embedding of glass and polymer optical fibre sensors (see previous sections) as well as to embedding and integration of the optoelectronic devices (described in the next section). The polymer materials should be easily processable, low-cost, entirely compatible with the embedding technologies and preferably exhibit controllable levels of flexibility. This required significant advancements on the state-of-the-art in the field of optical polymer materials.

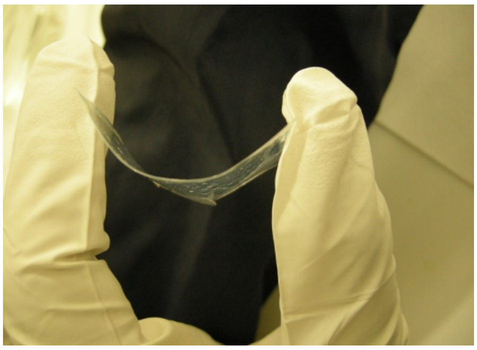
The current state-of-art of UV curable commercially available material heavily relies on a polymer formulation known as Truemode™. This formulation is known to contain a complicated mix of halogenated aromatic, oligomers and monomer components. However when cured – i.e. when polymerised – the material hardens and becomes rigid, inelastic and brittle. A major additional disadvantage of Truemode™ is the occurrence of significant batch-to-batch variations, i.e. the characteristics of the material tend to change depending on the fabrication batch that one buys. To solve this problem PHOSFOS has developed a series of tailored (co)polymers which by-pass the limitations of the current materials. In addition to excluding batch-to-batch variations, the approach led to the development of inherently flexible (co)polymers that could either be admixed or covalently linked to the commercial formulation. **Using this technology, the commercial formulations exhibited significant and controllable flexible characteristics.**

Since Truemode™ is based on partly known compounds we could anticipate optimal material compatibility between PHOSFOS monomers/polymers and the commercially available formulation. PHOSFOS polymers were synthesised via a radical solution polymerisation technique in order to fabricate base (co)polymers that were necessary to impose tuneable features into the Truemode™ formulations. A large variety of both homopolymers and copolymers, containing respectively one or multiple building blocks in the polymer chains, were synthesised and characterised chemically (with proton nuclear magnetic resonance – NMR), physically (with rheology and gel permeation chromatography) and thermally (with differential scanning calorimetry and thermogravimetric analysis).

Proton NMR data showed that the empirical molar ratio was similar to the theoretical ratio whilst confirming that the purification procedure was adequate to remove any residual monomers after synthesis. **An important issue for optical applications is that a multi-step method was elaborated for obtaining monomer free final polymers, which typically remains one of the issues in the development of some polymer types.** Gel permeation chromatography showed that the molecular weight average was between 60000 g/mol to 120000 g/mol. Interestingly the physical appearance of the polymers could be varied between resin to a viscous melt with varying degree of tackiness. Thermal degradation studies showed that the (co)polymers were observed with a single step degradation mechanism at an onset greater than 250°C, thus confirming their thermal suitability with standard clean room fabrication temperatures. Figure 10 gives an idea to the degree of flexibility introduced into the commercial formulation.



(a)



(b)

Figure 10. Images of Truemode™ samples admixed with PHOSFOS (co)polymers showing enhanced flexibility. Note: Truemode™ only samples cannot bend without breaking.

A second very important material type that has attracted a great deal of attention recently and is now widely used for optical applications includes hybrid materials containing organic–inorganic compositions. This is in part due to the purpose of developing new useful materials that have enhanced combined properties. On one hand, the organic component provides the possibility of adding functionality to the organic phase thus tailoring its molecular architecture to suit the intended application, while the inorganic siloxane polymers possess excellent thermal stability, low moisture retention, environmental and solvent resistance, low optical loss and high reliability. Such combined properties of the final material are therefore ideal for use in the optoelectronic industry either as waveguides, cladding structures or optical interconnects. The current state-of-art of UV curable siloxane based commercial formulations is LightLink® which is based on siloxanes. Silsesquioxane is one of the three-dimensional oligomeric organosiliceous compounds with the general structural formula (RSiO1.5)n, where n is an even number and R can be any number of groups (such as methyl, halogen, vinyl or phenyl). Each silicon atom is bound to an average of one and one-half oxygen atoms ("sesqui-") and to one hydrocarbon group ("-ane"), see Figure 11.

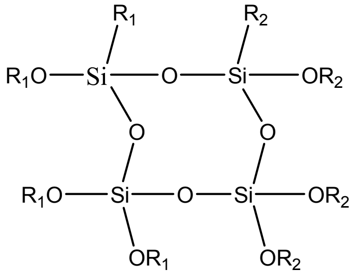


Figure 11. The general structure of a polysilsesquioxanes.

An extensive literature and patent search indicated that prior to PHOSFOS there has been no attempt made at influencing the flexibility in LightLink® clad resin, which for PHOSFOS was an important issue. The flexibility of the new formulations (PHOSFOS monomers/polymers plus LightLink®) confirmed that increasing the amount of (co)polymers in the final material resulted in an increase in the degree of elongation of the films, thus confirming their flexibility.

In addition to material flexibility, stretch-ability and thermal stability were also major requirements for the objectives of the project. We have successfully shown that both the elongation and stretch-ability of the films can be controlled at the molecular level to suit the intended application. The thermal stability was found to be perfectly compatible with the processing parameters of standard optical applications. The polymers were indeed found to exhibit tuneable flexibility and thermal stability owing to the ability to control their glass transition temperatures and molecular weight respectively. **PHOSFOS thus substantially enhanced the usability of state-of-the-art commercial formulations (Truemode™ and LighLink®) by building in controllable material flexibility.**

A second PHOSFOS breakthrough was related to the development of novel stand-alone formulations developed as replacement materials for the commercially available Truemode™ and Lightlink®. One of the PHOSFOS monomers/polymers was chosen as the starting material owing to the fact that the polymer had so far outperformed the commercial material Truemode™ in previously performed PHOSFOS work. The rationale was to modify the existing polymer since its key properties were already established. Here also the resourcefulness of polymer technology was applied to develop new materials for optical applications. For Truemode™ the base homopolymer was modified with cross-linkable groups to impose curing characteristics that allow it to cure in the right conditions. In addition a new monomer was developed that resulted in a novel polymer for optical applications. This new polymer possessed functional groups which allow for post polymerisation modification if desired. **The polymer can be used both as polymer to fabricate the sensor pads in which optical fibre sensors are embedded and as coating material for optical fibres themselves.** This guarantees perfect compatibility between fibre coating and the surrounding polymer sheet. For the optical fibre coating aspects of the project, the crucial aspect of the curing kinetics of the formulation upon application on the fibre was successfully solved by fine-tuning the exact PHOSFOS monomer/polymer mix. Significant improvements in this field are still anticipated in follow-up projects in collaboration with industry.

As a replacement formulation for Lightlink®, the previously mentioned base homopolymer was also modified with inorganic functional groups in order to achieve an organic-inorganic hybrid polymer. Modification of the base homopolymer was successfully achieved. In addition, further enhancement to the base homopolymer was achieved via the synthesis of a non commercial organic-inorganic hybrid monomer which could be copolymerised with other monomers to generate other novel polymers.

Starting from one single base polymer PHOSFOS thus developed low-cost and easily processable replacement materials for both Truemode™ and Lightlink® by a careful selection of the applied chemical reaction strategy.

Finally PHOSFOS also endeavoured to develop thermoshrinkable polymers. These are polymeric materials that shrink and conform to the dimensions of a secondary object when heat is applied. These polymers are used as a protective barrier against environmental or biological elements and they are known to perform their functions by imposing mechanical strain either through being stretched after curing or manufactured as stretched (blended) polyolefin thin sheets. Blended polyolefins are known to shrink as a result of chemical cross-linking using high energy ionizing irradiation. However such irradiation installations are very expensive and the resulting cost of these polymers prevents wide deployment. **PHOSFOS instead developed polymers with thermal shrinking capability as well as with shape memory features using conventional low-cost UV curing installations.** Figure 12 shows how such polymer pad recovers its original shape upon heating.

Figure 12. Polymer strips recovering to their original shape under heat treatment.

As overall conclusion of this PHOSFOS cornerstone capability, a series of polymers with flexible and stretchable traits have been developed in order to enhance the applicability and capability of existing well known state-of-the-art commercial formulations. These have been made possible by selecting starting materials that possessed low tuneable glass transition values. Furthermore, novel monomers and their corresponding polymers have also been developed and subjected to an in-depth material characterization. These new reagents were synthesised with added benefit that would allow further modification of the polymer (post polymerisation modification) if needed. To package the electronic components developed while ensuring a perfect fit with the optical component(s), thermoshrinkable and shape memory polymers were developed. The very particular properties of these thermo-responsive polymers allow the extension of their applications well beyond the scope of PHOSFOS into areas of biomedicine, environmental science or even the automotive.

Integration and embedding technologies

PHOSFOS intended to realize polymer sensor pads with embedded optical fibre sensor elements (described in the previous sections) and embedded optoelectronic devices including adequate light sources to provide optical power to the sensor elements and photodetectors to detect the signal coming back from the sensor elements.

To do so PHOSFOS started with developing **three different approaches for embedding fibre sensors in thermally curable Polydimethylsiloxane (PDMS) material**; including injection moulding, laser structuring, and soft lithography. In addition, the techniques have been explored for commercially available UV curable materials, as well as for materials developed within PHOSFOS. Two different types of Polymer Optical Fibre (POF) were embedded in the course of the project, a single mode step index fibre, as well as a microstructured multimode fibre. Silica FBGs were used as a reference for all experiments. Three different types of highly birefringent (HiBi) microstructured silica fibres were available for embedding, all specifically designed to have a high transverse mechanical sensitivity and a low thermal response. In addition, standard silica draw tower gratings (DTG) were embedded in Ormocer® host materials, to allow full compatibility with the DTG Ormocer® coating.

The first embedding approach was to use **injection moulding** within a PMMA or glass mould where the fibres are supported in channels at the edge of the mould. A typical result of the injection moulding process is illustrated in Figure 13.

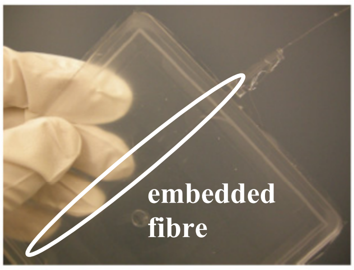


Figure 13. Moulded silica fibre in a thermally curable Polydimethylsiloxane (PDMS) material, Sylgard®184 from Dow Corning. A slow curing and cooling process is needed in order not to apply too much stress to the embedded fibre caused by the mismatch in thermal expansion coefficients.

The second approach was to use **laser ablation** to create tracks in a cured sheet of flexible or stretchable host material. Three different laser sources have been evaluated for this purpose: a KrF Excimer (λ = 248 nm), a frequency tripled Nd-YAG laser (λ = 355 nm), and a CO_2 laser (λ = 10.6 µm). The main advantage of this approach is the flexibility in terms of fibre embedding design, which allows the use of a recent popular design within the research area of stretchable (opto)electronics, incorporating meander shapes of non-stretchable materials (e.g. fibres) to allow for a certain amount of elasticity (Figure 14).

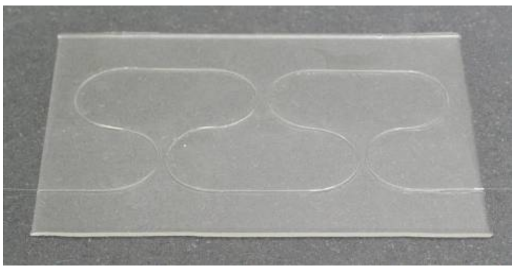


Figure 14. Fibre embedded in PDMS using laser ablation for the definition of the meandering design, allowing for skin elasticity. For Sylgard®184, the CO_2 laser provided the best results in terms of quality and speed. After laser patterning, the fibre is fixed into the track using dedicated glue allowing for firm fixation.

The final approach is based on a **soft lithography** process for which the position of the optical fibre is defined even more accurately, by transferring a well defined negative master mould into the skin host material. As a master mould, we have investigated SU-8 patterning on a silicon wafer, since this allows for high accuracies in XYZ, highly compatible with the requirements for fibre embedding. After patterning the SU-8 as part of the master mould, a controlled amount of PDMS material is poured on the silicon wafer, which can be easily removed from the master mould, after a moderate thermal curing step. As a result, the stretchable PDMS layer with U-shaped grooves serves as a base substrate for embedding the fibre sensor. This process is illustrated in Figure 15.

Figure 15. Releasing the PDMS material from the negative master mould, which serves as a base substrate for the optical skin. The next step consists of mounting, aligning and fixing of the fibre into the U-grooves, followed by a hot embossing step to control the top layer thickness. A liquid PDMS layer serves as glue between the bottom substrate and the (half cured) top layer.

Following the development of these embedding methods the response of fibre sensor elements embedded in polymer sensing pads was evaluated. During the experimental characterization the performance of embedded POF samples was compared with that of embedded silica fibres to illustrate the increased level of sensitivity. This section only shows a limited part of the characterization results for Sylgard 184 skin material.

The difference in strain response of POF grating sensors versus regular silica FBGs is probably the most important results in terms of characterization. The response investigated here is the result of longitudinal strain induced on the fibre sensor element as a result of strain applied to the polymer sensor pad. The silica fibre behaves very poorly even at modest strains in the millistrain range. There is evidence of slip and slide behaviour leading to a considerable amount hysteresis. Interestingly, even in the quasi-linear ranges, the strain sensitivity is only about 0.03 pm/µstrain, which is roughly a factor of 30 less than the sensitivity of the bare fibre. This is evidence that strain transfer from the elastic skin to the stiff silica fibre is very poor.

Bare fibre sensitivity		Skin sensitivity	
POF FBG	Silica FBG	POF FBG	Silica FBG
1.5 pm/ µstrain	1 pm/ µstrain	1.0 pm/ µstrain	0.03 pm/µ µstrain

Table 5. Linear strain sensitivities for bare fibre versus skin. Results for silica FBG are listed for comparison.

The POFBG exhibits a much more linear response with very little hysteresis and displays a sensitivity of 1.0 pm/µε. This is much closer to the bare fibre value of 1.5 pm/µstrain, but the difference is significant and indicative of the disparity between the elastic modulii of the POF and the Sylgard 184 material.

Sensitivity to contact pressure was assessed with the sensor pad lying on a hard flat surface, using a cylindrical post of mass 74 g and diameter 12 mm on which additional weights could be placed in various positions relative to the FBG, centred at postion (0,0). The response to pressure along the fibre axis for both the silica and POF sensors is shown in Figure 16 (Left). It may be seen that the lower elastic modulus of the POF results in a sensitivity approximately 10 times greater than the silica FBG. Finally, Figure 16 (Right) indicates a linear relationship between the Bragg wavelength and the applied weight. The response investigated here is results from longitudinal strain induced on the fibre sensor element as a result of a transverse force applied to the polymer sensor pad.

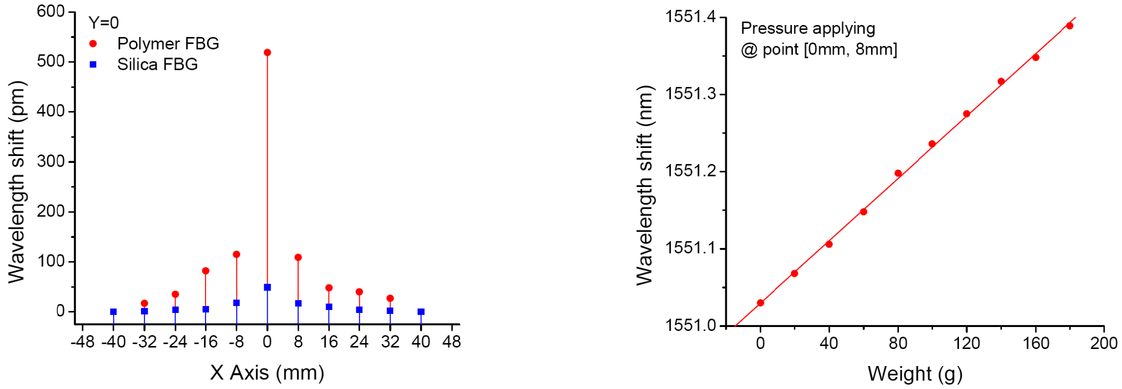


Figure 16. Left: Response of embedded silica and POF FBGs to pressure along the fibre axis. Right: Sensitivity to load at a point laterally offset 8mm from grating position.

