FIBER BRAGG GRATING SENSORS EMBEDDED IN POLYMERIC FOILS

A. F. Silva[1], F. Gonçalves[2], L. A. Ferreira[3,4], F. M. Araújo[3,4], I. Dias[4], P. M. Mendes[1], J. H. Correia[1]

[1] University of Minho, DEI, Campus de Azurem, Guimaraes, Portugal

[2] TMG Automotive, Campelos, Guimaraes, Portugal

[3] FiberSensing, Maia, Portugal

[4] INESC Porto, Faculty of Science, University of Porto, Porto, Portugal

e-mail: asilva@dei.uminho.pt

Abstract *— This paper presents the fabrication and characterization of a polymeric foil able to sense deformation, gather sensitive information and send it for further analysis. Fiber Bragg Grating sensors are embedded in laminated polymeric sheets commonly used in the car's flooring. The fabrication of the Bragg sensors and the integration of the optic sensors in the foil is described, using industrial fabrication processes. The obtained foil is capable of transferring the full deformation to the optic sensor and returning to the initial position when no deformation exists, providing good sensibility. Application of this sensing foil includes automobile chassis monitoring.*

Key Words*: optical sensor integration, fiber Bragg gratings*

I INTRODUCTION

Optical sensing technologies have associated advantages that make them very attractive in a broad range of applications. Optical fiber sensors, in particular, provide low-cost solutions, with immunity to electromagnetic interference, multiplexing capabilities and a high degree of miniaturization/integration. Presently, optical fiber sensors offer a high performance alternative, in comparison to standard technologies, in many different areas, either for measuring physical parameters like strain, temperature or pressure, or for performing highly sensitive biochemical analysis [1, 2]. Integrated optics devices, on the other hand, are now emerging as next generation sensing structures where virtually any parameter can be determined with high accuracy in a highly miniaturized optoelectronic device [3].

Linking textiles or textiles-polymer-laminates (artificial leather) with optical devices and electronics is more realistic than ever. An emerging new field of research that combines the strengths and capabilities of electronics, optics and polymers like Polyvinyl Chloride (PVC) is opening new opportunities.

Industries like the automotive, aeronautics and biomedical look for ways to gather information from their systems status. Lower production cost, wider exploitation of integrated circuit technology and wider applicability to sensor arrays ensure the integration of microsensors in almost any structure, providing the desired system data.

I.1 FIBER BRAGG GRATINGS

A Fiber Bragg Grating (FBG) is a small size microstructure (less than 10 mm long) that can be photo imprinted in photosensitive optical fibers by side-exposure to patterned UV laser radiation. Such a microstructure consists on a periodic modulation of the refractive index of the core of the optical fiber that is characterized by a narrowband resonance spectral reflection. Since this is a deeply embedded device in the optical fiber structure, the resonance behavior strictly follows external actions in the exact proportion as the silica matrix surrounding the component. This results in a localized sensor offering high sensitivity to temperature and strain, particularly suitable for quasi-distributed measurements ranging from few centimeters to tens of kilometers.

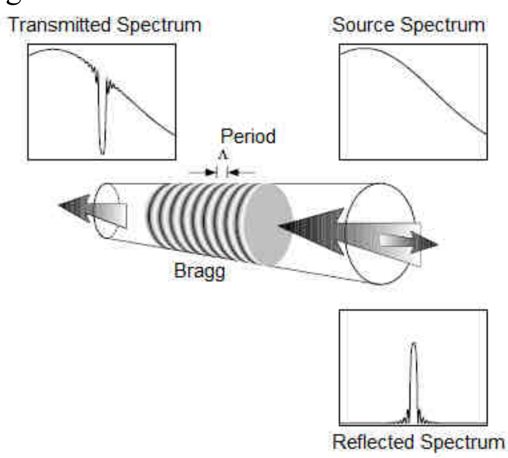

Figure 1 – Schematic representation of Bragg sensor.

The main feature that makes Bragg grating sensors so competitive for structural monitoring is its inherent multiplexing capability, which arises directly from their intrinsic properties. Since each Bragg sensor has its own wavelength signature, in an array of sensors is possible to identify each sensors individually. This multiplexing capability enables many grating sensors to be interrogated using common optoelectronic instrumentation. In addition, fiber Bragg grating sensors offer immunity to EMI/RFI, remote monitoring capacity, small size and weight, electrical isolation, intrinsically safe operation in hazardous environments, high sensitivity and long-term reliability.

