Photonic Skins for Optical Sensing – Highlights of the PHOSFOS Project

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ABSTRACT

PHOSFOS (Photonic Skins For Optical Sensing) is a research project funded by the European Commission's 7[th] Framework Programme. The project aims at developing a flexible and stretchable foil that integrates highly advanced optical fibre sensing elements as well as optical and electrical powering functionalities and read-out of the sensors. This skin-like foil can be wrapped around or attached to irregularly shaped objects or bodies and will allow quasi-distributed sensing of mechanical quantities such as deformation and pressure. The applications targeted can be found in the fields of structural health monitoring and healthcare.

Keywords: photonic crystal fibre, polymer optical fibre, optical fibre sensor, flexible electronics

1. INTRODUCTION

PHOSFOS (Photonic Skins for Optical Sensing) aims at developing a flexible and stretchable optical sensing foil:

- in which all necessary optical sensing elements can be integrated;
- that whenever necessary can include optical and electrical powering and communication, as well as onboard signal processing units;
- that can be wrapped around, embedded in, attached and/or anchored to irregularly shaped and/or moving objects;
- that allows quasi-distributed sensing.

This concept is illustrated in Fig. 1.

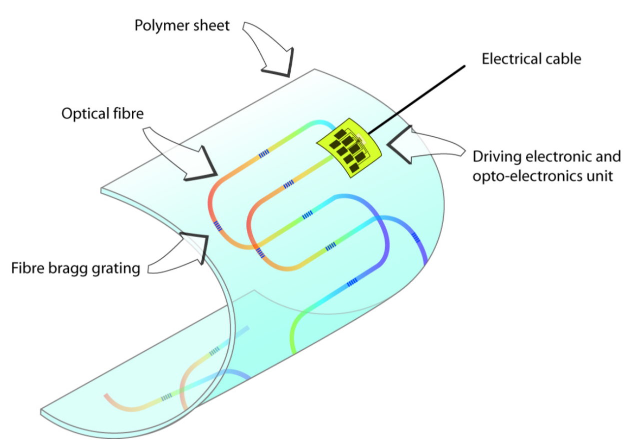

Fig. 1. Illustration of the flexible photonic sensing skin with embedded optical fibre sensors and flexible electronic driving circuitry.

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The project introduces a new paradigm for optical sensors by integrating them in an unprecedented manner with optoelectronic and electronic circuitry in flexible and stretchable skins. The many advantages of optical sensors, and more particularly optical fibre sensors, such as immunity to electromagnetic interference, high sensitivity, small size and low weight, passiveness, resistance to harsh environments, multiplexing capabilities and possibility to parallelize the readout, make these sensors more versatile and often more reliable than their electronic counterparts for many applications in diverse fields including structural health monitoring, automotive industry, oil and gas extraction, aeronautics and aerospace, robotics, healthcare, etc. By combining these assets with packaging, true strain transfer, optical coupling, reliability, and fully-fledged system integration PHOSFOS holds potential to solve a number of issues encountered in the fibre-optic sensing field, i.e.

- the need for low cost and miniaturized optical interrogation units;
- the need to have fibre sensor modules installed by trained personnel;
- the competition with planar sensors that can displace fibre sensors in many applications;
- the need for integration with wireless communications;
- the possibility to provide local powering in inaccessible areas.

To achieve its overall objective PHOSFOS pursues two fibre sensor routes and builds on the combination of these with new optoelectronic integration technologies. The approach can be broken down in two specific targets. The first specific target of PHOSFOS is to develop sensing structures consisting of a Bragg grating in two fibre types. These two types each come with their specific advantages that justify the choice for two complementary routes. The first type is micro-structured silica fibres (MSFs) that allow, when correctly designed, measuring a single parameter without need for any complex cross-sensitivity compensation scheme. The second type is polymer optical fibre (POF, either micro-structured or not). Polymer fibre sensors offer unique challenges but have some distinct advantages over silica fibre for certain sensing applications.

The second specific target of PHOSFOS is to integrate and to embed 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) has already proven to be a possible route to overcome the packaging and alignment problem, but has never been tried on flexible circuits.

This text will introduce the different technologies on which PHOSFOS relies, while highlights and recent results will be covered in more detail in the presentation.

2. PHOSFOS TECHNOLOGIES

PHOSFOS first relies on MSF based sensors. This topic has already been reviewed several times in literature.[1,2] More particularly PHOSFOS works towards achieving very high birefringence in MSF and enhancing the sensitivity to pressure or line-load in these fibres while keeping the cross-sensitivity to temperature to negligible levels.[3] The possibility to fabricate sensor FBGs in birefringent MSF and the integration of MSF sensors in composite materials has recently been reported. [4,5] This evidenced the feasibility of using such sensors for mechanical sensing purposes with a sensing principle as illustrated in Fig. 2. Integrating these sensors in compliant polymer materials has however not yet been demonstrated.