The previous results were valid for FBGs in regular silica fibre and dealt with shift of the single Bragg resonance wavelength resulting from longitudinal strain on the fibre. We also characterized the performance of embedded highly birefringent microstructured fibres developed by PHOSFOS and described earlier. In the latter case we consider the change in peak separation between the two Bragg resonance wavelengths that results directly from transverse load acting on the fibre.

The temperature sensitivity for the Bragg peak wavelengths and the peak separation was also measured. Results for the sensitivity of the Bragg peak separation are provided in Table 6. This evidences that, although the temperature sensitivity is one order of magnitude higher than the extremely low values reported for the bare fibre sensors, the response of these embedded sensors is still one order of magnitude smaller than those of the individual Bragg peak wavelengths. The PHOSFOS sensor elements thus still contain a temperature insensitive property.

MSF Type I (Figure 3) embedded in PDMS			MSF Type II – butterfly (Figure 3) embedded in PDMS		
	Peak separation			Peak separation	
(pm/°C)	Linear fit	Standard error	(pm/°C)	Linear fit	Standard error
FBG1	0,16	0,07	FBG1	0,30	0,07

Table 6. Temperature sensitivity of the two types of PHOSFOS MSF after embedding in PDMS.

Contact pressure tests on the PDMS samples showed that the two Bragg peaks both respond with wavelength shifts of several tens of picometers, but that the corresponding change of the Bragg peak separation is fairly low (see Figure 17). This behaviour was confirmed for both PDMS and Ormocer® samples.

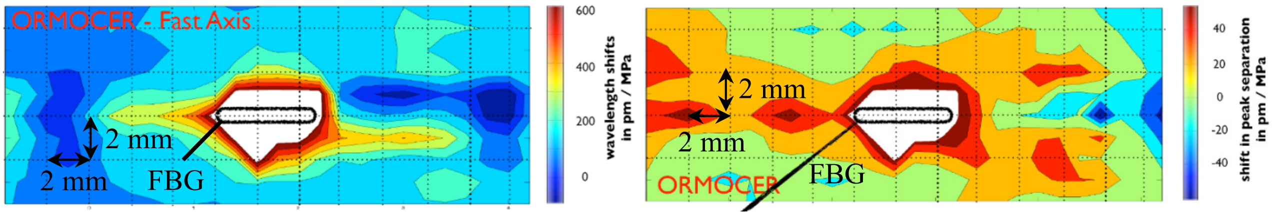


Figure 17. Colour plots showing the change of one of the Bragg peak wavelengths (left) and Bragg peak separation (right), when a load of 5 N is applied at different positions indicated by the grid. The sample is an Ormocer® skin containing a butterfly MSF (Type II). The position of the sensor is indicated with "FBG".

Due to the difference in material properties of the polymer pad material and the fibre glass, transverse load applied to the pad was initially not translated into a fibre sensor Bragg peak separation with amounts that did not yet meet application demands. To overcome this issue we have proposed to structure the polymer skin with grooves or airholes in order to create stress concentrating areas in the skin region that holds the MSF sensors. Our simulations predict sensitivity improvements up to 73% (Figure 18), depending on the geometry of the macrostructure. This brings the sensitivities close to those required to measure pressure distributions in prosthesis sockets, for example.

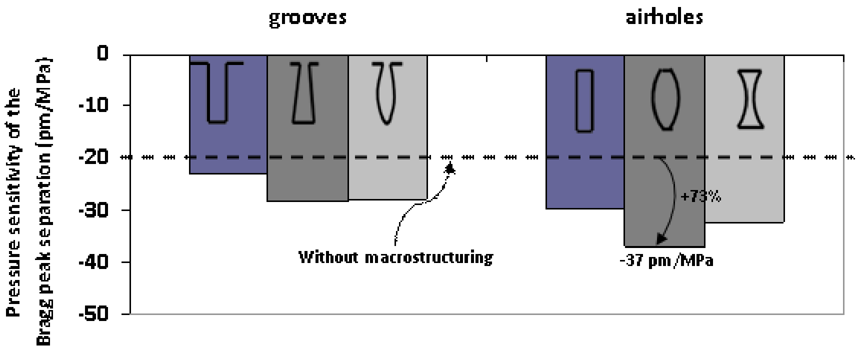


Figure 18. Overview of improved pressure sensitivities for different types of local macrostructures created in the polymer pad.

To conclude on embedded fibre sensor, **PHOSFOS has developed and tested different techniques to embed fibre sensors in flexible sensing skins with an accurate control on the fibre position within the skin**. These embedding techniques are compliant with both silica and polymer fibre sensors. This was the first crucial step towards a fully embedded photonic sensing skin.

Besides optical fibre sensors, optoelectronic devices including both optical sources and detectors also needed to be integrated within flexible polymer sensor pads. Optoelectronic devices are commercially available with a thickness of typically 150 µm. To realize a flexible package of the device, the chip itself needs to bend along with the surrounding substrate. Therefore the stiffness or bending resistance must be decreased. This is achieved by removing a significant part of the chip's backside substrate. **Using this approach very thin optoelectronics can be obtained, with a thickness of only 20 µm.** The presented die thinning process is purely mechanical and demonstrated on single mode and multimode vertical-cavity surface-emitting lasers (VCSELs) operating at 850 nm and at 1550 nm, as well as on photodiodes with an original thickness of 150 µm. Lapping reduces the thickness down to 50 µm and after subsequent polishing the die thickness is 20 µm. Figure 19 shows pictures of original and thinned VCSELs and photodiodes.

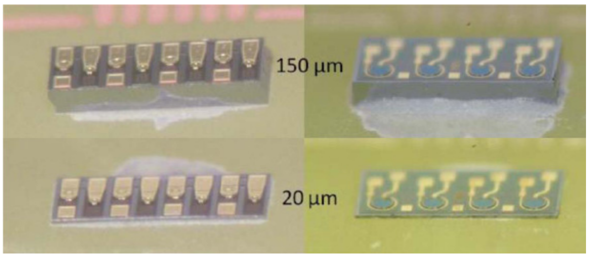


Figure 19. Commercially available 1 x 4 VCSEL array (ULM Photonics, left) and 1 x 4 photodiode array (Albis Optoelectronics, right) with dimensions of 1000 µm × 350 µm before (top) and after (bottom) thinning to a thickness of 20 µm.

The main characteristics to evaluate the thinning process are the yield, chip warpage, backside roughness and total thickness variation. The yield of the thinning process is related to the chip size, and for chips smaller than 1 mm^2 the yield is almost 100%. The chip flatness is within ±1 µm, and also the total thickness variation of the thinned dies is ±1 µm. The backside roughness after polishing is below 10 nm for very small dies (1000 x 350 μm^2), measured with a non-contact optical profiler on an area of 45 × 45 μm^2.

For the top-bottom contact devices (e.g. single mode VCSELs provided by ULM Photonics), a dedicated process for applying a new bottom contact after chip thinning was applied, based on AuGeNiAu. The measured voltage versus current (V-I) and optical power output versus current (L-I) curves of the original non-thinned and thinned devices are included in the graphs in Figure 20. The curves are almost identical which evidences that the devices operate properly after thinning and back-contacting.

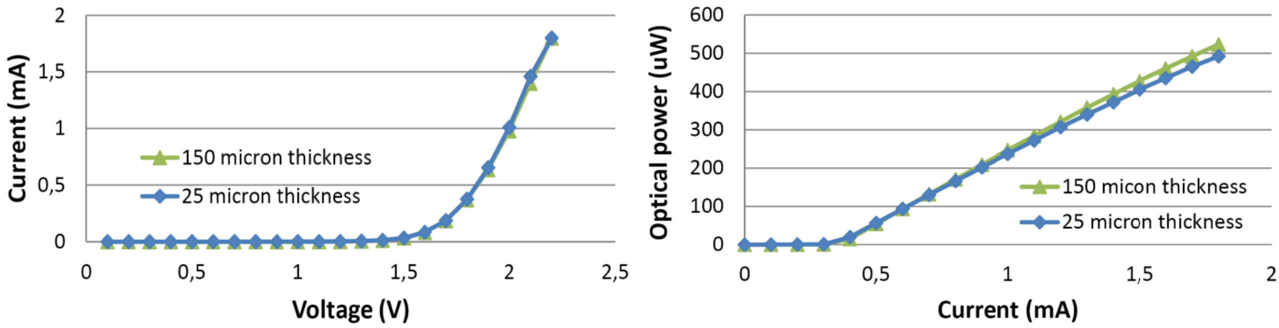


Figure 20. 850 nm single mode VCSEL V-I and L-I curves comparing original and thinned devices.

The basic process for embedding optoelectronic components in polymer layers is illustrated in Figure 21, incorporating application of the optical cladding layer on a rigid glass carrier, laser ablation of the cavity, in which the optoelectronic device will be mounted, mounting of the optoelectronic chip in the cavity, using a dedicated adhesive, levelling of the optoelectronic chip in the cavity, covering of the device with a thin optical cladding layer, and laser drilling to the chip contacts, metal deposition and pattern definition, and covering with an optical cladding layer. **This process has been demonstrated to work properly and after several adjustments the embedding of top-bottom contact devices was also proven to work.**

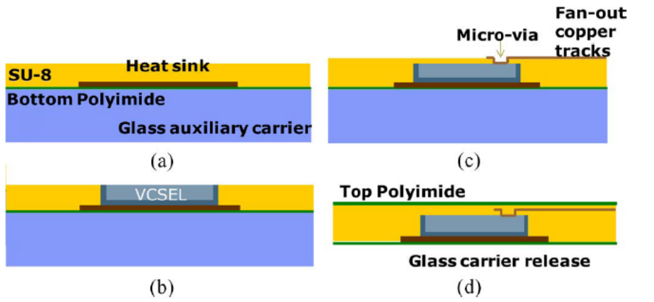


Figure 21. Schematic overview of the fabrication steps of the ultrathin flexible optoelectronic device package.

To test the bend-ability of embedded optoelectronic dies, a VCSEL chip was thinned down to 18 µm and embedded in a polymer package, as described above. Figure 22 shows pictures of the bended sample, down to a bending radius of 2 mm. **Up to 100 bending cycles over a cylinder with diameter of 4 mm were performed, without failure in functionality**.

Figure 22. Pictures of the optical foil with embedded optoelectronic devices (VCSELs), bended down to a radius of 2 mm.

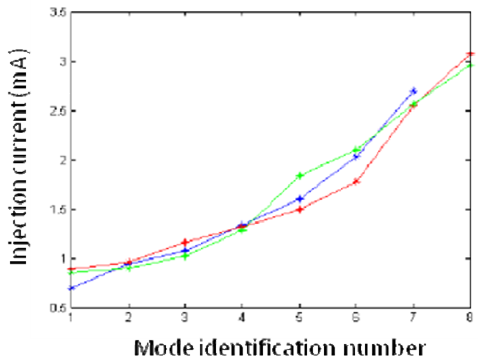


Figure 23. Average threshold current for the first 8 VCSEL modes for (Blue: average of the 150, 50, and 30 µm thick chips; Red: embedded chip in SU-8; Green: embedded chip in SU-8 with additional Truemode™ layer).

The influence of embedding multimode VCSELs was investigated comparing the threshold of each mode, i.e. the current at which a certain optical emission mode starts to appear, both for non-embedded dies (150, 50 and 30 µm thick) and for embedded dies (see Figure 23). The three curves are not identical (due to different VCSEL properties after fabrication), but the fluctuations are within an acceptable window, allowing us to conclude that **the thinning and embedding process of VCSELs has no significant influence on the functionality and optical characteristics of these devices.**

As soon as we had shown that these elements can be properly embedded we investigated how we can control the VCSEL emission wavelength in order to track the resonance wavelength of a fibre Bragg grating sensor and hence how we could use an embedded VCSEL to read out embedded fibre sensor elements. In this particular study we have evaluated the embedding configuration with respect to maximum wavelength shift for 850 nm single mode VCSELs (as this wavelength corresponds to the wavelength for which POFBGs are designed).

Figure 24 shows the red-shift for the different sample lay-outs. The labels for the samples refer to the substrate (FR4 "fiberglass reinforced epoxy" or PI "polyimid" type), the heat sink layer thickness, and the VCSEL thickness. From the graph, we cannot see any clear change in the slope $d\lambda_{fm}/dI_{VCSEL}$ by changing the package parameters. **A maximum possible wavelength tuning is limited to about 3 nm.**

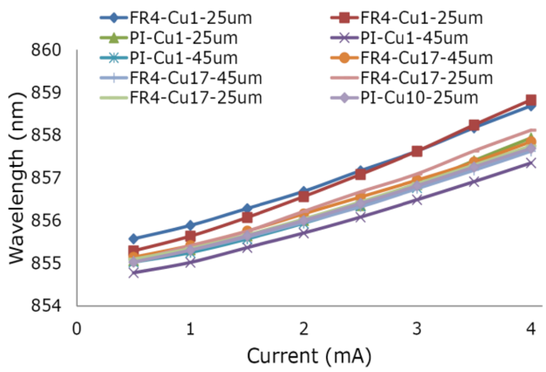


Figure 24: Fundamental mode wavelength for increasing VCSEL driver current (different 850 nm single mode VCSEL package situations).

Finally the optoelectronics need to be optically coupled to the optical fibres embedded in the polymer pads. To do so **we developed a coupling technology was developed providing a low-loss, robust, small, skin-compatible solution (i.e. enabling embedding in thin planar sensing pads).**

The coupling scheme consists of a PMMA plug (500 µm thickness) with a V-groove to clamp the fibre. A 45° mirror facet is introduced by using a dedicated 45° clamping master tool and different lapping/polishing steps. The reflecting layer is applied by evaporating a thin layer of gold. The coupling plug is to be mounted directly on top of the VCSEL or photodiode package. By applying the reflecting mirror directly on the coupling fibre, the free space optical path length is minimized.

To validate the coupling scheme, simulations have been performed using commercially available software. The following parameters were taken into account.

- Lateral misalignment tolerance
- Longitudinal misalignment tolerance
- Influence of the fibre type (single mode versus multimode)
- Influence of the VCSEL driving current
- Influence of the optical package top polyimide layer
- Influence of the thickness of the chip covering SU-8 layer (as part of the optical package)

The micromirror lapping and polishing process consists of subsequent mechanical lapping and polishing steps of the coupling plug. In Figure 25, microscope images are shown of the fibre facet after mechanical lapping and after polishing with different grain sizes. The end result is a flat fibre facet of optical quality with an average surface roughness of 23 nm on a 50 µm x 50 µm area.

Coupling losses inherent to the fibre coupling plugs were measured using a single-mode commercial single mode laser diode at 850 nm. A resulting coupling loss of 1 dB is measured.

