in Proc. SPIE Photonics Europe, SPIE vol.8439,
(Brussels, Belgium, April 16-19, 2012), p.8439-20

A novel highly birefringent fiber loop mirror sensor based on a 3×3 fiber coupler

R. M. Silva[a,b], A. B. Lobo Ribeiro[c], J. L. Santos[a,b], O. Frazão[*a]
[a]INESC Porto, Rua do Campo Alegre 687, 4169-007 Porto, Portugal ;
[b]Faculty of Sciences of University of Porto, Rua do Campo Alegre 687, 4169-007 Porto, Portugal;
[c]Faculty of Heath Sciences, University Fernando Pessoa, Rua Carlos da Maia 296, 4200-150 Porto, Portugal

ABSTRACT

In this work, a novel high birefringent (HiBi) fiber loop mirror sensor based on a "figure-of-eight" constructed with a 3×3 fiber coupler, is presented. The "figure-of-eight" is formed by two fiber loop mirrors (FLM's) made by four of the six fiber arms of the 3×3 fiber coupler. The other two remaining fiber ports of the 3×3 coupler are used as input and output fibers of the compound sensor. The sensing head is located in the one of the FLM and it is formed by a spliced section of HiBi elliptical core fiber. The spectral response of this "figure-of-eight" configuration presents two interference optical signals that can be easily tuned by a polarization controller that is located in the other FLM, and which is made only of standard singlemode fiber from two arms of the 3×3 coupler. The sensor head was optically characterized both in temperature and strain, showing wavelength dependence sensitivities of -0.23 nm/ºC and -2.6 pm/με, for temperature and strain, respectively. It is noticed that these sensitivities are practically the same for the two interference signals. Future work will explore the possibility to use the singlemode FLM to interrogate the sensor head made by HiBi fiber section, and providing elimination of phase fluctuations that can occur, increasing its potential for remote sensing applications.

Keywords: Optical fiber sensors, fiber loop mirror, physical parameters.

1. INTRODUCTION

The fiber loop mirror (FLM) has been demonstrated as an attractive device for optical fiber sensing since the end of the 80's [1]. The FLM was made up of a splice between two output ports of a 2×2 directional fiber optic coupler. In this case, the two waves travel within identical optical path lengths in opposite directions and a constructive interference is assured when the waves recombine at the coupling region. Thus, all light is reflected back into the input port, while none is transmitted to the output port. When a section of highly birefringent (HiBi) optical fiber is spliced inside the FLM, a path imbalance is introduced between the light that propagates along different polarization eigenaxis and an interferometric channeled spectrum is observed at the output.

The first high birefringent fiber loop mirror (HiBi FLM) used for temperature measurement was reported by De la Rosa et al [2] in 1997. The configuration consisted of a 2×2 polarization maintaining (PM) fiber coupler, fabricated with HiBi "bow-tie" fiber. By cross splicing the output fiber ports of the PM coupler at an angle of 90 degree, it was guaranteed that both fiber port lengths were different, forming an unbalanced Sagnac loop interferometer. This temperature sensor could operate both in transmission and reflection, and its operation did not depend on the state of polarization of the light at the input port [2, 3]. Recently, two new configurations of HiBi FLMs with an output port probe were proposed [4]. Both configurations using two 2×2 couplers spliced together, with unbalanced arms and one output port was used as the probe sensor. The difference between them was the location of the HiBi fiber section length. The sensing probe was optically characterized when subject to strain and also as an optical refractometer.

A fiber optic gyroscope using a directional 3×3 fiber coupler was proposed and experimentally demonstrated by S. K. Sheem, in 1980 [5]. One year later, the same author analyzed interferometric configurations utilizing 3×3 fiber couplers

[*] ofrazao@inescporto.pt

[6]. The optical characteristics of such fiber interferometers were compared with conventional ones that use 2×2 fiber couplers. In 1982, R. G. Priest made a theoretical analysis of the properties of the 3×3 fiber coupler reveling that four parameters are required to characterize the optical power transfer properties of this type of fiber coupler [7]. A different technique was proposed to demodulate the output signals of a directional 3×3 fiber optic coupler eliminating the dependence on the idealization of these couplers, providing enhanced tolerance to the variance of photoelectric converters [8].

In this work, a new interrogation system combining standard singlemode FLM and an HiBi FLM based on a single 3×3 fiber optic coupler, is reported. Due to the characteristics of this configuration, two polarization states of light are generated. The sensing configuration was optically characterized in strain, temperature and torsion measurements.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup used. To illuminate the "figure-of-eight" configuration, an optical broadband source with a spectral bandwidth (FWHM) of 100 nm centered at 1550 nm was placed at the input fiber port. A singlemode fiber splice was made between the two other ports of the 3×3, creating the FLM1 (see Fig.1). The polarization controller (PC) was located in the FLM1, acting as a polarization state rotator for both clockwise and counterclockwise propagating beams circulating on the "figure-of-eight".