I.2 POLYMERIC FOIL

Vinyl mixtures or so-called Plastisols, are liquid dispersions of a finely divided thermoplastic, polyvinyl chloride resin, in a plasticizer. It is a 100% non-volatile paste-like composition and consists of a physical mixture of finely sized PVC polymer particles and liquid plasticizers, such as phthalates and epoxy oils.

These resulting pastes are highly viscous mixtures that, after heated above the curing-temperature (130 to 400 ºC), become homogenized and a solid phase results. When cooled, the Plastisol provides a tough material with specific physical characteristics.

The Plastisol material is formulated to be a dense solid and elastic polymer, which retains toughness even at low temperatures. Plastisols can be formulated with hardness ranging from 30 to 90 *Shore A* (relative hardness of elastic materials) and tensile strength ranging from 750 to 3000 psi. It can be formulated to resist chemical attack, is self-extinguishing due to the chlorine groups, provides good weatherability and can be used as support structure when looking for flexibility

II FABRICATION PROCEDURE

II.1 FIBER BRAGG GRATINGS

The mechanism responsible for the non-linear photoinduction change of the refraction index is known as photosensitivity and is associated with the silica matrix doped with germanium that is the core of photosensitive optical fiber [5]. This mechanism enables the direct fabrication of the microstructures in the core of optical fibers by exposure across the periodic pattern of UV radiation. Each individual component of the microstructure is formed by irradiation spot of the core of the fiber, which locally causes a change of the refraction index on adjacent positions not exposed.

Figure 2 illustrates the experimental setup used in the fabrication of Bragg structures by the phase mask method. The optical fiber is maintained along the surface of the mask aligned transversely with the depressions, and the UV radiation focused along the fiber optic through a cylindrical lens. It should be noted that, an ideal mask ideal – i.e., with total abolition of the order zero - the period of the modulated interference pattern is always half of the period of the phase mask, and independent of wavelength of the laser emission (Figure 2).

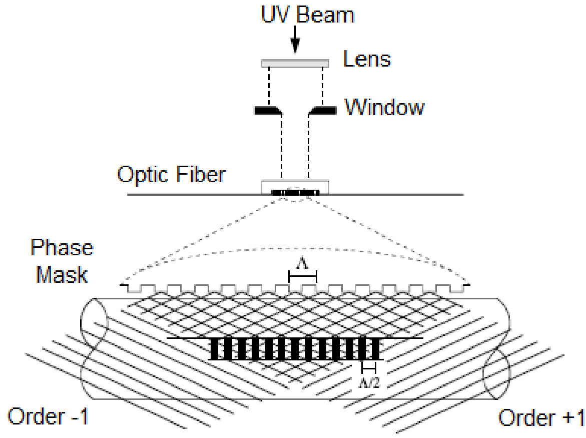

Figure 2 – Schematic of the FBG fabrication setup.

The period of the modulated interference pattern depends only on the period of the phase mask. The manufacturing of the Bragg structure with different wavelengths requires the use of different phase masks. However, the extreme simplicity of alignment and stability of the inherent pattern of interference can produce networks of Bragg with high reproducibility.

The used optic fiber was a single mode Corning 28-e, a standard optic fiber for communication applications, with acrylate coating. The Bragg structures printed in the core of the fiber were in the communication wavelength range (1520-1570 nm).

II.2 POLYMERIC FOILS

The fiber optic sensor is packaged with the polymeric foil that works also as a support structure. By this, is important that the optic fiber becomes very well embedded on the foil in order to

eliminate any possibility of losing sense sensibility by the flexible foil.
In order to accomplish such goal, a three layer foil approach was considered (Figure 3).

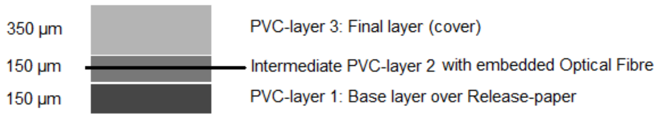

Figure 3 – Three layer foil approach.