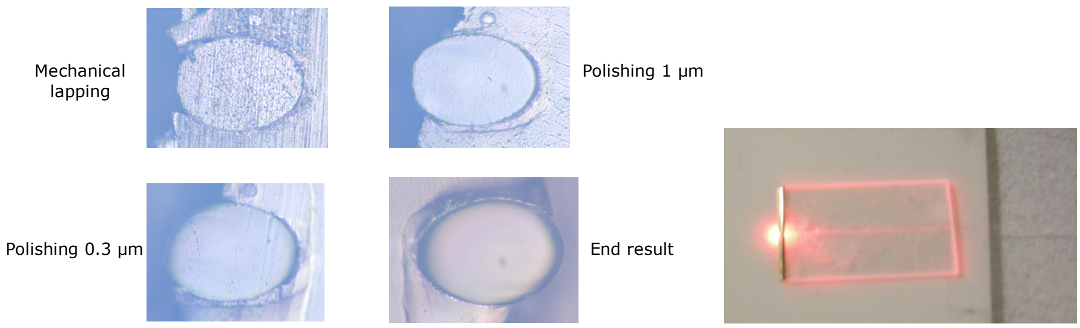


Figure 25. 45 degree facet (microscope view) of the fibre during lapping and polishing and a final coupling plug illuminated with a 635 nm light source.

To maximize the fibre-coupled power, the alignment process of the coupling plug is done actively. This implies real-time monitoring of the optical power coupled in the fibre during the alignment and fixing process. The resulting flexible optical packages, coupled to an optical fibre are shown in Figure 26. Electrical interconnections are provided by simple wires. These can easily be replaced by mechanically flexible connectors.

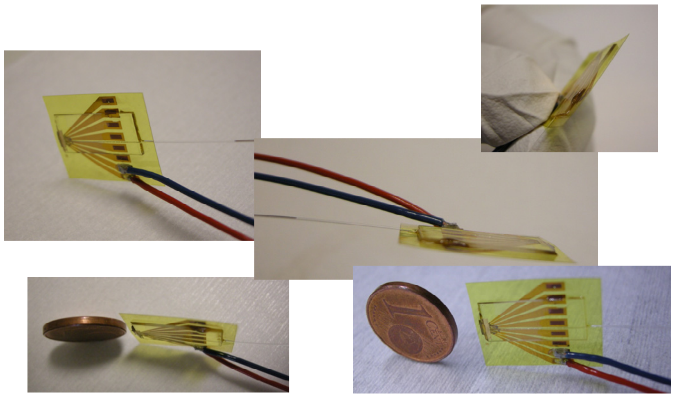


Figure 26. An ultra-thin flexible optical package bonded to a thin PMMA micromirror plug.

After aligning, coupling and fixing of the micromirror, the pigtailed devices were characterized. Coupling results are shown in Figure 27. After glue dispensing, a coupling loss of 2.8 dB and a tuning range of 3 nm is found. By making small adjustments to the coupling set-up (flatness of the sample, roughness of the coupling plug, pressure applied to the coupling during glue dispension), the coupling loss is further limited to 2 dB.

Integrated photodetectors have been pigtailed to the optical fibres using the same techniques as described above. Coupling losses are typically limited to 1 dB in this case.

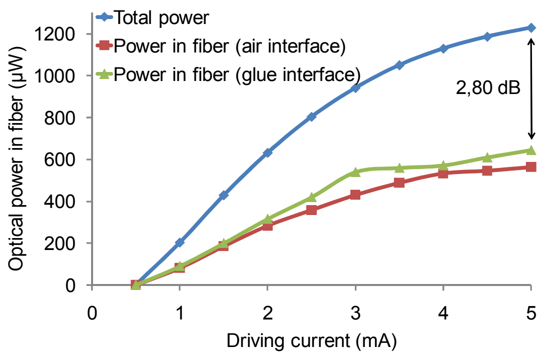


Figure 27. Coupling results.

To conclude on the integration and embedding technologies, final achievements versus targets are summarized in Table 7. **PHOSFOS has developed technologies to integrate every building block of a dynamic fibre sensing system, including highly accurate fibre embedding techniques which allow precise fibre positioning, dedicated thinning and embedding processes for optoelectronic driving units and low-cost, compact fibre coupling units.** These technologies are cornerstone to the fabrication of POF proof-of-concept systems and pave the way towards portable polymer sensing skins for a wide variety of applications.

Specification	Target	Achievement
Thinning of OE components	< 30 µm thickness < 1 µm edge roundness < 10 nm surface roughness	• Chip thickness down to 20 µm • Edge roundness down to 0.8 µm • Surface roughness down to 10 nm
Mechanical flexibility OE components	Down to 5 mm bending radii	Bending of embedded optoelectronic components down to 2 mm
Coupling interface	< 1 dB optical loss @ multimode POF	• Integrated single mode VCSEL to multimode silica fibre: 2 dB loss • Multimode silica fibre to integrated photodetector: 1 dB loss • POF losses inherently too high for the time being to assemble a fully embedded POF interrogation

Table 7. PHOSFOS detailed targets and achievements for the integration and embedding technologies.

Realization of the pre-product prototype and proof-of-concept systems

The final objective of PHOSFOS was to assemble systems that demonstrate the operation of all the technological features developed throughout the project. These systems should also pave the way to commercialization of the technologies by the two SMEs involved in the project, FOS&S and Astasense Ltd., in their respective market sectors. The systems were therefore selected based on clear market demands.

PHOSFOS targeted the embedding of optical fibre sensors in flexible polymer materials to obtain sensitive “photonic skins”. In the course of the project, it became obvious that owing to its unique features the glass microstructured fibre (MSF) sensor itself – without being embedded in a polymer pad – had a clear valorisation potential in the oil and gas industry. Application fields for complete glass fibre based photonic skins could also be identified, but were of lesser immediate commercial interest to FOS&S because the valorisation route was expected to be longer and more risky. **PHOSFOS therefore focused on rapid exploitation of the silica microstructured fibre sensors and developed a pre-product prototype based on this novel technology.**

The PHOSFOS glass fibre sensor acts as a tiny pressure sensor as already described in the previous sections. Owing to the special design of the microstructure of the fibre, it was possible to achieve pressure sensitivity whilst making the sensor insensitive to temperature variations. Most classical state-of-the-art pressure sensors exhibit temperature cross-sensitivity. This is for example because small variations in temperature will cause thermal expansion or shrinkage of the sensor packaging which in its turn affects the pressure readings. For pressure sensing this is particularly disadvantageous since pressure variations are often accompanied by temperature variations, resulting into an increased measurement error during pressure transients. Having a pressure sensor that is completely decoupled from temperature effects is therefore an important asset. **The PHOSFOS MSF sensor was found be outstanding with respect to the state-of-the-art for high pressure regimes as those encountered in the field of oil and gas exploration.**

For down hole monitoring in the oil and gas industry, there is indeed a clear need to measure in large pressure regimes (up to 1000 bar) and this in variable temperature conditions. Furthermore oil and gas industry is currently exploring fibre optic sensing solutions for various other applications because of the many well-known advantages of this technology that were already mentioned earlier. This application allowed FOS&S to define a clear business plan for commercializing PHOSFOS technology in the years to come and to identify which features a pre-product prototype should have in order to convince its customers.

The pre-product prototype consists of the MSF sensor contained in a specific ruggedized packaging with connection cable (Figure 28). The readout of the sensor was done using a commercially available interrogation system from FOS&S that was modified in order to comply with the new sensor technology.

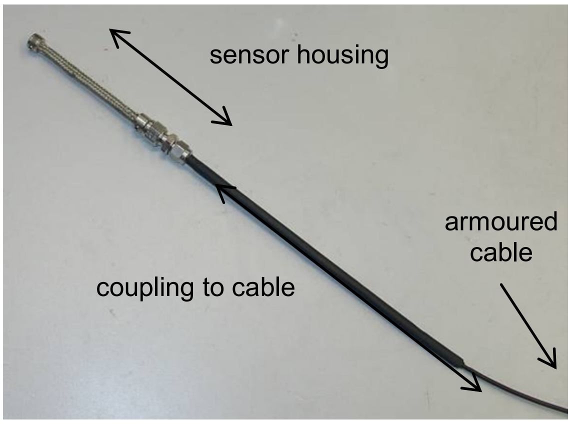


Figure 28. Picture of the sensor housing as used in the pre-product prototype.

The pre-product prototype was completely characterized in order to assess its measurement performance and in order to evidence that it can indeed be used for the targeted application. PHOSFOS thus focused on its performance at high pressures, during pressure transients and on its temperature cross-sensitivity features. **PHOSFOS constructed a dedicated setup with the pre-product prototype that clearly shows the proper operation of the sensor and that also shows that there are no main obstructions or 'showstoppers' for using this sensor in the envisaged application.**

The characterization revealed that the sensor can easily be used up to 1000 bar. Furthermore, the sensor showed good linearity and reproducibility over this entire pressure range, both properties that are required for proper operation. The temperature cross-sensitivity was also determined and was found to be negligibly small (of the order of -0.03 bar/°C). Hence the required decoupling between pressure and temperature could also be met. Finally the sensor was capable of operating at temperatures up to 250°C, a range that is currently sufficient for most oil wells.

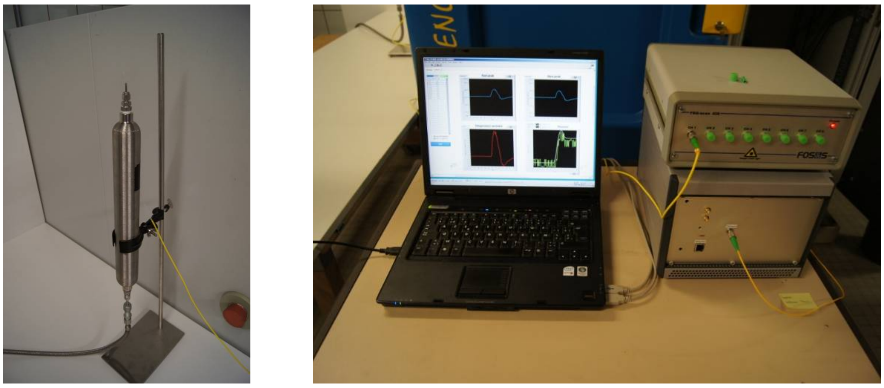


Figure 29. Picture of the air pressure vessel (left) and the interrogator system with controller software (right) used for the demonstrator.

A demonstration set-up was put together to allow showing the product and its unique properties to industry and to the public. In this set-up the sensor is exposed to compressed air in a pressure vessel (Figure 29). When the air is rapidly compressed the temperature rises, whereas cooling occurs during decompression. Hence pressure and temperature transients occur simultaneously. Both the controller and the interrogator were steered by specially designed LabView software that allows automatic cyclic pressure calibrations. The pressure readings nicely correspond with those from the electrical reference sensor and this in the presence of a clear thermal gradient. The ability of the sensor to de-couple and independently measure pressure and temperature are clearly visible. In a second similar but more simplified demonstrator setup, the sensor was exposed to a thermal shock while being kept at atmospheric pressure. The thermal shock was applied by placing the sensor from room temperature into boiling water. During this rapid temperature increase the pressure reading remains constant. This also nicely evidences the unique selling point of the PHOSFOS glass MSF sensor.

In conclusion, both the characterization and the demonstration set-ups for the pre-product prototype of the glass microstructured fibre sensor evidenced that this sensor is adapted for down hole monitoring in the oil and gas industry and that there are no showstoppers for further development and commercialization of the product.

We now turn to the area of polymer optical fibre based sensors and sensor pads. Body area sensor networks present many commercial opportunities and can enable novel applications in healthcare as well as improving the efficacy of existing techniques. Whilst silica fibre sensors have in recent years taken a significant market share in the measurement of hard structures such as wind turbines, tunnels and bridge they have made fewer inroads into the sensing of more compliant materials. It is in this area that the emerging technology of polymer optical fibre (POF) sensors and more specifically POF fibre Bragg gratings (FBGs) are beneficial and it is here that the second SME involved in PHOSFOS, Astasense Ltd., developed its business plan.

As discussed earlier the key advantages that polymer FBGs have are:

- they can measure very high strain ratios – ten times more than silica FBGs;
- the elastic modulus is low so they can be embedded in things that need to stretch or into materials that are not themselves strong and where the additional strength from the inserted sensors in undesirable;
- the materials are safer to use, e.g. in medical applications it is undesirable to insert silica fibre into the body if there is a risk of the fibre breaking;
- in the long term the systems should be lower cost since the lasers used to make the POF FBGs are significantly cheaper and the preferred operating wavelength is around 800 nm which makes the light sources and detectors required to power and interrogate the sensors are lower cost.

Commercial applications, where polymer FBGs are merely replacing glass fibre FBGs, are unlikely to be successful at this stage since glass fibre technology is much more mature, well understood and reliable. Therefore the most attractive applications are where there are technical advantages, that require the features listed above, that address issues where there are known significant problems with the alternative technology. At the start of PHOSFOS POF FBG technology was in its infancy. Grating writing times were very long, the process was unrepeatable, permanent connections to the fibre were not possible in order to accurately test the devices, there were concerns about the reliability of the device which had also never been embedded and commercial fibre was not available. **Significant progress has now been made by PHOSFOS in these areas that will enable commercial manufacture of POF FBGs**.

The aim of PHOSFOS was not just to make these POF FBG devices reliably but also to embed them in a flexible skin or tube that could be wrapped around a non uniform shape like a person's body or inserted into tube like a catheter. Work within PHOSFOS has shown that embedding results in more robust and easy to use sensors. Additionally, it was planned, where possible, to embed the optoelectronics (light sources and detectors) in the skin which is a significant step towards producing a self contained sensor system. **This work has moved the realisation of sensing patches costing a few hundred EURO significantly forward.**

As part of PHOSFOS two proof-of-concept systems highlighting the potential of the PHOSFOS technology in POF were built with two application areas in mind: gastro-intestinal pressure sensing and respiratory/cardiac monitoring. These areas were selected as a result of a market pull described in the Astasense Ltd. business plan.

The gastro-intestinal pressure sensing demonstrator is shown in Figure 30. The system has been designed to operate at 850 nm and uses multimode POF to maximise the light being reflected. The system can monitor a number of different sensors. **The pressure sensitivity for the embedded POFBG is over five times higher than an equivalent glass FBG, which relaxes the resolution requirements of the interrogation system.**

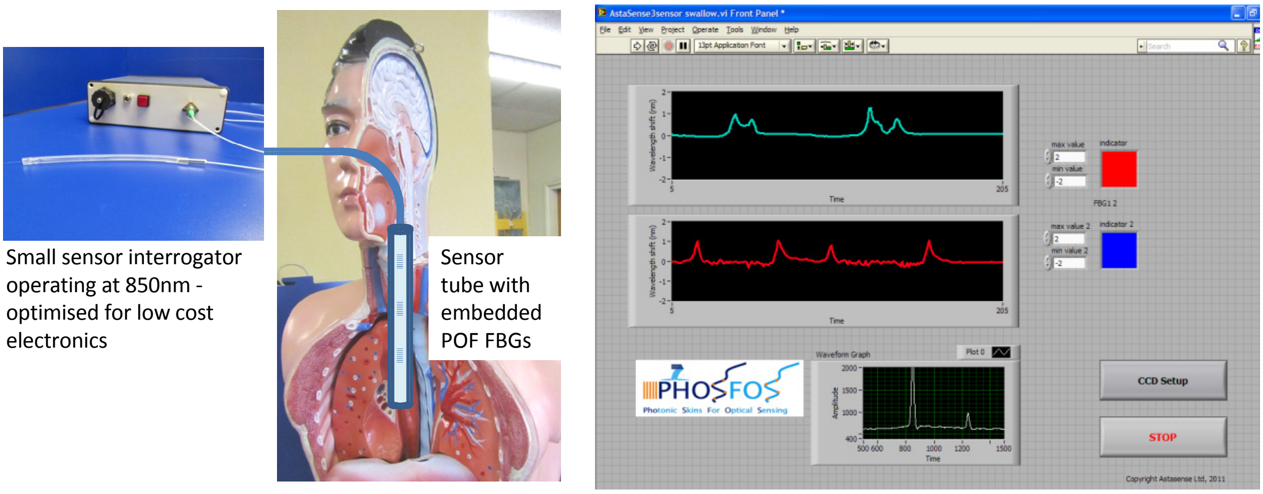


Figure 30. Gastro-intestinal pressure sensor with low cost interrogation unit developed during the PHOSFOS project (left) and the software interface showing the output of a two sensor POF FBG array (right). The software is designed to show a graphical output for the pressure and a coloured display where the colour changes with the amount of pressure.

