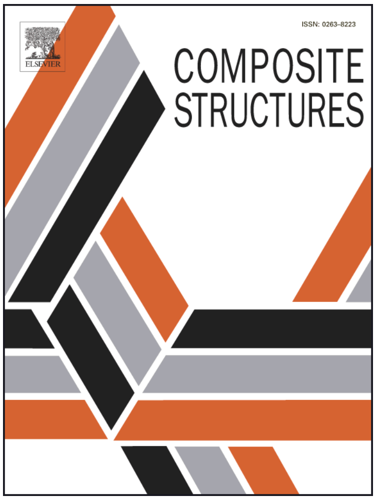

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S. Miclos, D. Savastru, R. Savastru, I.I. Lancranjan

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Numerical analysis of long period grating fibre sensor operational characteristics as embedded in polymer

S. Miclos[a], D. Savastru[a], R. Savastru[a], I. I. Lancranjan[a,*]

[a]National Institute of R&D for Optoelectronics – INOE 2000, 409 Atomistilor Str., Magurele, Ilfov, RO-077125, Romania

Abstract

The paper main purpose is to present the results obtained in development of a LPGFS (Long Period Grating Fibre Sensor) embedded into a polymer composite simulation model. In this way the polymer composite transforms into a “smart one”. The developed simulation model is a “must be accomplished” stage for a proper manner engineering the smart polymer composite materials fabrication and for improved designs of their applications in various fields such as aeronautics, chemical industry and defence. A LPGFS is operated by observing the spectral shifts, broadenings and splitting of its Bragg resonance absorption bands appearing into its transmission spectrum. The developed simulation model of the LPGFS embedded into a polymer composite must cover basically the modification of its transmission spectrum caused by polymer refractive index characteristics, firstly with no applied mechanical loads and secondly by considering the mechanical stress induced in the optic fibre by the polymer embedment. The LPGFS simulation model is developed considering the role of optic fibre birefringence induced by polymer embedment. After that, it follows the specific application stage in which it is analysed the LPGFS response to loads applied to smart composite material by its environment.

Keywords: Long Period Grating Fibre Sensor, polymer refractive index, smart polymer composite material, fibre optic birefringence.

*Corresponding author at: National Institute of R&D for Optoelectronics – INOE 2000, 409 Atomistilor Str., Magurele, Ilfov, RO-077125, Romania. E-mail address: j_j_f_l@yahoo.com.

1. Introduction

The main purpose of the paper consists in presenting the results obtained in development of a simulation model applicable for Long Period Grating Fibre Sensor (LPGFS) embedded into a polymer composite which is transformed in this way into a “smart one” able to generate a feedback signal for applied ambient mechanical, thermal and chemical stimuli [1 - 5]. The simulation model is a “must be accomplished” stage for engineering in a proper manner the fabrication of smart polymer composite materials and for improved designs of their applications in various fields such as aeronautics, chemical industry and defence [1-5]. LPGFS is usually manufactured into single mode (SM) communication fused silica optical fibre having a core diameter of 4-10 μm and a cladding diameter of 125 μm by inscribing on it or into the core, along the axis, over a 5-50 mm length diffraction gratings with 10 - 1000 μm period, the inscribed grating being known as Long Period Grating (LPG) [1 - 10]. Thus the LPG is formed by core periodic small amplitude refractive index non-uniformities (10^{-4} relative to the main value) [11 - 15] or of successive small relative amplitude tapers of the cladding [16 – 20]. These non-uniformities are composed of fused silica colour centres induced by focused laser UV radiation applied using a point-by-point technique and, because of colour centres thermal instability at temperatures larger than 250-300 K, cautions should be taken in temperature measurements. Actually, by using UV laser irradiation technique, the period of the inscribed in the core can be shortened to 0.5 - 1.0 μm in which case Fibre Bragg Gratings (FBG) are obtained [11 – 13]. The successive small relative amplitude tapers of SM optical fibre are fabricated by using the thermal processing techniques such as irradiation using a CO_2 laser, electric arc discharge from a modified commercial fibre fusion installation, controlled flame heating and pre-heating followed by permanent bending [16-25]. It can be noticed that the thermal processing techniques are cheaper compared to the use of UV laser radiation. LPG operation, as well as that of FBG, can be justified using the coupled mode theory with the Bragg resonance condition as key point for defining diffraction maxima [26-30], as will be explained in the next section. Regarding optical fibre applications in sensing LPGs, as well as FBGs, they were developed in order to increase the sensitivity of fibre sensors to the changes of the ambient. LPG and FBG operation modes consist in injection of a light signal with a defined spectrum at one end of the optical fibre in its core and observing at the other end the absorption bands induced in the transmission spectrum as the light signal power is coupled, transferred by the LPG to the co-propagating cladding modes, in the LPGFS case, or the absorption line induced in the transmission spectrum by the coupling of injected light signal by the Bragg grating to a counter-propagating core mode or the corresponding reflection line Bragg grating line at the same injection end. FBG sensors operate almost exclusively by grating period modification under mechanical or thermal environment action [13 - 17]. LPGFS operates not only by using LPG period modification induced by thermo-mechanical stimulus but also by any transmission spectrum modification induced by any environment refractive index changes [13-18, 20, 24, 27-32].

In the case of smart composite materials using LPGFS embedded into a polymer, its operation mode consists in observing the spectral shifts, broadenings and splitting of Bragg resonances absorption bands existing in its transmission spectrum [1-5, 16-20]. The LPGFS embedded into a polymer composite simulation model must cover two main aspects related to how it is operated: a) modification of spectral characteristic caused by polymer induced mechanical stress and b) LPGFS response to loads applied to smart composite material by its environment. The developed simulation model is composed of four modules which can be operated separately or interactively: the first one has the role of simulation of LPGFS transmission spectrum with its peak absorption wavelengths, strengths and linewidths, without any mechanical load applied on the optical fibre; the second module consists into the same as the first one, but taking into account the role of role of polarization of light propagating through the LPGFS; the third has the role of defining internal mechanical stress created inside a SM optical fibre under applied mechanical loads and, on this basis, of describing the transverse distribution across the optical fibre of refraction index effective value; the fourth module simulates the LPGFS transmission spectrum considering the results obtained in the second and third module.

2. Theory

For a better understanding of the investigated LPGFS, in Fig. 1 is schematically shown its structure and its operation mode, in a longitudinal section. In the upper part of Fig. 1 are represented the core and cladding of the SM optical fibre and the grating lines corresponding to a usually sinusoidal modulation of the core refraction index between n_{co} and $n_{co}+\delta n_{co}$ (detailed in the lower part of Fig. 1) with the amplitude $\delta n_{co}\sim 10^{-4}\times n_{co}$ [14-25]. In the lower part of Fig. 1 there can be observed the LPG mode of operation, based on scattering of incoming light signal guided through the core by the grating lines, in this way being coupled to the possible cladding propagating modes with the net result of absorption bands which appear in LPGFS transmission spectrum at peak resonance