At the output fiber port of the 3×3 coupler, an optical spectrum analyzer (OSA) with a maximum spectral resolution of 0.5 nm, was used to measure the transmission spectra produced by the sensor configuration. With the remaining two fiber ports of the total of six of them, an HiBi FLM was formed (FLM2 on Fig.1) using elliptical-core fiber (*e*-core fiber) spliced between these two ports. The HiBi fiber inserted had 1 m length and his cross section [13] is schematically shown in Figure 1. The main typical parameters of the *e*-core fiber (reference: 48280 1550S 5) are the group birefringence of 3.85×10^{-4} and the beat length of 4.0 mm. The sensing head was located in this HiBi FLM region. With the insertion of FLM1, two polarization states of light are generated.

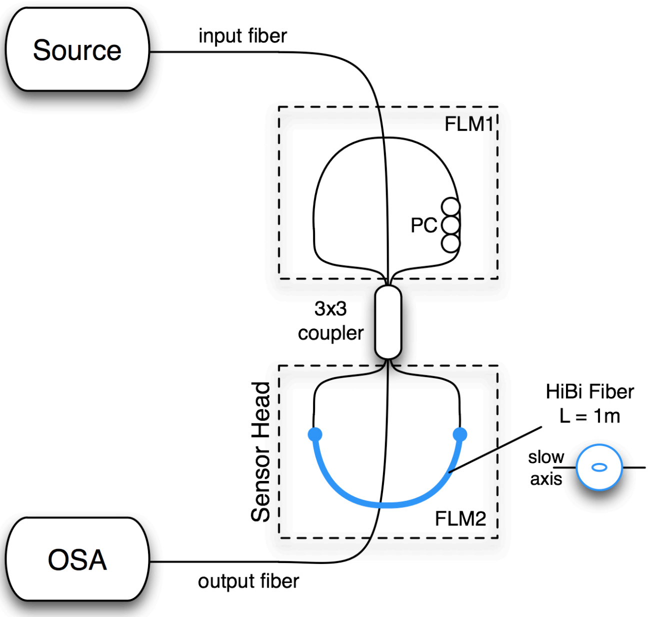

Figure 1 - Schematic of the experimental setup, exhibiting the cross-section of the HiBi fiber used.

3. EXPERIMENTAL RESULTS

In Figure 2 several spectral responses can be distinguished, which resulted from changing one paddle on the polarization controller at the FLM1. The two polarization states mentioned before are graphically represented by the more intense (dash line) and the less intense (dot line) curves in the figure. It can be observed that the frequency is the same for both, but a phase difference of $\pi / 2$ is visible. When the two polarization states interfere, due to the frequency and phase difference, they give rise to the remaining spectral responses observed on Fig. 2. While the paddle of the PC device is moved, the interference pattern varies according to the vertical arrow indicated on Fig. 2,. For all measurements, the optical characterization of the sensing head was done using the spectral response where the interference between the two polarization states are visible (dash-dot line of Fig. 2).

The sensor head at FLM2 was attached to a translation stage (displacement resolution of 1 μm) in order to perform strain measurements. Figure 3 shows the strain response of the sensor head at constant temperature. Longitudinal strain was applied between 0 and 1200 με, resulting in a linear curve-fitting slope with a sensitivity of -2.6 pm/με. The negative behavior is resulted of the elasto-optic effect is dominant. For the temperature measurements, the sensor head section containing the Hi-Bi fiber was placed into a tubular oven, which permitted a temperature setting with an error smaller than 0.1 ºC. The temperature response of the sensor is shown on Fig.4. These experimental data gives a wavelength-to-temperature sensitivity of -0.23 nm/ºC. In this case, the dominant effect is due to the termo-optic effect.

For the torsion measurement, the twist is applied only in the region of the HiBi fiber and the consequence is a variation of the channeled spectrum fringe amplitude. Using the Fast Fourier Transform (FFT) in the spectral response three different frequencies can be identified, but only two were analyzed due to be the most sensitive to torsion. Figure 5a shows the amplitude behavior, determined through the FFT, towards large torsion angles. For the torsion range of [-270º, +270º], the two frequencies have a similar response but quite different behavior in amplitude variation. Figure 5b shows the difference between the two torsion responses observed in Fig. 5a. The processing of the difference between the frequencies provides elimination of the power fluctuations.

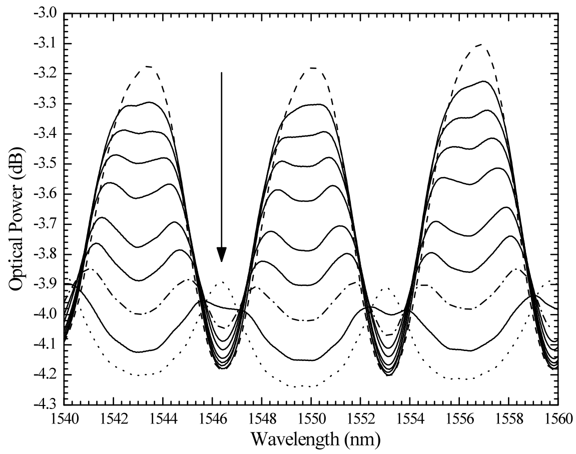

Figure 2 - Channeled spectrum of the sensing configuration when one paddle of the polarization controller was moved.