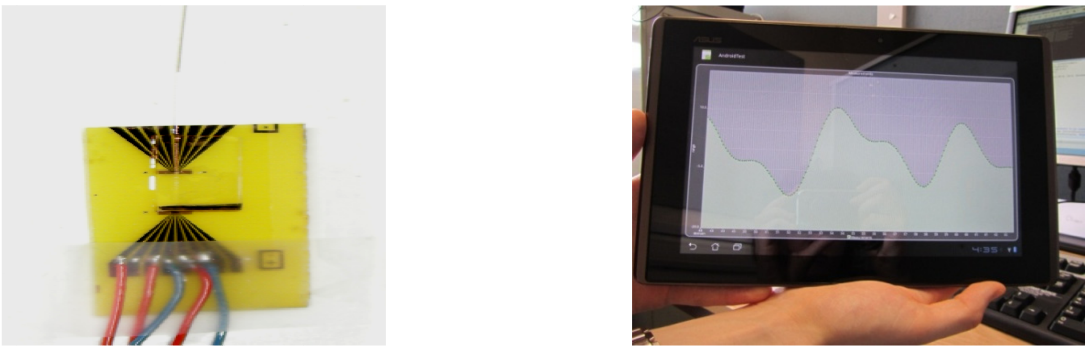


Figure 31. Flexible skin demonstrator embedded detector (left) and Android display (right).

The flexible skin demonstrator was developed with respiratory monitoring in mind. The system uses a low cost VCSEL light source and embedded glass FBG sensor and detector. The data is collected by a portable electronics board and the data is transmitted via Bluetooth to a standard Android tablet or phone which can display current or stored data (Figure 31). **This approaches opens up the possibility of a single channel sensor that costs only a few hundred EURO** – a significant cost reduction for this technology. In the future it will also become possible to use this miniaturized interrogator with embedded POFBGs. With the skin sensors (either in glass or polymer fibres) it is also possible to use the interrogator system developed for the pressure sensing demonstrator allowing the monitoring of multiplexed sensors.

Whilst there is still progress to be made the POF sensors offer a real advantage in terms of the significantly higher strains that they can survive and the low rigidity which makes them ideal for monitoring flexible subjects. In addition, the polymer material of the fibre opens up design parameters not available to silica fibre manufacturers in terms of optimising the chemical nature of the material. **The spectrometer-based interrogator and the integrated VCSEL-based interrogator can be used with both silica and POFBGs. Because they are both low-cost alternatives to the currently available devices they will have immediate commercial relevance. PHOSFOS has thus significantly advanced both the near and long term commercial impact of FBGs in general and of POF gratings in particular.**

1.4. The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results.

Targeted scientific and technical dissemination

PHOSFOS research results were published in **22 journal publications** indexed by the ISI Web of Science as listed in Table 8.

N°	Authors	Title	Journal info	Partners involved
1	T. Geernaert et al.	Transversal Load Sensing With Fiber Bragg Gratings in Microstructured Optical Fibers	IEEE PTL, vol. 21, pp. 6-8, (2009)	VUB WRUT UMCS
2	T. Martynkien et al.	Birefringent photonic crystal fibers with zero polarimetric sensitivity to temperature	Appl. Phys. B, vol. 94, pp. 635-640 (2009)	WRUT UMCS VUB
3	G. Luyckx et al.	Response of FBGs in Microstructured and Bow Tie Fibers Embedded in Laminated Composite	IEEE PTL, vol. 21, pp. 1290-1292, (2009)	VUB WRUT UMCS
4	E. Bosman et al.	High reliable flexible active optical links	IEEE PTL, vol. 22, pp. 287-289 (2010)	IMEC
5	T. Geernaert et al.	Bragg Grating Inscription in GeO_2-Doped Microstructured Optical Fibers	IEEE JLT, vol. 28, pp. 1459-1467 (2010)	VUB WRUT UMCS
6	T. Geernaert et al.	Point-by-point Fibre Bragg Grating Inscription in Free-standing Step-Index and Photonic Crystal Fibres using NIR Femtosecond Laser	Optics Letters, vol. 35, pp. 1647-1649 (2010)	VUB CUT WRUT UMCS
7	C. Zhang et al.	Optical fibre temperature and humidity sensor	Electronics Letters vol. 46, pp. 643-644 (2010)	AU
8	D. Sáez-Rodríguez et al.	Water diffusion into UV inscripted Long Period Grating in microstructured polymer fibre	IEEE Sensors Journal vol. 10, pp. 1169-1173 (2010)	AU
9	X. Chen et al.	Highly Sensitive Bend Sensor Based on Bragg Grating in Eccentric Core Polymer Fiber	IEEE PTL, vol. 22, pp. 850-852 (2010)	AU CUT
10	X. Chen et al.	Bragg grating in polymer optical fibre for strain, bend and temperature sensing	Measurement Science and Technology, vol. 21, pp. 94005 (2010)	AU CUT
11	E. Bosman et al	Fully flexible opto-electronic foil	Journal of Selected Topics in Quantum Electronics, vol. 16, pp. 1355-1362 (2010)	IMEC VUB
12	T. Martynkien et al.	Highly birefringent microstructured fibers with enhanced sensitivity to hydrostatic pressure	Optics Express, vol. 18, pp. 15113-15121 (2010)	WRUT UMCS VUB
13	M. Szczurowski et al.	Measurements of polarimetric sensitivity to hydrostatic pressure, strain and temperature in birefringent dual-core microstructured polymer fiber	Optics Express, vol. 18, pp. 12076-12087(2010)	WRUT AU
14	M. Szczurowski et al.	Measurements of stress-optic coefficient in polymer optical fibers	Optics Letters vol. 35, pp. 2013-2015 (2010)	WRUT AU
15	G. Statkiewicz-Barabach et al.	Polarizing photonic crystal fiber with low index inclusion in the core	Journal of Optics, vol. 12, pp. 75402 (2010)	WRUT UMCS VUB
16	I.P. Johnson et al.	827 nm Bragg grating sensor in multimode microstructured polymer optical fibre	Electronics Letters, vol. 46, pp. 1217-1218 (2010)	AU CUT
17	C. Sonnenfeld et al.	Microstructured Optical Fiber Sensors Embedded in a Laminate Composite for Smart Material Applications	MDPI Sensors, vol. 11, pp. 2566-2579 (2011)	VUB WRUT UMCS
18	T. Baghdasaryan et al.	Geometrical study of a hexagonal lattice photonic crystal fiber for efficient femtosecond laser grating inscription	Optics Express, vol. 19, pp. 7705-7716 (2011)	VUB
19	E. Bosman et al.	Ultra thin optoelectronic device packaging in flexible carriers	IEEE Journal of Selected Topics in Quantum Electronics vol. 17, pp. 617-628 (2011)	IMEC VUB UG
20	J. Missinne et al.	Flexible Shear Sensor Based on Embedded Optoelectronic Components	IEEE PTL, Vol. 23, pp. 771-773 (2011)	IMEC
21	G.N. Smith et al.	Characterisation and performance of a Terfenol-D coated femtosecond laser inscribed optical fibre Bragg sensor with a laser ablated microslot for the detection of static magnetic fields	Optics Express, vol. 19, pp. 363-370 (2011)	CUT AU
22	C. Koutsides et al.	Characterizing femtosecond laser inscribed Bragg grating spectra	Optics Express, vol. 19, pp. 342-352 (2011)	CUT AU

Table 8. List of PHOSFOS Journal Publications.

Furthermore PHOSFOS contributed to conferences and workshops with **67 presentations and posters**, of which were invited. This provided great international visibility of PHOSFOS results with a scientifically educated public.

In addition to the journal publications and conference presentations, the book "Advanced Fibre Optics" edited by L. Thévenaz that has been published by CRC Press in April 2011 holds two chapters that explicitly acknowledge EU Commission Funding and PHOSFOS:

- F. Berghmans (VUB) and T. Geernaert (VUB), "Optical Fibre Point Sensors";
- K. Kalli (CUT) and D.J. Webb (AU), "Polymer Optical Fibre Based Sensors".

There were close links between PHOSFOS and two European initiatives in the field of optical fibre technology, more particularly the COST 299 Action "Optical Fibres for New Challenges Facing the Information Society" (finalized in 2009) and the new COST TD1001 Action "Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications" (started in 2011). The coordinator of PHOSFOS was vice-chair of the COST 299 Action, which also involved the participation of CUT. This action has allowed **PHOSFOS to contribute to the field of standardization** by means of the participation in the writing of the document "Guideline for Use of Fibre Optic Sensors" edited by the Action's study group on Applications and Standardization of Fibre Sensors. This guideline is now used as a basis for updating of standard document "IEC 61757-1 Ed. 2.0: Fibre optic sensors - Part 1: Generic specification" by the IEC Study Group 86C. VUB, WRUT, UMCS, CUT, AU and AS are now also actively participating to COST TD1001: VUB as management committee member, CUT as working group leader, and AU as secretary. This will ensure continued dissemination of PHOSFOS spin-out results with a truly specialist audience.

No.	Company Name	Logo	No.	Company Name	Logo
1	Melexis (BE)		10	General Electrics Research	
2	OpTech-Net (DE)		11	Thales Alenia Space (FR)	
3	TE Connectivity (BE)		12	Airborne (NL)	
4	Ineos Oxide NV (BE)		13	Xenics (BE)	
5	Cetemmsa (ES)		14	WTCB (BE)	
6	Orfit Industries (BE)		15	Shell International E&P BV (NL)	
7	Vanderhoek Photonics (NL)		16	Verhaert (BE)	
8	BAM (DE)		17	S.S.F. Safe Smart Fabric Adaptable Surfaces Ltd. (CY)	
9	Centexbel (BE)		18	Bioimerosin (GR)	
			1	European Space Agency (NL)	

Table 9. List of PHOSFOS Industrial User Club members.

In order to achieve **targeted dissemination of results to industries** that had a clear interest in PHOSFOS technologies, an Industrial User Club (IUC) was set up. Companies and research centres received the opportunity to sign up for this IUC. In return they would receive first hand information about the project results and they would be invited to attend the two "Benefits for Industry" workshops that were organized by PHOSFOS in 28th October 2009 (Brussels, Belgium) and 22nd May 2011 (Munich, Germany). The list of companies that asked for an IUC membership is given in Table 9. This IUC also proved a useful platform to start follow-up projects as detailed in the section on exploitation of results.

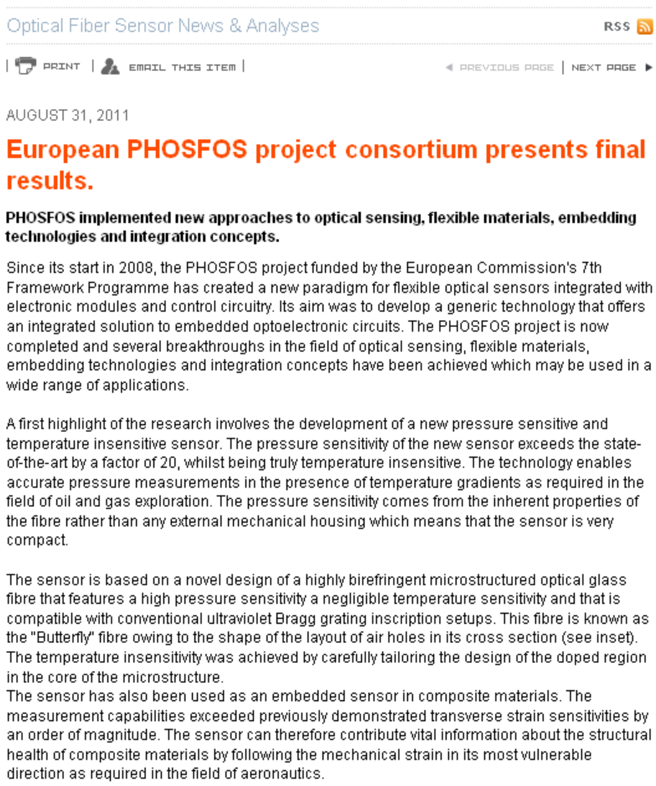
Dissemination to wider audience

Additional PHOSFOS dissemination activities also targeted a broader audience. These included the publication of articles in more general technical press as well as participation in conference exhibits and technical-scientific fairs.

PHOSFOS has appeared in technical press magazines as listed in Table 10 . Together with other types of press echoes such as reports in newsletters and in national periodicals, PHOSFOS has appeared 23 times in various types press. In addition, over 70 echoes referring to PHOSFOS were spotted on the internet. A most recent PHOSFOS news release appeared on opticalfibersensors.org on 31st August 2011 (Figure 32).

No.	Magazine	Article Title	Publication Date
1	Optics & Laser Europe	Flexible Photonics Shape up for Sensing	July/August 2008
2	Europhotonics	Optical Sensor System Uses Artificial 'Skins'	August/September 2008
3	Photonics Spectra	Give me some Photonic Skin	October 2008
4	Laser Focus World	IMEC paves the way toward optical-sensing foils	October 2008
5	Laser Focus World	Fiber-sensor technology is thin-skinned but robust	July 2010
6	Optics and Photonics News	Photonics in Europe	December 2010

Table 10. List of PHOSFOS related articles in technical press.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AUGUST 31, 2011

European PHOSFOS project consortium presents final results.

PHOSFOS implemented new approaches to optical sensing, flexible materials, embedding technologies and integration concepts.

Since its start in 2008, the PHOSFOS project funded by the European Commission's 7th Framework Programme has created a new paradigm for flexible optical sensors integrated with electronic modules and control circuitry. Its aim was to develop a generic technology that offers an integrated solution to embedded optoelectronic circuits. The PHOSFOS project is now completed and several breakthroughs in the field of optical sensing, flexible materials, embedding technologies and integration concepts have been achieved which may be used in a wide range of applications.

A first highlight of the research involves the development of a new pressure sensitive and temperature insensitive sensor. The pressure sensitivity of the new sensor exceeds the state-of-the-art by a factor of 20, whilst being truly temperature insensitive. The technology enables accurate pressure measurements in the presence of temperature gradients as required in the field of oil and gas exploration. The pressure sensitivity comes from the inherent properties of the fibre rather than any external mechanical housing which means that the sensor is very compact.

The sensor is based on a novel design of a highly birefringent microstructured optical glass fibre that features a high pressure sensitivity a negligible temperature sensitivity and that is compatible with conventional ultraviolet Bragg grating inscription setups. This fibre is known as the "Butterfly" fibre owing to the shape of the layout of air holes in its cross section (see inset). The temperature insensitivity was achieved by carefully tailoring the design of the doped region in the core of the microstructure.
The sensor has also been used as an embedded sensor in composite materials. The measurement capabilities exceeded previously demonstrated transverse strain sensitivities by an order of magnitude. The sensor can therefore contribute vital information about the structural health of composite materials by following the mechanical strain in its most vulnerable direction as required in the field of aeronautics.

Figure 32. Screenshot of latest PHOSFOS press release on http://www.opticalfibersensors.org.

A highlight of the dissemination activities was the visibility and presence of PHOSFOS at **SPIE Photonics Europe 2010**. PHOSFOS participated in the conference's European Village which allowed EU projects to advertise their results. PHOSFOS technology was on display as shown in Figure 33. IMEC presented its flexible integration technology with "Photonics in Motion: stretchable optical waveguide" at the Symposium's Innovation Village. This provided great visibility of the project on the European photonics scene.

PHOSFOS was also present at the September 2010 **British Science Festival** organised in Birmingham (UK) with an exhibit entitled "The Light and Sound show" (Figure 34). This show welcomed approximately 1200 visitors per day and was situated in the entrance foyer thus gaining significant exposure.