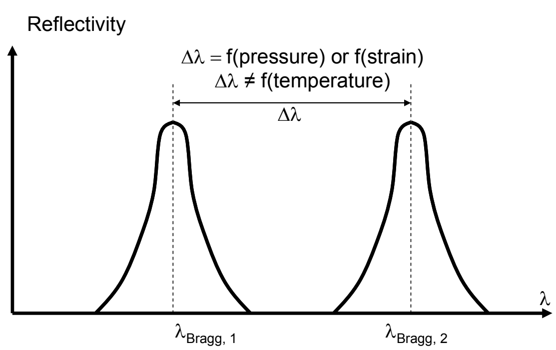


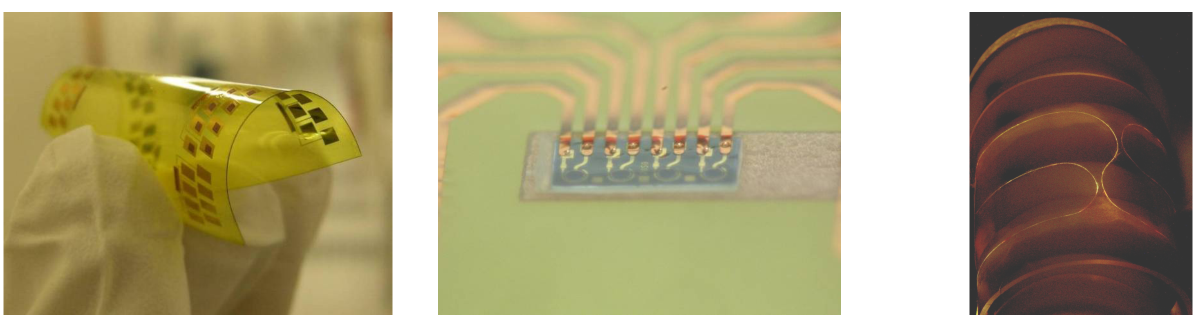
Fig. 2. Illustration of the sensing principle using fibre Bragg gratings in highly birefringent micro-structured silica optical fibres. The measurand is encoded in the spacing between the two Bragg peaks corresponding to the two orthogonally polarized modes propagating in the highly birefringent fibre.

PHOSFOS also uses POF based sensors which have attracted considerable interest in recent years.[6,7] More particularly we rely on the capability of FBGs fabricated in POF to survive much higher strains than silica fibre. POF based Bragg grating sensors are an order of magnitude more sensitive to temperature than silica fibre, which can be a disadvantage for strain sensing requiring accurate absolute measurements, but should not obstruct the rapid detection of strain state changes.[8] Furthermore POF lends itself potentially to modification by a wide spectrum of organic chemical techniques or to micro-structuring.

Both MSF and POF have to be embedded into a flexible skin made of a material which is also compatible with the thinning and embedding technologies used in the field of flex-stretch electronics and opto-electronic and electronic packaging. A variety of polymers have been developed for that purpose, but all with limited flexibility. Most of them are based on cross-linkable polymers which lead to insoluble network structures. Examples are polyurethanes, poly(meth)acrylates, polysiloxanes, and hybrid organic-inorganic composites. Cross-linkage can be induced by heat, photo-irradiation or chemical reactions under mild conditions. Ormocer® (Fraunhofer-Gesellschaft) and Truemode™ (Exxelis) are well-known examples that are widely used. PHOSFOS develops materials with tuneable properties and on-demand levels of flexibility (as illustrated in Fig. 3) that are compatible with packaging technologies.

Fig. 3. PHOSFOS polymer skin materials compatible with opto-electronic packaging technologies and with various levels of flexibility.

Finally PHOSFOS also seeks to embed the fibres in the flexible skins together with the opto-electronic devices required to power and read-out the fibre sensors. This requires these elements to be thinned down using adequate polishing and lapping techniques. PHOSFOS has shown that vertical-cavity surface-emitting laser diodes (VCSELs) and photodiodes (PDs) can be thinned down to become flexible while remaining fully functional (Fig. 4(a) and Fig. 4(b)). First fibre sensors were also already embedded in a flexible skin as shown in Fig. 4(c). The path of the fibre within the skin and the sensor location can be accurately defined using laser ablation techniques.



(a) (b) (c)

Fig. 4. Optical foil with embedded optoelectronic devices (a) array of VCSELs; (b) array of PDs; (c) MSF with FBG powered with supercontinuum light.

3. CONCLUSION

PHOSFOS is a challenging project that attempts to combine novel fibre sensor techniques with advanced opto-electronic integration technologies. The individual devices and technologies have proven to be functional. The next challenge lying ahead is to combine all the elements into a functional system.

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