The fabrication relies on an industrial process. A first layer in applied in a substrate (support for the fabrication) and layer-by-layer, the structure passes through a gap between the "blade" and counter cylinder to ensure the desired thickness.
As the coating and substrate pass through, the excess is scraped off. At the end, the layer goes to the inside of the oven to cure and become a solid state structure.

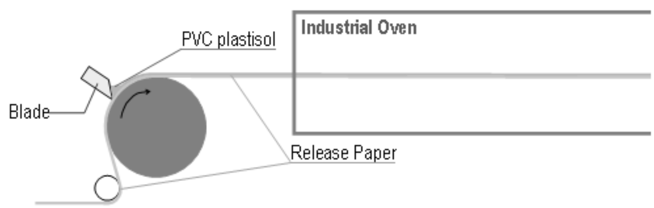

Figure 4 – Procedure schematic.

The second layer suffers a partial cure in order to increase the viscosity and facilitate the insertion of the optic fiber.
The main concern of this process was the high temperature of the oven that would be sufficient to destroy the optic fiber coating and change the refraction index of the fiber, damaging it.

Table 1 – Polymeric foil fabrication procedure.

Step	Operation	Condition		
		Gap [µm]	Temp. [ºC]	Heating time [s]
1	Application of PVC-layer 1	150	-	-
2	Heat-curing of PVC-layer 1	-	200	60
3	Application of PVC-layer 2	150	-	-
4	Heat-curing of PVC-layer 2	-	200	5
5	Optical fibres insertion	-	-	-
6	Heat-curing of PVC-layer 2	-	200	60
7	Application of PVC-layer 3	350	-	-
8	Heat-curing of PVC-layer 3	-	200	60
9	Cooling + manual release	-	-	-

III RESULTS

Figure 5 shows the result of the fabrication process previously presented.
The polymeric foil, with 210x297 mm size, has optic fiber based sensors embedded in it. By visual inspection, we can conclude that the fabrication process has run successfully, appearing only to be some deformation waves on the surface as result of the heating process followed by a cooling period (Table 1). The temperature difference made the polymeric material to initially expand and then contract, pushing the fiber along, creating the waves.

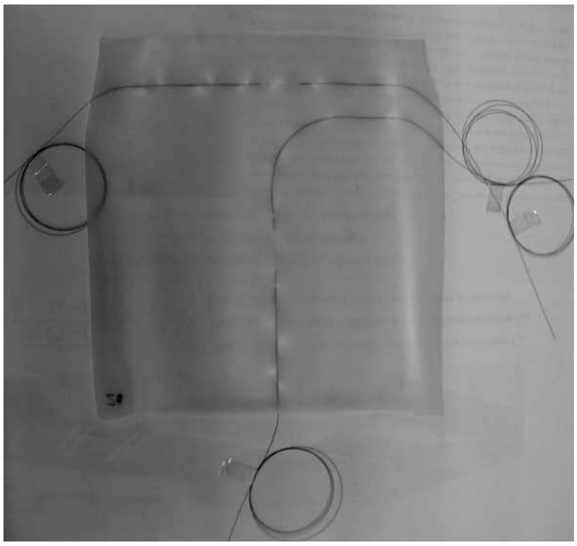

Figure 5 – Polymeric foil with optic fiber sensors embedded.

Figure 6 presents the reflected spectrum of the FBG sensor. The side lobes come from the grating fabrication process, resulting from the radiation transmission function. They can be smoothed by apodization function.

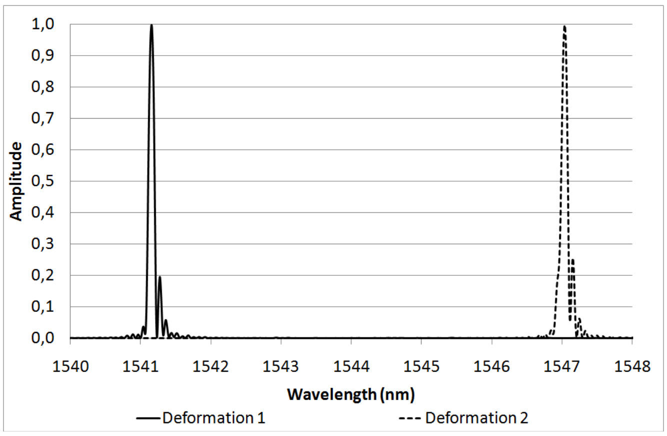

Figure 6 – Reflected spectrum from the FBG sensor for two distinct tensile forces.