(a) (b)

Figure 33. (a) PHOSFOS booth at SPIE Photonics Europe – European Village (b) H. Thienpont (VUB) interviewed by Belgian VTM Television Channel for prime time news in front of PHOSFOS booth.

Figure 34. The "Light and Sound Show" booth at the British Science Festival.

PHOSFOS embedded fibre sensor technology was also presented at the Brussels Photonics Team B-PHOT (VUB) booth during the European Commission's **ICT 2010 fair** organized at Brussels Expo from 27 to 29 September 2010. This booth allowed attracting interest from many companies. In addition, the Coordinator was able to explain to Mrs. Neelie Kroes (Vice President of the European Commission and European Digital Agenda Commissioner), to His Royal Highness Prins Philippe of Belgium and to Minister Benoît Cerexhe (Brussels Capital Region – minister in charge of Research) about:

- how vital it was for research teams to participate in EU funded projects;
- how it allowed collaborating with industry, with PHOSFOS as an example;
- and about the role of Photonics in our modern society (Figure 35).

Dissemination to a wider audience is also achieved with a PHOSFOS page on wikipedia.org that has received over 3300 visits. Finally, PHOSFOS produced an introductory and promotional movie about the project that has been made available on youtube.com (see also section 1.5 and Figure 38) and that has already been viewed over 1200 times.

Figure 35. Visit of Mrs. Neelie Kroes, HRH Prins Philippe of Belgium and Minister Benoît Cerexhe to VUB's B-PHOT booth with PHOSFOS on display at ICT2010

Exploitation of results

Exploitation of PHOSFOS foreground knowledge was conducted on several fronts by the beneficiaries. The academic partners protected foreground knowledge through patent filings and used that knowledge to start new funded research projects. The SMEs intend to commercialize PHOSFOS results and have made clear business plans for that purpose.

Table 11 below lists the patents that were filed by academic partners to protect foreground results and that pertain to 5 specific project developments. Two of these are currently being transferred to industry through license agreements:

- the silica micro-structured fibre structures for sensors;
- the polymer optical fibre sensor for water in fuel detection.

PHOSFOS Patent	Patent document titles and filing/publication information	Subject	PHOSFOS Beneficiaries Involved
1	"Optical Fibre structure for sensors" PCT/EP2009/065458, filed 19th Nov. 2009 "Birefringent micro-structured optical fiber for sensor application" PCT/EP2010/067862, filed 19th Nov. 2010 "Birefringent micro-structured optical fiber for sensor application" WO 2011061309, published 05th May 2011	Silica micro-structured fibre structures for sensors	VUB WRUT UMCS
2	"Optical Fibers" US Provisional Application 61/357,226, filed 22nd Jun. 2010 "Methods and systems in optical fiber technology" PCT/EP2011/060518, filed 22nd Jun. 1011	Silica micro-structured fibre structures for grating writing	VUB
3	"Optical Tactile Sensors" PCT/EP2010/058808, filed 22nd Jun. 2010 "Optical Tactile Sensors" WO 2010149651, published 29th Dec. 2010	Tactile sensors based on thinned and packaged VCSELs	IMEC VUB
4	"Water-in-fuel sensor" PCT/GB2010/001623, filed 27th Aug. 2010 "Water-in-fuel sensor" WO 2011027099, published 11th Mar. 2011	Polymer optical fibre sensor for water in fuel detection	AU
5	"Optical shear sensor and method of producing such an optical shear sensor" PCT/EP2011/055517, filed 8th Apr. 2011	Shear sensors based on thinned and packaged opto-electronics	IMEC

Table 11. Summary of PHOSFOS IP protection measures. The 2nd column lists all the relevant documents pertaining to the same IP protection measure.

PHOSFOS developments allowed defining many new research projects of which 14 have been started. 8 of these projects also involve PHOSFOS IUC members. They are shortly described below.

No.	Project Title	Project Type	Project subject	PHOSFOS Beneficiaries Involved
1	"Advanced Polymer Prototyping Line for Micro- and Micro-Optical Systems" - APPLIE4MOS	Hercules Foundation Flanders - Large scale infrastructure grant	This project puts together a micro-technological fabrication platform for micro-optical elements. The project builds on the following topics: Biophotonic Lab-on-a-chip micro-systems Minimally-invasive micro-systems for medical applications Micro- and nano-structured biosurfaces and artificial biomedical skins Large area flexible, stretchable, and wearable electronics Embedded optical fibre sensor systems Micro-systems for functional lighting and solar energy Micro-systems for optical datacom and interconnect applications Micro-systems for 3-D projection and displays	VUB IMEC UG
2*	"Intelligent amputee sockets employing real time advanced photonic sensors for optimum fit and pressure relief through active controls" - SmartSOCKET	EU FP7 People Programme - Marie Curie Industry Academia Partnerships and Pathways (IAPP)	SmartSOCKET aims at realizing an intelligent amputee socket with optimum fitting and pressure relief utilizing embedded fibre sensors for strain/shear measurement and countershear actuators for readjusting the pressure map distribution across the knee-socket interface. SmartSOCKET is the first project addressing fibre sensing configurations in true rehabilitation and biomechanic applications, intending to exploit the advantages of real-time and high-accuracy sensing capabilities of optical fibre structures towards equipping amputee sockets with true pressure-detection and subsequently pressure-relief characteristics	VUB
3*	"Evaluation of building blocks and Proof of concept demonstration of Easy installable Physical Contact connectors for future optical networks" - EP(2)CON	Agency for Innovation by Science and Technology- Flanders (IWT) – Industrial Research and Development Project	The objective focuses on building blocks allowing for very accurate alignments in demateable concepts and optical polymer formulations addressing the problems of the index matching chemicals used in all kinds of field installable connectivity products. The project is led by TE Connectivity.	VUB IMEC UG
4*	"Platform for Large Area Conformable Electronics by Integration" - PLACE-it	EU FP7 Integrated Project	PLACE-it aims to analyse, develop and implement technology for the proper combination of functionalities in foil, stretchable and fabric substrates, resulting in conformable opto-electronic systems. Two application areas will profit from the developments in the PLACE-it project: - "On the body" healthcare and wellness applications - Consumer product design freedom	IMEC
5	"Water in fuel sensor"	UK Research Council sponsored Knowledge Transfer Challenge	Humidity sensing using Bragg gratings in POF based on the ability of PMMA to absorb water leading to a swelling and increase in refractive index. His answers a commercial requirement for water in fuel sensing in the aviation industry.	AU
6	"Effective Structural Health Monitoring with Additive Manufacturing" - e-SHM	Agency for Innovation by Science and Technology- Flanders (IWT) – Strategic Basic Research Project	The aim is to develop new additive manufacturing techniques that incorporate in-situ structural health monitoring techniques. One of these techniques relies on micro-structured optical fibre technology.	VUB
7*	"Proof-of-concept System for an Optical Fibre Sensor System Integrated in an Irradiation Head Plate"	User project funded under the EU FP7 Coordination and Support Action ACTMOST	The aim of this feasibility study is to verify if optical fibre sensors based on fibre Bragg gratings in micro-structured optical fibre can be successfully applied for measuring the fixation force on and potentially the movement of a human head when fixed in the head plates developed by Orfit Industries Belgium. These head plates are used in the treatment of tumours during radiotherapy.	VUB UMCS IMEC
8*	"Multilayer Photonic Circuits made by Nano-Imprinting of Waveguides and Photonic Crystals" - FireFly	EU FP7 Specifically Targeted Research Project	The objective of FireFly is the introduction of novel polymer waveguide and photonic crystal structures based on highly structured 3D nano-hybrids into industrial applications by using a	IMEC

			new cost effective production process for larger scale manufacturing. The target applications are optical waveguides and photonic structures for the manipulation of light in, for example, optical interconnects	
9	"Flexible and stretchable optical materials with liquid crystals"	Research Foundation Flanders (FWO) - Basic Research Project	The project targets new electro-optic, opto-mechanic, and electro-mechanic phenomena, with applications in flexible displays, artificial muscles, tunable gratings, intelligent lenses etc.	UG
10*	"Stimuli responsive textile materials" - HYGEL	Agency for Innovation by Science and Technology- Flanders (IWT) – Bilateral Research Project	The aim is to develop thermo-responsive materials to be used as coating for various textile materials as investigated by Centexbel.	UG
11*	"Materials for the Irradiation Head Plate"	Bilateral Project	The project aims to tackle stability issues of materials used for irradiation head plates manufactured by Orfit Industries upon storage under conditions with varying humidity levels.	UG
12*	"Development of polyethylene oxide derivatives"	Bilateral Project	The project targets the development of polyethylene oxide (PEO) derivatives with various end groups with INEOS, which is the world-leader in the production of PEO with various molecular weights.	UG
13	No title	Ministry of Science and Education grant (Poland)	Development of fabrication technology of rocking filters in microstructured silica fibers and sensing applications of such structures.	WRUT UMCS
14	No title	National Structural Funds for the EIT+ platform (Poland)	Development of the fabrication technology of polymer microstructured fibers for sensing purposes.	WRUT UMCS

Table 12. List of new funded research projects that have emerged from PHOSFOS results. The project numbers marked with an asterisk indicate those projects involving a PHOSFOS IUC member.

The SMEs have defined detailed business plans in view of commercializing the technologies developed by PHOSFOS or part thereof. These business plans are confidential and therefore only general information regarding these plans is provided here.

The first SME involved in PHOSFOS – FOS&S – has elaborated a business plan targeting the application field of oil and gas exploration using the micro-structured optical fibre sensor technology developed by PHOSFOS. The plan builds on the unique selling point of the technology, i.e. the demonstrated possibility to carry out high pressure measurements in a temperature insensitive manner. There is a clear market demand in this field as modern well completions can be complex; the reservoir can be split between multiple levels, with each zone producing at differing rates, gas/oil/water ratios, pressures and temperatures. The reservoir engineer's goal is to recover most of the hydrocarbon reserves in the field. Unfortunately, current recovery efficiency averages only about 35%. To optimize recovery efficiency, the industry is turning toward enhanced-well and reservoir-management techniques, such as "smartwells" or "intelligent" completions. Inherent to this trend is the need to deploy permanent-sensor capability in the wellbore or wireline systems for regular checks and fine tuning of the oil well management process. Pressure and temperature are fundamental reservoir-engineering parameters, and permanent monitoring of downhole pressure and temperature is widely utilized. FOS&S will continue the development of the pre-product prototype manufactured as part of PHOSFOS up to the product level and commercialize the sensor systems with commercial revenue of 84,000 EURO in the first year of commercialization to 2.3 million EURO after five years.

The second SME involved in PHOSFOS – Astasense Ltd. – has elaborated a business plan targeting the sector of healthcare and medical applications using the polymer optical fibre sensor technology developed by PHOSFOS. Here also the market demand arises from the unique selling points of the developments:

- POF sensors can measure very high strain ratios;
- the elastic modulus is low and therefore POFs can be embedded in things that need to stretch;
- the materials are safer to use as in medical applications it is undesirable to insert silica fibre into the body;
- the sensors are minimally intrusive and very flexible;
- PHOSFOS has demonstrated that POF can be used outside the laboratory environment and that POF sensors can be efficiently read out using low-cost modules.

Astasense Ltd. envisages the immediate commercialization of the low-cost POF sensor interrogators and of the POF to silica connection technology which are universally deployable in many other applications with commercial revenues increasing from 15,000 EURO in the first year to 90,000 EURO in the third year. Furthermore, Astasense Ltd will continue the development of the proof-of-concept systems developed in PHOSFOS up to useable end products for two particular and very important applications. Firstly gastro-intestinal pressure sensing. Gastro-intestinal disorders have a significant impact on health care resources and accounts for an estimated 31 million annual clinic visits in the US addressing a range of disorders such as abdominal pain, dysphagia (the inability to swallow), irritable bowel syndrome, diarrhea, constipation, nausea and vomiting. These disorders can be caused for example by stroke or cancer. Improved therapies for many of these conditions depend on understanding and monitoring what is happening in the gastro-intestinal tract. The second application is the measurement of the effectiveness of someone's breathing function which is required for the effective treatment of a number of different conditions, for example to distinguish between obstructive and central apnea, in measuring the triggers and treatment of asthma and during the monitoring of cardiac activity. It is estimated that nearly 8% of the population in Europe suffers from asthma (14% of these people have what is classed as severe asthma). The total US/European asthma market in 2003 was over USD 11 billion.

Wider societal implications

All academic beneficiaries of PHOSFOS have reported on how Master level students were exposed to PHOSFOS results through teaching and education activities. Most academic beneficiaries are represented by scientists that carry a substantial teaching load and that use their latest research results to provide the best possible and up-to-date teaching material for their students. Furthermore several Master thesis works have been conducted on PHOSFOS related subjects. From these reports (summary in Table 13) a fair estimation returns an **average of 175 MSc level students per year exposed to PHOSFOS technologies**.

Beneficiary	Master Course/Lecture/Training type	Average amount of Master students per year	Average amount of PhD students per year
VUB	• Course on Optical Sensors – Erasmus Mundus Master in Photonics and VUB English Master in Photonics • Course on Entrepreneurship • Master Thesis	17	3
IMEC	• Course on "Technology for Integrated Circuits and Microsystems" – UG Master in Electronics and "Physics of Semiconductor Technologies and Components"–Erasmus Mundus Master in Photonics • Master Thesis	29	3.5
UG	• Course on "Biomaterials" – UG Master in Biomedical and Clinical Engineering Sciences • Course on "Polymers for Bio-inspired Applications" – UG Master in Chemistry • Course on "Biomedical Polymer" UG Master in Biomedical Sciences • Course on "Polymer Materials" – UG Master in Chemistry • Master Thesis	70	1
WRUT	• Master Thesis	2	2
UMCS	• Course on "Technology and application of optical fibres" – UMCS Master in Materials Chemistry And Master in Informatics • Course on "Optics, theory and metrology of optical fibers" – UMCS Master in Materials Chemistry Master Thesis	56	1
AU	Master Thesis	1	2.5
CUT	MSc programme to start in 2013	-	2
	Total	**175**	**15**

Table 13. Summary of Master student exposure to PHOSFOS work per year.

Many PhD students were also involved in PHOSFOS research. The academic partners reported on the average number of active PhD students per year (summary in Table 13) that carried out their research work on

PHOSFOS related subjects and that generated results that were used in PHOSFOS. From these reports we conclude that **on average 15 young scientists per year were trained on PHOSFOS research with a total involvement of 19 PhD students**.

In terms of wider societal implications PHOSFOS thus first contributed to the education and training of students and young researchers in a truly competitive field of engineering and science. By doing so PHOSFOS responded to the urgent need expressed by European industry for an increased amount of professionals that are specifically trained in the domain of new technologies. At the same time PHOSFOS also contributed to safeguard the innovation potential and competitiveness of European economy by delivering a large number of well educated young professionals.

A second important societal impact of PHOSFOS relates to the application fields targeted by the technical developments and the solutions provided by PHOSFOS to rise to the important challenges faced by the Europe Union.

Two application fields are immediately targeted by the PHOSFOS: first the domain oil and gas exploration and second, healthcare. The sensor technique developed by PHOSFOS will be used to exploit our energy resources in a more economic and safe manner. It will help increasing the oil recovery efficiency by means of a better monitoring of the most important process parameters (pressure and temperature) and will also contribute to a safer exploitation of oil wells and possibly help to avoid catastrophic events as the 2010 oil spill in the Gulf of Mexico. In the field of healthcare the possibility to provide a comfortable, effective and low-cost method for measuring the swallowing function as developed by PHOSFOS will be beneficial to a large amount of patients suffering from gastro-intestinal disorders e.g. as a result of stroke or cancer, and will help improving treatment. The technique to monitor the respiratory effort proposed by PHOSFOS can also alleviate some of the shortcoming of current techniques and may help the 8% of the European population that suffers from an asthma condition. In the long run this will lead to improved low-cost diagnostic tools and to the development of more effective treatments which will help managing the increased healthcare costs that stem from an ageing population.