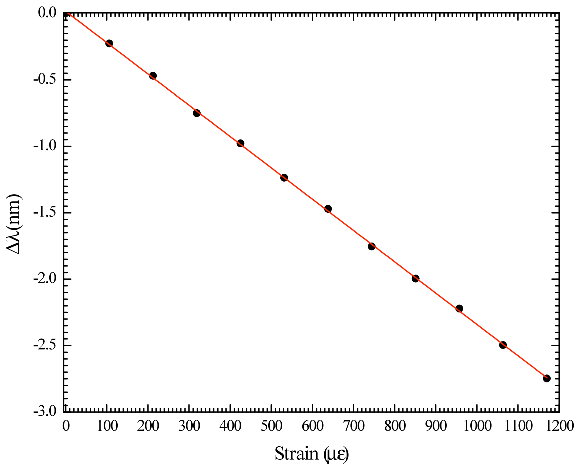

Figure 3 - Strain response of the sensing head.

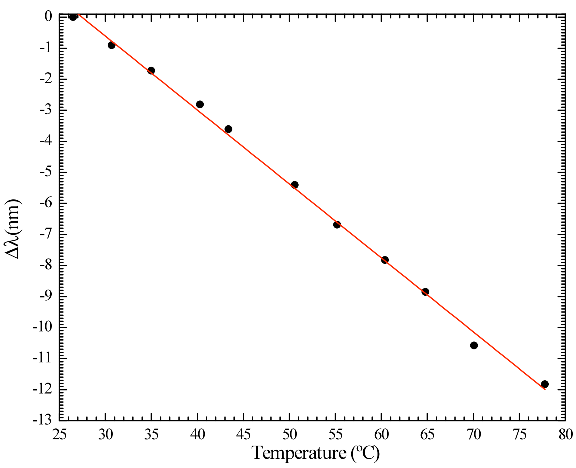

Figure 4 - Temperature response of the sensing head.

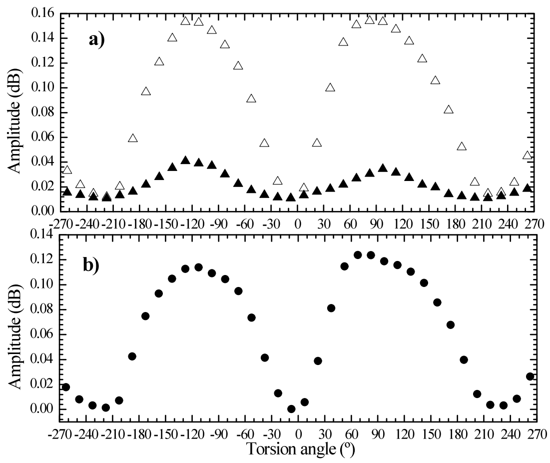

Figure 5 - Torsion response of the sensing head.

4. CONCLUSIONS

In this work, a new sensor head configuration combining two FLM's (one made with HiBi fiber and the other with standard singlemode fiber) on a single 3×3 fiber optic coupler was presented. The sensing head was optically characterized in strain, temperature and torsion. The wavelength dependence sensitivities obtained were -0.23 nm/ºC and -2.6 pm/με for temperature and strain, respectively. It was observed that optical phase is not change but the amplitude of the fringes of the channeled spectra is very sensitive to mechanic torsion. This "figure-of-eight" sensing configuration with proper signal processing provides a cancelation of the optical power fluctuations that can occur on the source.

REFERENCES

[1] D. B. Mortimore, "Fiber Loop Reflectors," J Lightwave Technol., 6(7), 1217-1224 (1988).

[2] E. DelaRosa, L. A. Zenteno, A. N. Starodumov *et al.*, "All-fiber absolute temperature sensor using an unbalanced high-birefringence Sagnac loop," Opt. Lett., 22(7), 481-483 (1997).

[3] A. N. Starodumov, L. A. Zenteno, D. Monzon *et al.*, "Fiber Sagnac interferometer temperature sensor," Appl. Phys. Lett., 70(1), 19-21 (1997).

[4] O. Frazao, R. M. Silva, and J. L. Santos, "High-Birefringent Fiber Loop Mirror Sensors With an Output Port Probe," IEEE Photon. Tech. Lett., 23(2), 103-105 (2011).

[5] S. K. Sheem, "Fiberoptic Gyroscope with [3x3] Directional Coupler," Appl Phys Lett, 37(10), 869-871 (1980).

[6] S. K. Sheem, "Optical Fiber Interferometers with [3by3] Directional-Couplers - Analysis," J Appl. Phys., 52(6), 3865-3872 (1981).

[7] R. G. Priest, "Analysis of Fiber Interferometer Utilizing 3x3 Fiber Coupler," IEEE J Quantum Electron., 18(10), 1601-1603 (1982).

[8] T. T. Liu, J. Cui, D. S. Chen *et al.*, "A new demodulation technique for optical fiber interferometric sensors with [3x3] directional couplers," Chinese Opt. Lett., 6(1), 12-15 (2008).