When deforming the polymeric foil, the embedded FBG sensor follows the deformation and the reflected spectrum suffers a wavelength deviation. This variation, without changing the spectrum shape, can be translated to a deformation value by a mathematical expression.
The high sensitivity verified is representative of a successful implementation of the optic fibers in the PVC foil.
Figure 7 presents the progression of the deformation sensed, by the FBG structure, versus time. The FBG sensor presents a linear behavior while undergoing a tensile force. When the force is released, the spectrum comes back to the initial wavelength, intrinsic to the FBG sensor.

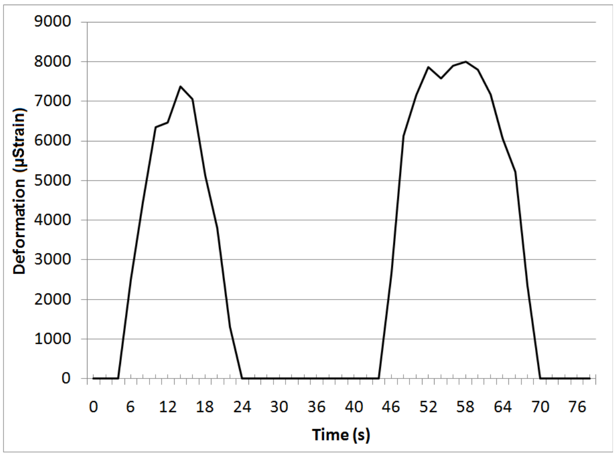

Figure 7 - Deformation sensed by the FBG over time.

A final analysis was done, in order to evaluate the ability to sense in a real structure. A foil with optic sensors was glued to a metallic structure that was later subject to force. The polymeric foil, as well as the optic sensors, was able to follow the deformation of the metallic structure with a sensitivity of 1pm/µε (picometer per microstrain).

IV DISCUSSION

The integration step has been presented but a few problems must be taken into account.
First, the temperature restraints in the foil fabrication need to be analyzed, since the use temperature (200 ºC) was below the temperature used in the industrial process (230 ºC). The possible damages to the optic fiber due to high temperatures may be overcome by the use of fiber coated by polyamide, capable of supporting higher temperatures.
Secondly, there is a need to reduce the deformation caused by the heat and cooling process. A possible solution will be the creation of a fabric mesh with optic sensors integrated that are later inserted in the polymeric foil.
Further work, also includes the design of optoelectronic components capable of being also inserted in the polymeric foil. The main goal is to have a flexible polymeric foil with a sensing network inside it, capable of detecting deformation.

V CONCLUSION

The prototype model presented an excellent behavior, 1pm/µε, allowing further improvements. The fabrication process of the optic fibers with FBG sensors is standard, not presenting any major problems. The manufacturing of the polymeric foil integrating the FBG sensors, presents restraints, especially in terms of temperature, requiring more research, but is clear that this flexible material can be use as structure material.
In terms of performance, the structure showed that, not only the spectrum shape did not change during the force application, but also that it returned to its initial position (without any reduction of the signal amplitude).
Integration of FBG based-sensors in PVC foils is demonstrated, promising production of large FBG based-sensors in PVC foils and mass production in industrial environment.

VI ACKNOWLEDGEMENT

Alexandre Ferreira da Silva is supported by Portuguese Foundation for Science and Technology (SFRH/BD/39459/2007).

REFERENCES

[1] Grattan, K. T. V. and T. Sun, Fiber optic sensor technology: an overview. Sensors and Actuators a-Physical, 2000. 82(1-3): p. 40-61.
[2] Wolfbeis, O. S., Fiber-optic chemical sensors and biosensors. Analytical Chemistry, 2006. 78(12): p. 3859-3873.
[3] Blue, R., et al., Platform for enhanced detection efficiency in luminescence-based sensors. Electronics Letters, 2005. 41(12): p. 682-684.
[4] Norm Schiller, Hamamatsu Corporation. Selecting Optical Detectors for Automotive Designs, in ECN, December,1, 2004.
[5] Hill, K.O., Photosensitivity in optical fiber waveguides: from discovery to commercialization. Selected Topics in Quantum Electronics, IEEE Journal of, 2000. 6(6): p. 1186-1189.