Furthermore the new research projects that have emerged from PHOSFOS cover a much wider range of applications with substantial societal impact. We mention two examples. A first spin-out project targets the development of new field installable connectors for optical data communication. This project will impact the development of affordable fibre-to-the-home and broadband connections in Europe and will contribute to bridging the digital divide. A second spin out result is the use of the sensors in the field of structural monitoring of composite materials used in the fabrication of lightweight structures for wind turbines or airplanes, thereby contributing to efficient generation of sustainable energy.

Summary and Conclusion

After 41 months of PHOSFOS research and development:

- 22 ISI Web of Science indexed journal papers have been published;
- 67 conference contributions have been presented;
- several exhibition booths were organized as part of SPIE Photonics Europe 2010, ICT 2010 and the British Science Festival 2010;
- a PHOSFOS promotion movie was produced that was already viewed over 1200 times on youtube.com;
- the www.phosfos.eu website has received over unique 3800 visitors;
- the PHOSFOS Wikipedia page has received over 3300 visits;
- 23 press articles have been published;
- 70 internet echoes of PHOSFOS appeared on independent websites;
- 14 spin-out projects have been started;
- a total of 19 PhD students were active and trained on PHOSFOS related research;
- 175 Master students were exposed every year to PHOSFOS results;
- 5 IP protection measures have been taken that immediately relate to PHOSFOS foreground;
- 3 immediate technology transfer/commercialization actions are underway, i.e. the licensing of sensor technology for oil and gas exploration, the commercialization of polymer fibre connection technology and fibre sensor read-out systems, and the technology transfer of polymer fibre based water-in-fuel sensors.

PHOSFOS thus created substantial added value for the beneficiaries by:

- allowing to team up with new partner institutions in Europe and to set up new collaborations, as well as to consolidate links with existing partners;
- increasing the workforce on important research topics;
- achieving many scientific and technological breakthroughs;
- increasing the visibility on the international scientific scene;
- strengthening the international position in the respective research domains;
- generating new knowledge that supports the start of new research activities;
- producing intellectual property that can be protected and that can result in income for the academic partners through licensing and that can support the competitiveness of European industry;
- providing new links to potential industrial partners and setting up new development projects with these;
- fostering the development of innovative solutions that answer market demands with immediate commercialization potential and therefore with demonstrated potential for short and long term job creation and economic growth.

Both the achieved results and the follow-up activities of PHOSFOS cover a truly broad range of specific applications including oil and gas exploration, gastro-intestinal sensing, respiratory monitoring, structural health monitoring, prosthetics, radiotherapy, fibre optic connectors, optical interconnects, textiles, tapestry monitoring, humidity sensing, polymer material processing and sport sciences. This evidences that PHOSFOS technology carries great potential for immediate and future exploitation.

1.5. Project public website and relevant contact details

The public website of PHOSFOS is http://www.phosfos.eu. Figure 36 shows a screenshot of the homepage. The homepage immediately links to the project facts and results, to the latest press information (at the time of writing of this report) on opticalfibersensors.org, to the PHOSFOS video on youtube.com and to the PHOSFOS Wikipedia page (see below). The website is organised in 8 sections.

- Facts&Results
  This tab leads to 10 downloadable fact sheets about PHOSFOS, each highlighting a particular technological development of the project and mentioning contact information in case more detailed information is required.
- About Us
  This tab leads to general project information such as coordinator info, a downloadable project flyer, a project summary, the work package and management structure and a contact form.
- Partners
  The list of PHOSFOS beneficiaries and related contact information is available from here. This information is repeated in Table 14 for sake of completeness.
- Events
  This page lists all the events (conferences, workshops, scientific events, fairs, etc.) at which PHOSFOS was present.
- Conferences and Presentations
  The list of conference contributions is available here.
- Journals
  All journal publications are listed here, together with full reference information and a screenshot of the title page
- Press
  Most relevant appearances of PHOSFOS in press (magazines, important websites, etc.) are listed here with a downloadable pdf of the article
- Industrial User Club
  This page allows industrial companies to sign up for the industrial user club (IUC) of PHOSFOS. By the end of the project the IUC membership count was 19 companies.
- Links
  Links to relevant webpages are provided here.

PHOSFOS also has a Wikipedia page at http://en.wikipedia.org/wiki/PHOSFOS. A screenshot of this page is shown in Figure 37.

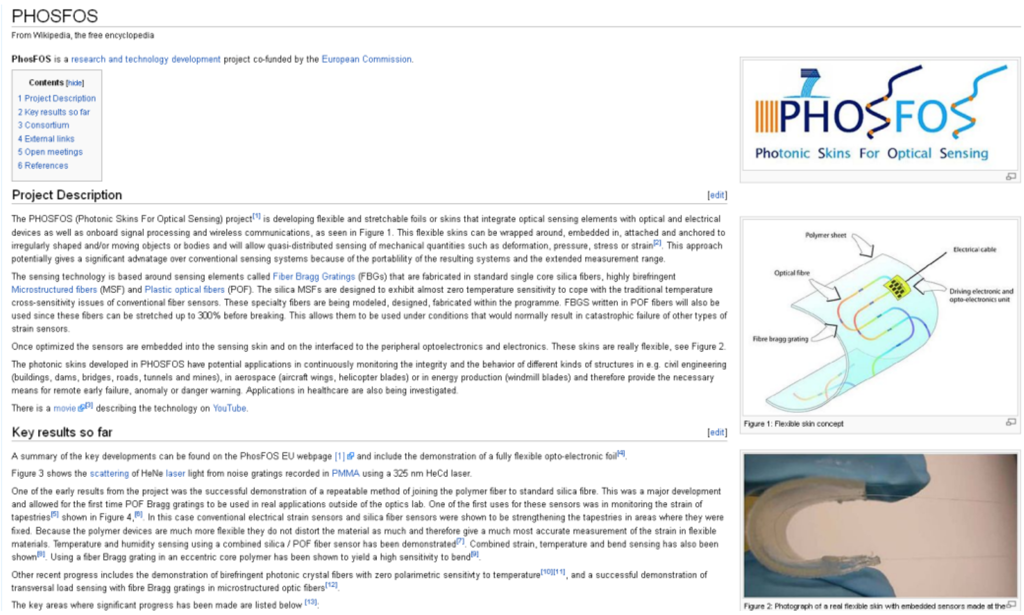
An introductory video about PHOSFOS is available on youtube.com at http://www.youtube.com/watch?v=pGpL_icFn1c. A screenshot is shown in Figure 38.

The project logo (Figure 39) is visible on all PHOSFOS reports and dissemination material such as the websites mentioned above, flyers and conference and exhibit posters.

Figure 36. Screenshot of the homepage of the public website of PHOSFOS at http://www.phosfos.eu.

Beneficiary	Acronym	Contact person	Contact Address	E-mail
Vrije Universiteit Brussel	VUB	Prof. Francis Berghmans	Brussels Photonics Team Pleinlaan 2 1050 Brussels Belgium	fberghma@vub.ac.be
Interuniversitair Micro-Electronica Centrum VZW	IMEC	Dr. Geert Van Steenberge	Centre for Microsystems Technology Technologiepark 914 9052 Gent Belgium	geert.vansteenberge@imec.be
Universteit Gent	UG	Prof. Peter Dubruel	Polymer Chemistry and Biomaterials Group Universiteit Gent Krijgslaan 281 9000 Gent	Peter.Dubruel@UGent.be
Politechnika Wroclawska	WRUT	Prof. Waclaw Urbanczyk	Fiber-Optic Group Wybrzeże Wyspiańskiego Str. 27 50-370 Wrocław Poland	Waclaw.Urbanczyk@pwr.wroc.pl
Uniwersitet Marie Curie Sklodowskiej	UMCS	Dr. Pawel Mergo	Laboratory of Optical Fibre Technology Pl. Marii Curie-Sklodowskiej 3 20-031 Lublin Poland	pawel.mergo@umcs.lublin.pl
Aston University	AS	Prof. David Webb	Photonics Research Group Aston Triangle B4 7ET Birmingham United Kingdom	d.j.webb@aston.ac.uk
Fiber Optic Sensors and Systems BVBA	FOS	Dr. Jan Van Roosbroeck	Bell Telephonelaan 3 2440 Geel Belgium	jvanroosbroeck@fbgs-international.com
Cyprus University of Technology	CUT	Prof. Kyriacos Kalli	Archbishop Kyprianos Str. 31 3036 Lemesos Cyprus	kyriacos.kalli@cut.ac.cy
Astasense Ltd	AS	Dr. Kate Sugden	52 Torrin Drive SY3 6AW Shrewsbury United Kingdom	K.Sugden@aston.ac.uk

Table 14. PHOSFOS contact details.


PHOSFOS

From Wikipedia, the free encyclopedia

PhosFOS is a research and technology development project co-funded by the European Commission.

Contents [hide]

1 Project Description
2 Key results so far
3 Consortium
4 External links
5 Open meetings
6 References

Project Description [edit]

The PHOSFOS (Photonic Skins For Optical Sensing) project[1] is developing flexible and stretchable foils or skins that integrate optical sensing elements with optical and electrical devices as well as onboard signal processing and wireless communications, as seen in Figure 1. This flexible skins can be wrapped around, embedded in, attached and anchored to irregularly shaped and/or moving objects or bodies and will allow quasi-distributed sensing of mechanical quantities such as deformation, pressure, stress or strain[2]. This approach potentially gives a significant advnatage over conventional sensing systems because of the portablility of the resulting systems and the extended measurement range.

The sensing technology is based around sensing elements called Fiber Bragg Gratings (FBGs) that are fabricated in standard single core silica fibers, highly birefringent Microstructured fibers (MSF) and Plastic optical fibers (POF). The silica MSFs are designed to exhibit almost zero temperature sensitivity to cope with the traditional temperature cross-sensitivity issues of conventional fiber sensors. These specialty fibers are being modeled, designed, fabricated within the programme. FBGS written in POF fibers will also be used since these fibers can be stretched up to 300% before breaking. This allows them to be used under conditions that would normally result in catastrophic failure of other types of strain sensors.

Once optimized the sensors are embedded into the sensing skin and on the interfaced to the peripheral optoelectronics and electronics. These skins are really flexible, see Figure 2.

The photonic skins developed in PHOSFOS have potential applications in continuously monitoring the integrity and the behavior of different kinds of structures in e.g. civil engineering (buildings, dams, bridges, roads, tunnels and mines), in aerospace (aircraft wings, helicopter blades) or in energy production (windmill blades) and therefore provide the necessary means for remote early failure, anomaly or danger warning. Applications in healthcare are also being investigated.

There is a movie[3] describing the technology on YouTube.

Key results so far [edit]

A summary of the key developments can be found on the PhosFOS EU webpage [1] and include the demonstration of a fully flexible opto-electronic foil[4].

Figure 3 shows the scattering of HeNe laser light from noise gratings recorded in PMMA using a 325 nm HeCd laser.

One of the early results from the project was the successful demonstration of a repeatable method of joining the polymer fiber to standard silica fibre. This was a major development and allowed for the first time POF Bragg gratings to be used in real applications outside of the optics lab. One of the first uses for these sensors was in monitoring the strain of tapestries[5] shown in Figure 4,[6]. In this case conventional electrical strain sensors and silica fiber sensors were shown to be strengthening the tapestries in areas where they were fixed. Because the polymer devices are much more flexible they do not distort the material as much and therefore give a much most accurate measurement of the strain in flexible materials. Temperature and humidity sensing using a combined silica / POF fiber sensor has been demonstrated[7]. Combined strain, temperature and bend sensing has also been shown[8]. Using a fiber Bragg grating in an eccentric core polymer has been shown to yield a high sensitivity to bend[9].

Other recent progress includes the demonstration of birefringent photonic crystal fibers with zero polarimetric sensitivity to temperature[10][11], and a successful demonstration of transversal load sensing with fibre Bragg gratings in microstructured optic fibers[12].

The key areas where significant progress has been made are listed below [13].

Figure 37. Screenshot of the Wikipedia page of PHOSFOS at http://en.wikipedia.org/wiki/PHOSFOS.

Figure 38. Screenshot of the PHOSFOS movie at http://www.youtube.com/watch?v=pGpL_icFn1c.

Figure 39. PHOSFOS logo.

2. Use and dissemination of foreground

The plan for use and dissemination of foreground as presented here consists of:

- Section A

This section describes the dissemination measures, including any scientific publications relating to foreground. **Its content can be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

This section specifies the exploitable foreground and provides the plans for exploitation. All these data can be public or confidential; the report clearly marks non-publishable (confidential) parts that will be treated as such by the Commission. Actually all information under Section B is confidential and **will not be made available in the public domain**. A confidential final plan for use and dissemination together with 2 confidential annexes has already been submitted as deliverable D6.14 of the project. This plan can be annexed to the Section B of this Final Report. Information that is public with respect to the use of foreground has been made available in the first section of this Final Report, more particularly in the Final Publishable Summary.

Section A (public)

This section includes two templates as requested by the EU Commission:

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they show all publications and activities from the beginning until after the end of the project.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[4] (if available)	Is/Will open access[5] provided to this publication?
1	Transversal Load Sensing With Fiber Bragg Gratings in Microstructured Optical Fibers	T. Geernaert	IEEE PHOTONICS TECHNOLOGY LETTERS	vol. 21, no. 1	IEEE		2009	pp. 6-8	DOI: 10.1109/LPT.2008.2007915	No
2	Birefringent photonic crystal fibers with zero polarimetric sensitivity to temperature	T. Martynkien	APPLIED PHYSICS B: LASERS AND OPTICS	vol. 94, no. 4	Springer		2009	pp. 635-640	DOI: 10.1007/s00340-009-3394-2	No
3	Response of FBGs in Microstructured and Bow Tie Fibers Embedded in Laminated Composite	G. Luyckx	IEEE PHOTONICS TECHNOLOGY LETTERS,	vol. 21, no. 18	IEEE		2009	pp. 1290-1292	DOI: 10.1109/LPT.2009.2025262	No
4	Highly reliable flexible active optical links	E. Bosman	IEEE PHOTONICS TECHNOLOGY LETTERS,	vol. 22, no. 5	IEEE		2010	pp. 287-289	DOI: 10.1109/LPT.2009.2038797	No
5	Bragg Grating Inscription in GeO_2-	T. Geernaert	IEEE JOURNAL	vol. 28, no. 10	IEEE		2010	pp. 1459-1467	DOI:	No

[4] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[5] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	Doped Microstructured Optical Fibers		OF LIGHTWAVE TECHNOLOGY						10.1109/JLT.2010.2043414	
6	Point-by-point Fibre Bragg Grating Inscription in Free-standing Step-Index and Photonic Crystal Fibres using NIR Femtosecond Laser	T. Geernaert	OPTICS LETTERS	vol. 35, no. 10	OSA		2010	pp. 1647-1649	DOI: 10.1364/OL.35.001647	No
7	Optical fibre temperature and humidity sensor	C. Zhang	ELECTRONICS LETTERS	vol. 46, no. 9	IEEE		2010	pp. 643-644	DOI: 10.1049/el.2010.0879	No
8	Water diffusion into UV inscripted Long Period Grating in microstructured polymer fibre	D. Saéz-Rodriguez	IEEE SENSORS JOURNAL	vol. 10, no. 7	IEEE		2010	pp. 1169-1173	DOI: 10.1109/JSEN.2010.2042952	No
9	Highly Sensitive Bend Sensor Based on Bragg Grating in Eccentric Core Polymer Fiber	X. Chen	IEEE PHOTONICS TECHNOLOGY LETTERS	vol. 22, no. 11	IEEE		2010	pp. 850-852	DOI: 10.1109/LPT.2010.2046482	No
10	Bragg grating in polymer optical fibre for strain, bend and temperature sensing	X. Chen	MEASUREMENT SCIENCE AND TECHNOLOGY	vol. 21, no. 9	IOP		2010	pp. 94005	DOI: 10.1088/0957-0233/21/9/094005	No
11	Fully flexible opto-electronic foil	E. Bosman	IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS	vol. 16, no. 5	IEEE		2010	pp. 1355-1362	DOI: 10.1109/JSTQE.2009.2039466	No
12	Highly birefringent microstructured fibers with enhanced sensitivity to hydrostatic pressure	T. Martynkien	OPTICS EXPRESS	vol. 18, no.14	OSA		2010	pp. 15113-15121	DOI: 10.1364/OE.18.015113	Yes
13	Measurements of polarimetric sensitivity to hydrostatic pressure, strain and temperature in birefringent dual-core microstructured polymer fiber	M.K. Szczurowski	OPTICS EXPRES	vol. 18, no. 12	OSA		2010	pp. 12076-12087	DOI: 10.1364/OE.18.012076	Yes
14	Measurements of stress-optic coefficient in polymer optical fibers	M.K. Szczurowski	OPTICS LETTERS	vol. 35, no. 12	OSA		2010	pp. 2013-2015	DOI: 10.1364/OL.35.002013	No
15	Polarizing photonic crystal fiber with low index inclusion in the core	G Statkiewicz-Barabach	JOURNAL OF OPTICS	vol. 12, no. 7	IOP		2010	pp. 75402	DOI: 10.1088/2040-8978/12/7/075402	No
16	827 nm Bragg grating sensor in multimode microstructured polymer optical fibre	I.P. Johnson	ELECTRONICS LETTERS	vol. 46, no. 17	IEEE		2010	pp. 1217-1218	DOI: 10.1049/el.2010.1595	No
17	Microstructured Optical Fiber Sensors Embedded in a Laminate Composite for Smart Material Applications	C. Sonnenfeld	SENSORS	vol. 11, no. 3	MDPI		2011	pp. 2566-2579	DOI: 10.3390/s110302566	Yes
18	Geometrical study of a hexagonal lattice photonic crystal fiber for efficient femtosecond laser grating inscription	T. Baghdasaryan	OPTICS EXPRESS	vol. 19, no. 8	OSA		2011	pp. 7705-7716	DOI: 10.1364/OE.19.007705	Yes
19	Ultra thin optoelectronic device packaging in flexible carriers	E. Bosman	IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS	vol. 17, no. 3	IEEE		2011	pp. 617-628	DOI: 10.1109/JSTQE.2010.2096407	No
20	Flexible Shear Sensor Based on Embedded Optoelectronic Components	J. Missinne	IEEE PHOTONICS TECHNOLOGY	Vol. 23, no. 12	IEEE		2011	pp. 771-773	DOI: 10.1109/LPT.2011.2134844	No

			LETTERS							
21	Characterisation and performance of a Terfenol-D coated femtosecond laser inscribed optical fibre Bragg sensor with a laser ablated microslot for the detection of static magnetic fields	G.N. Smith	OPTICS EXPRESS	vol. 19, no. 1	OSA		2011	pp. 363-370	DOI: 10.1364/OE.19.000363	Yes
22	Characterizing femtosecond laser inscribed Bragg grating spectra	C. Koutsides	OPTICS EXPRESS	vol. 19, no. 1	OSA		2011	pp. 342-352	DOI: 10.1364/OE.19.000342	Yes

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[6]	Main leader	Title	Date	Place	Type of audience[7]	Size of audience	Countries addressed
1	Technical Meeting Presentation	VUB	Photonic Skins for Optical Sensing: COST299 Technical Meeting	September 2008	Funchal, Portugal	Scientific Community	50+	EU
2	Concertation Meeting Presentation	VUB	Photonic Skins for Optical Sensing: EU FP7 Concertation Meeting – Kick-Off Photonic Projects	September 2008	Barcelona, Spain	Scientific Community Policy Makers	30+	EU
3	Conference Invited Presentation	VUB	Optical fibre sensors: setting the scene: ECOC 2008 – Workshop on Optical Fibre Sensors	September 2008,	Brussels, Belgium	Scientific Community	35+	EU
4	Conference Invited Presentation	CUT	Trends in polymer optical fiber based sensors: ECOC 2008 – Workshop on Optical Fibre Sensors	September 2008	Brussels, Belgium	Scientific Community	35+	EU
5	Conference Invited Presentation	FOS	Opportunities and pitfalls of optical fiber sensors in real field applications: ECOC 2008 – Workshop on Optical Fibre Sensors	September 2008	Brussels, Belgium	Scientific Community	35+	EU
6	Conference Invited Presentation	VUB	Trends in photonic crystal fiber based sensors: ECOC 2008 – Workshop on Optical Fibre Sensors	September 2008	Brussels, Belgium	Scientific Community	35+	EU
7	Conference Presentation	VUB	Polarization properties of an uniform bragg grating in highly birefringent PCF: 14th Microoptics Conference - MOC '08	September 2008	Brussels, Belgium	Scientific Community	100+	EU, Japan
8	Conference Presentation	VUB	PHOSFOS – Photonic Skins for Optical Sensing : CMOI 2008 Colloque international francophone du club SFO/CMOI Contrôle et	November 2008	Nantes, France	Scientific Community Industry	50+	France, Belgium

[6] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[7] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

			Mesures Optiques pour l'Industrie					
9	Conference Invited Presentation	AU	Bragg grating sensors in polymer optical fibres: 1st Asia Pacific Optical Sensors Conference	November 2008	Chengdu, China	Scientific Community	100+	China, EU, USA
10	Conference Invited Presentation	IMEC	Flexible Optical Interconnects: International Symposium on Photonic Packaging - Electrical Optical Circuit Board and Optical Backplane,	November 2008	Munich, Germany	Scientific Community	50+	EU, USA
11	Meeting Invited Presentation	AU	Gratings in POF: potential for applications in the heritage sector: Advisory panel meeting, Institute of Archaeology	February 2009	London, UK	Scientific Community	25+	UK
12	Meeting Presentation	AU	Advances in fibre grating technology: Sensors and Instrumentation Knowledge Transfer Network 30th meeting	March 2009	London, UK	Scientific Community Industry	25+	UK
13	Lecture	VUB	Optical Fibre Point Sensors: COST 299 Spring School, Lectures in Advanced Fiber Optics	31 March-01 April 2009	Larnaca, Cyprus	Scientific Community Higher Education	70+	EU, Israël
14	Lecture	CUT	Polymer Optical Fibre Based Sensors: COST 299 Spring School, Lectures in Advanced Fiber Optics	31 March-01 April 2009	Larnaca, Cyprus	Scientific Community Higher Education	70+	EU, Israël
15	Workshop Invited Presentation	IMEC	Flexible and stretchable optical sensing skin: Fotonica Evenement	April 2009	Eindhoven, The Netherlands	Scientific Community Industry	100+	EU
16	Conference Presentation	VUB	Fiber Bragg gratings in microstructured optical fibers for stress monitoring: Conference on Photonic Crystal Fibers, SPIE Europe Optics + Optoelectronics	April 2009	Prague, Czech Republic	Scientific Community	45+	EU, Russia
17	Conference Presentation	AU	Long period fibre gratings photoinscribed in a microstructured polymer optical fibre by UV radiation : Conference on Photonic Crystal Fibers, SPIE Europe Optics + Optoelectronics	April 2009	Prague, Czech Republic	Scientific Community	45+	EU, Russia
18	Conference Presentation	VUB	Fiber Bragg Gratings in Microstructured Optical Fibers for Stress Monitoring: OPTO 2009 Conference, Sensor+Test 2009	May 2009	Nürnberg, Germany	Scientific Community	60+	EU
19	Conference Presentation	IMEC	Fully embedded optical and electrical interconnections in flexible foils: European Microelectronics and Packaging Conference	June 2009	Rimini, Italy	Scientific Community	50+	EU
20	Workshop Presentation	VUB	Fiber Bragg Gratings in Microstructured Optical Fibers for Stress Monitoring in Composite Laminates: ESA Worksop on "Fibre Optic Sensor for Space Applications"	June 2009	Noordwijk, The Netherlands	Scientific Community Industry	20+	EU
21	Conference Presentation	WRUT	Photonic crystal fibers-unusual properties and applications: Ist Polish Optical Conference	27 June – 1 July 2009	Bedlewo,Poland	Scientific Community	50+	Poland
22	Workshop Invited Presentation	AU	Gratings in mPOF: 3rd international workshop on Microstructured Polymer Optical Fibres	September 2009	Sydney, Australia	Scientific Community	40+	Australia, EU, Japan, USA
23	Conference Presentation	AU	Applications of polymer fibre grating sensors: 18th International conference on Plastic Optical Fibers	September 2009	Sydney, Australia	Scientific Community	100+	Australia, EU, Japan, USA
24	Concertation Meeting Presentation	IMEC	Phosfos embedding technology for integrated sensing solutions: EU FP7 4th Concertation Meeting on Photonics Enabled Applications	September 2009	Athens, Greece	Scientific Community Policy Makers	35+	EU
25	Conference Poster	AU	Water detection in jet fuel using a polymer optical fibre Bragg grating: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA

26	Conference Poster	AU	Optical bend sensor for vector curvature measurement based on Bragg grating in eccentric core polymer optical fibre: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
27	Conference Poster	AU	Applications of polymer optical fibre grating sensors to condition monitoring of textiles: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
28	Conference Poster	CUT	Point-by-point Bragg grating inscription in single-mode microstructure fibre using NIR femtosecond laser: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
29	Conference Poster	VUB	Benchmarking the response of Bragg gratings written in micro-structured and bow tie fiber embedded in composites: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
30	Conference Invited Presentation	VUB	Photonic Skins for Optical Sensing - Highlights of the PHOSFOS Project: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
31	Conference Invited Presentation	WRUT	Birefringent photonic crystal fibers for sensing applications: 20th International Conference on Optical Fibre Sensors	October 2009	Edinburgh, UK	Scientific Community	100+	EU, Japan, USA
32	Conference Invited Presentation	VUB	Micro-structured fibre grating sensors: International Commission for Optics (ICO) Topical Meeting on “Emerging Trends and Novel Materials in Photonics”	October 2009	Delphi, Greece	Scientific Community	75+	EU, Japan, USA
33	Conference Presentation	VUB	Analyse de contraintes dans les matériaux composites à l’aide de réseaux de Bragg dans des fibres micro-structurée : CMOI 2009 Dixième colloque international francophone Méthodes et Techniques Optiques pour l’Industrie	November 2009	Reims, France	Scientific Community Industry	50+	France, Belgium
34	Workshop Presentation	IMEC	Flexible Optical Interconnects: 2nd International Symposium on Photonic Packaging	November 2009	München, Germany	Scientific Community	50+	EU
35	Workshop Presentation	IMEC	Skin-like optical tactile sensors: 2nd International Workshop on Flexible and Stretchable Electronics	November 2009	Gent, Belgium	Scientific Community	50+	EU
36	Workshop Presentation	IMEC	Embedded optics in flex: 2nd International Workshop on Flexible and Stretchable Electronics	November 2009	Gent, Belgium	Scientific Community	50+	EU
37	Workshop Presentation	VUB	Fibre bragg gratings in new optical fibres embedded in flexible substrates for selective sensing applications: 2nd International Workshop on Flexible and Stretchable Electronics	November 2009	Gent, Belgium	Scientific Community	50+	EU
38	Workshop Invited Presentation	VUB	Photonic Skins for Optical Sensing - Recent results of the Phosfos Project: Third Workshop on Optical Technologies, Hannover Center for Optical Technologies	November 2009	Hannover, Germany	Scientific Community	25+	Germany
39	Workshop Invited Presentation	VUB	New fiber optic technologies in the EU FP7 PHOSFOS Project: Photonic Skins for Optical	December 2009	Jena, Germany	Scientific Community Industry	40+	Germany

			Sensing: Workshop Trends in der Phaseroptik, IPHT					
40	Workshop Invited Presentation	WRUT	Birefringent photonic crystal fibers for sensing applications: Workshop Trends in der Phaseroptik, IPHT	December 2009	Jena, Germany	Scientific Community Industry	40+	Germany
41	Conference Presentation	IMEC	Packaging of opto-electronic devices for flexible applications: SPIE Photonics West, Conference on Optical Interconnects: Integration and Packaging	January 2010	San Francisco, USA	Scientific Community	30+	USA, EU, Japan
42	Conference Presentation	UG	Flexible polymers for optical sensing applications: VJC10 – 10th Flemish Congress for Chemistry	March 2010	Blankenberge, Belgium	Scientific Community	40+	Belgium
43	Meeting Presentation	UG	(Bio)polymers as versatile materials for biomedical applications: Successful R&D in Europe, 2nd European Networking Event of the State Government of North RIne	March 2010	Düsseldorf, Germany	Scientific Community	50+	Germany
44	Meeting Presentation	UG	Biomedical and Optical Applications of Polymers: Research Meeting Innovation Centre	June 2010	Gent, Belgium	Scientific Community	20+	Belgium
45	Meeting Poster	UG	Flexible polymer materials for optical sensing applications: BPG Annual Meeting 2010	May 2010	Blankenberge, Belgium	Scientific Community	30+	Belgium
46	Conference Presentation	UG	Polymer materials for optical sensing applications: i-SUP 2010	April 2010	Brugge, Belgium	Scientific Community	30+	EU
47	Conference Invited Presentation	AU	Photonics skin for pressure and strain sensing: SPIE Photonics Europe, Conference on Optical Sensors and Detection	April 2010	Brussels, Belgium	Scientific Community	45+	EU
48	Conference Presentation	IMEC	Optical fiber sensors embedded in flexible polymer foils: SPIE Photonics Europe, Conference on Optical Sensors and Detection	April 2010	Brussels, Belgium	Scientific Community	40+	EU
49	Conference Invited Presentation	AU	Multiplexed FBG sensor recorded in multimode microstructured polymer optical fibre: SPIE Photonics Europe, Conference on Photonic Crystal Fibres	April 2010	Brussels, Belgium	Scientific Community	40+	EU
50	Conference Presentation	WRUT	Measurements of stress-optic coefficient and Young's modulus in PMMA fibers drawn under different conditions: SPIE Photonics Europe, Conference on Photonic Crystal Fibres	April 2010	Brussels, Belgium	Scientific Community	40+	EU
51	Conference Presentation	VUB	UV Bragg grating inscription in germanium-doped photonic crystal fibers: SPIE Photonics Europe, Conference on Photonic Crystal Fibres	April 2010	Brussels, Belgium	Scientific Community	40+	EU
52	Conference Presentation	IMEC	Characterization of flexible fully embedded optical links: SPIE Photonics Europe, Conference on Micro-Optics	April 2010	Brussels, Belgium	Scientific Community	80+	EU
53	Conference Invited Presentation	AU	Polymer photonic crystal fibre for sensor applications: SPIE Photonics Europe, Conference on Optical Sensors and Detection	April 2010	Brussels, Belgium	Scientific Community	45+	EU
54	Conference Presentation	CUT	Femtosecond Laser Inscription of Fiber Bragg Gratings with Low Insertion Loss and Minor Polarization Dependence: Topical Meeting on Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides	June 2010	Karslruhe, Germany	Scientific Community	50+	EU, USA
55	Workshop Presentation	AU	Polymer photonic sensing skin: Fourth European Workshop on Optical Fiber Sensors	September 2010	Porto, Portugal,	Scientific Community	70+	EU

56	Workshop Presentation	WRUT	Polarimetric sensitivity to hydrostatic pressure and temperature in birefringent dual-core microstructured polymer fiber: Fourth European Workshop on Optical Fiber Sensors	September 2010	Porto, Portugal	Scientific Community	70+	EU
57	Conference Presentation	IMEC	Embedded Flexible Optical Shear Sensors: IEEE Sensors 2010	November 2010	Waikola (Hawai), USA	Scientific Community	100+	USA, Japan, EU
58	Conference Presentation	VUB	Capteurs à Fibres Optiques pour matériaux composites : CMOI 2010 Onzième colloque international francophone Méthodes et Techniques Optiques pour l'Industrie	November 2009,	Toulouse, France	Scientific Community	50+	France, Belgium
59	Meeting Presentation	IMEC	Optical Force Sensors for Smart Prostheses: 11th Ugent FEA PhD symposium	December 2010	Gent, Belgium	Scientific Community Higher Education	25+	Belgium
60	Conference Presentation	IMEC	Packaging technology enabling flexible optical interconnections: SPIE Photonics West, Conference on Optoelectronic Interconnects and Component Integration	January 2011	San Francisco, USA	Scientific Community	50+	USA, EU, Japan
61	Conference Presentation	AU	Polymer PCF Bragg grating sensors based on poly(methyl methacrylate) and TOPAS cyclic olefin copolymer: SPIE Optics + Optoelecronics, Conference on Photonic Crystal FIbers	April 2011	Prague, Czech Republic	Scientific Community	30+	EU, Russia
62	Conference Poster	UG	Polymers for biomedical applications @ UGent: Knowledge for Growth Symposium	May 2011	Gent, Belgium	Scientific Community	50+	Belgium
63	Conference Poster	AU	Utilisation of thermal annealing to record multiplexed FBG sensors in multimode microstructured polymer optical fibre: 21st International Conference on Optical Fiber Sensors	May 2011	Ottawa, Canada	Scientific Community	100+	USA, EU, Japan
64	Conference Presentation	CUT	Femtosecond laser inscribed Bragg sensor in Terfenol-D coated optical fibre with ablated microslot for the detection of static magnetic fields: 21st International Conference on Optical Fiber Sensors	May 2011	Ottawa, Canada	Scientific Community	100+	USA, EU, Japan
65	Conference Presentation	CUT	Numerical modeling of complex femtosecond laser inscribed fiber gratings: comparison with experiment: 21st International Conference on Optical Fiber Sensors	May 2011	Ottawa, Canada	Scientific Community	100+	USA, EU, Japan
66	Workshop Invited Presentation	VUB	European Project PHOSFOS - "Photonic Skins for Optical Sensing" – SPIE Industry Meets Academia Workshop	May 2011	Munchen, Germany	Scientific Community	100+	EU
67	Workshop Invited Presentation	VUB	Microstructured fiber Bragg grating sensors: from fiber design to sensor implementation: 15th IEEE Photonics Society Benelux Annual Workshop	June 2011	Mons, Belgium	Scientific Community	45+	Benelux
68	Book Chapter	VUB	"Optical Fibre Point Sensors", in Advanced Fiber Optics, Ed. L. Thévenaz, EPFL Press, 2011, pp.309-344.	2011	Lausanne, Switzerland	Scientific Community		International
69	Book Chapter	CUT	"Polymer Optical Fibre Sensors", in Advanced Fiber Optics, , Ed. L. Thévenaz, EPFL Press, 2011, pp. 345-388.	2011	Lausanne, Switzerland	Scientific Community		International
70	Workshop	VUB	PHOSFOS 1st Benefits for Industry Workshop	November 2009	Brussels,Belgium	Industry	35+	EU

						Scientific Community		
71	Workshop	VUB	PHOSFOS 2nd Benefits for Industry Workshop	May 2011	Munchen, Germany	Industry Scientific Community	25+	EU
72	Exhibition Booth	VUB	SPIE Photonics Europe – European Village	April 2010	Brussels, Belgium	Scientific Community Industry Policy Makers Press	50+	EU
73	Exhibition Booth	IMEC	SPIE Photonics Europe – Innovation Village	April 2010	Brussels, Belgium	Scientific Community Industry Policy Makers Venture Capitalists Press	50+	EU
74	Exhibition Booth	VUB	ICT2010 Digitally Driven	September 2010	Brussels, Belgium	Industry Policy Makers Scientific Community	200+	EU
75	Exhibition Booth	AU	British Science Festival	September 2010	Birmingham, UK	Higher Education Scientific Community	1000+	UK
76	Exhibition Booth	UG	Open Day on Chemistry	May 2011	Ghent, BE	Students General Public	200+	BE
77	Press Release	VUB	Optical fibre technology delivers user friendly and affordable monitoring systems for civil engineering and healthcare	June 2008	Brussels, Belgium	Press Journalists		BE
78	Article in Printed Press	VUB	Flexible Photonics Shape up for Sensing: Optics & Laser Europe, Issue 163	July/August 2008		Scientific Community Industry Policy Makers		EU
79	Article in Printed Press	AU	Photonics Cluster member Aston University to develop futuristic optical fibre based monitoring systems for healthcare: Photonics Cluster UK Newsletter	July 2008		Scientific Community Industry Policy Makers		UK
80	Article in Printed Press	WRUT	PHOSFOS dla lecznictwa i budownictwa: Pryzmat, nr. 223	October 2008		General Public		Poland
81	Article in Printed Press	VUB	Optical Sensor System Uses Artificial 'Skins': Europhotonics	August/September 2008		Scientific Community Industry Policy Makers		EU
82	Article in Printed Press	VUB	Give me some Photonic Skin: Photonics Spectra	October 2008		Scientific Community Industry Policy Makers		International
83	Article in Printed Press	IMEC	IMEC embeds active optical links in flexible substrates: IMEC Newsletter	October 2008		Scientific Community Industry Policy Makers		International
84	Article in Printed Press	IMEC	IMEC paves the way toward optical-sensing foils: Laser Focus World	October 2008		Scientific Community Industry Policy Makers		International
85	Article in Printed Press	VUB	Fiber-sensor technology is thin-skinned but robust: Laser Focus World	July 2010		Scientific Community Industry		International

						Policy Makers		
86	Article in Printed Press	VUB	It all starts with the fibre: EOS Brochure - How optics and photonics address Europe's challenges of the 21st century	July 2010		Scientific Community Industry Policy Makers		International
87	Article in Printed Press	VUB	Photonics in Europe: Optics and Photonics News, vol. 21, Issue 12	December 2010		Scientific Community Industry Policy Makers		EU
88	Web Mentions and Echoes	VUB	More than 70 unique URLs refer or link to PHOSFOS, too many to list here					International
89	Movie	VUB	PHOSFOS Youtube Movie: http://www.youtube.com/watch?v=pGpL_icFn1c			General Public	1500+	International
90	Website	AS	PHOSFOS Wikipedia Page: http://en.wikipedia.org/wiki/PHOSFOS			General Public	3300+	International
91	Website	VUB	Project website: www.phosfos.eu			Scientific Community Industry General Public	3800+	International

Section B (Confidential) - Part B1 (Confidential)

The applications for patents, trademarks, registered designs, etc. are listed below according to the template B1 provided by the EU Commission. This table is cumulative, which means that it shows all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[8]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent	YES	Publication 26/05/2011	PCT/EP2009/065458	"OPTICAL FIBER STRUCTURE FOR SENSORS"	VRIJE UNIVERSITEIT BRUSSEL UNIWERSYTET MARII CURIE-SKLODOWSKIEJ POLITECHNIKA WROCLAWSKA (WROCLAW UNIVERSITY OF TECHNOLOGY GEERNAERT, Thomas BERGHMANS, Francis NASILOWSKI, Tomasz THIENPONT, Hugo WOJCIK, Jan, Jozef MAKARA, Mariusz MERGO, Pawel POTURAJ, Krzysztof, Grzegorz URBANCZYK, Waclaw MARTYNKIEN, Tadeusz OLSZEWSKI, Jacek Marek
Patent	YES	Publication 26/05/2011	PCT/EP2010/067862	"BIREFRINGENT MICRO-STRUCTURED OPTICAL FIBER FOR SENSOR APPLICATION"	VRIJE UNIVERSITEIT BRUSSEL UNIWERSYTET MARII CURIE-SKLODOWSKIEJ POLITECHNIKA WROCLAWSKA (WROCLAW UNIVERSITY OF TECHNOLOGY GEERNAERT, Thomas BERGHMANS, Francis NASILOWSKI, Tomasz THIENPONT, Hugo MAKARA, Mariusz MERGO, Pawel POTURAJ, Krzysztof, Grzegorz URBANCZYK, Waclaw MARTYNKIEN, Tadeusz OLSZEWSKI, Jacek Marek
Patent	YES	Publication 29/12/2010	PCT/EP2010/058808	"OPTICAL TACTILE SENSORS"	IMEC UNIVERSITEIT GENT VRIJE UNIVERSITEIT BRUSSEL VAN STEENBERGE, Geert

8 A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

					BOSMAN, Erwin THIENPONT, Hugo
Patent	YES	Publication 10/03/2011	PCT/GB2010/001623	“WATER-IN-FUEL SENSOR”	ASTON UNIVERSITY WEBB, David John ZHANG, Chi
Patent	YES	Filed 08/04/2011	PCT/EP2011/055517	“OPTICAL SHEAR SENSOR AND METHOD OF PRODUCING SUCH AN OPTICAL SENSOR”	IMEC VAN STEENBERGE, Geert MISSINE, Jeroen BOSMAN, Erwin VAN HOE, Bram
Patent	YES	Filed 22/06/2011	PCT/EP2011/060518	“METHODS AND SYSTEMS IN OPTICAL FIBER TECHNOLOGY”	VRIJE UNIVERSITEIT BRUSSEL BAGHDASARYAN, Tigran GEERNAERT, Thomas BERGHMANS, Francis THIENPONT, Hugo

Section B (Confidential) - Part B2 (Confidential)

The beneficiaries have completed the Template table below as requested by the EU Commission. More extensive information on the use and dissemination plans and on the exploitable foreground has been provided in deliverable report D6.14 "Final Plan for Use and Dissemination" of the project and in its **confidential** annexes. These documents can be considered as annexes to this Final Report and therefore the information reported in D6.14 is not repeated here.

Type of Exploitable Foreground[9]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[10]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Silica micro-structured fibre design methods	NO		New research projects	C27.3.1	Current	NO	VUB, WRUT
General advancement of knowledge	Grating writing in Silica MSF	NO		New research projects	C27.3.1 C26.5.1	Current	NO	VUB, FOS
Commercial exploitation of R&D results	Silica micro-structured fibre designs and fabrications	YES		Methods	C27.3.1 C26.5.1 C23.1.4	Current	PATENT PCT/EP2010/067862	VUB, WRUT, UMCS
Commercial exploitation of R&D results	Silica micro-structured fibre designs and fabrications	YES		Methods	C27.3.1 C23.1.4	3 years	PATENT PCT/EP2011/060518	VUB
Commercial exploitation of R&D results	Silica micro-structured fibre designs and fabrications	YES		Methods and products	C27.3.1 C26.5.1	1 year	PATENT LICENSE	VUB, WRUT, UMCS, FOS
General advancement of knowledge and screening for commercial application of R&D results	Polyacrylate based polymers as fibre coating	YES		Methods and products	C27.3.1 C22.2.9	Current	UNDER EVALUATION	UG, VUB, IMEC
General advancement of knowledge and screening for commercial application of R&D results	Polyacrylate based polymers as new polymer materials	YES		Methods and products	C22.2.9	Current	NO	UG
General advancement of knowledge	Glued connections silica-POF	NO		Methods	C26.5.1	Current	NO	AU, CUT, AS
General advancement of knowledge	Grating writing in different POFs	NO		Methods	C26.5.1	Current	NO	AU, CUT, AS
General advancement of knowledge	POFBG annealing	NO		Methods	C26.5.1	Current	NO	AU, CUT, AS, IMEC
General advancement of knowledge	FBGs at 850nm	NO		Methods	C26.5.1	Current	NO	AU, CUT, AS
General advancement of	Effects of POF	NO		Methods	C26.5.1	Current	NO	AU, WRUT

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[10] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[9]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[10]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
knowledge	drawing conditions							
General advancement of knowledge	Femtosecond grating inscription in microstructured optical fibre	NO		Methods	C26.5.1	Current	NO	CUT, VUB
General advancement of knowledge	Femtosecond sculpting of optical fibres	NO		Methods	C26.5.1	Current	NO	CUT
General advancement of knowledge	Development of vectorial sensors using femtosecond laser	NO		Methods	C26.5.1	Current	NO	CUT
General advancement of knowledge	Femtosecond laser inscription of polarisation selective components at arbitrary wavelengths	NO		Methods	C26.5.1	Current	NO	CUT
General advancement of knowledge	Femtosecond inscription and ablation of polymers	NO		Methods	C26.5.1	Current	NO	CUT
Commercial exploitation of R&D results	Humidity and water in fuel sensing	YES		Methods and products	C26.5.1	Current	PATENT PCT/GB2010/001623	AU
Commercial exploitation of R&D results	Embedded optoelectronic chips	YES		Methods	C26	1 year	PATENT PCT/EP2010/058808	IMEC, VUB
Commercial exploitation of R&D results	Embedded optoelectronic chips	YES		Methods	C26	1 year	PATENT PCT/EP2011/055517	IMEC
General advancement of knowledge	Embedded fibre sensors	NO		New research projects	C26	Current	NO	IMEC, VUB
General advancement of knowledge	Embedded optoelectronic chips	NO		New research projects	C26	Current	NO	IMEC
Commercial exploitation of R&D results	Interrogation system for 850 nm FBGs	YES		Methods and products	C26.5.1	0-6 months	NO	AS
Commercial exploitation of R&D results	Low cost interrogation system	YES		Methods and products	C26.5.1	1 year	NO	AS
General advancement of knowledge	Embedding of silica and polymer fibre sensors	YES		Methods and products	C26.5.1	1 year	NO	IMEC, AS

3. Report on societal implications

This section corresponds to Deliverable D7.6 of PHOSFOS, i.e. the report on "Awareness and wider societal implications". This deliverable has therefore not been submitted separately.
The report consists of replies to the questions in the questionnaire template provided by the EU Commission. It will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify whether the project has shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	224058
Title of Project:	Photonic Skins for Optical Sensing
Name and Title of Coordinator:	Francis Berghmans, Professor

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes ●No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***NO***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	

RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes ● No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		**1**
Work package leaders		**7**
Experienced researchers (i.e. PhD holders)	**2**	**25**
PhD Students	**4**	**15**
Other	**4**	**14**

4. How many additional researchers (in companies and universities) were recruited specifically for this project? 8 (but working only part-time on the project)	
Of which, indicate the number of men: 8 (but working only part-time on the project)	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
● No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

● No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

● Yes- please specify: British Science Festival 2010, Sept. 2010, Birmingham, UK
EU ICT2010 Digitally Driven, Sept. 2010, Brussels, BE
Open Day on Chemistry 2011, May 2011, Ghent, BE

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

● No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

● Main discipline[11]: 2.2

● Associated discipline[11]: 2.3

● Associated discipline[11]: 1.2

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
● No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[11] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ● No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ● No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**22**
To how many of these is open access[12] provided?	**12**
How many of these are published in open access journals?	**6**
How many of these are published in open repositories?	**6**
To how many of these is open access not provided?	**10**
Please check all applicable reasons for not providing open access:	
☑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[13]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**5**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☑ Increase in employment, or	☑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:7.8*

[12] Open Access is defined as free of charge access for anyone via Internet.
[13] For instance: classification for security project.

Difficult to estimate / not possible to quantify	❑

I	**Media and Communication to the general public**
20.	**As part of the project, were any of the beneficiaries professionals in communication or media relations?** ○ Yes ● No
21.	**As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?** ○ Yes ● No
22	**Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?**

☑	Press Release	☑	Coverage in specialist press
❑	Media briefing	☑	Coverage in general (non-specialist) press
❑	TV coverage / report	☑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☑	Brochures /posters / flyers	☑	Website for the general public / internet
☑	DVD /Film /Multimedia	☑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

☑	Language of the coordinator	☑	English
☑	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]