High Birefringence Fiber Loop Mirror Sensors

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Abstract— In the last years, there have been advances in devices and applications of high-birefringence fiber loop mirror sensors. Fiber loop mirrors are very attractive devices to use in the field of optical fiber communications, as well as optical fiber sensors. In optical sensing, these devices may be used as strain sensors, in refractive index measurement, optical filters for interrogate gratings structures and chemical etching control. In this paper, we only talk about strain sensors, where a phase between two quadrature phase-shifted signal was measured with the strain applied on the fiber. The most relevant results were the sensitivity of the fiber and the approximation of the Lissajous figure to a perfect circle. The sensitivity obtained was of $4.91*10^{-3}$ rads/με (radians/microstrain) and the coefficient of determination (R^2) was 0.99352.

I. INTRODUCTION

Fiber loop mirror (FLM) is a very attractive device for use in optical fiber communications or for use as an optical fiber sensor. The loop mirror is formed by a splice between the output ports of a directional optical coupler. In this case, the two waves travel with identical optical paths in opposite directions and a constructive interference is assured when the waves reenter in the coupler. All the light is then reflected back into the input port, with the reflectivity limited only by the losses of the splice, fiber and coupler, while no light is transmitted to the output port. A specific fiber loop mirror containing a section of highly birefringent fiber (Hi-Bi) has several advantages compared with a more traditional interferometer. One of them is the input polarization independence. Another one is the periodicity of the formed spectral filter, which depends only on the length of the Hi-Bi fiber and not on the total length of the fiber loop mirror.

The Hi-Bi fibers are polarization maintaining fibers where the linear polarization states are structurally maintained. Due to this it is easier to implement an interferometer based on a fiber loop mirror. Also, these fibers can be applied in optical sensing, mostly in polarimetric sensors.

Detailing more the impact of this fiber device, in optical communications it has been used as a wavelength division multiplexing filter, in gain flattening of Erbium-doped fiber amplifiers in multiwavelength fiber lasers and in dispersion compensation. In optical sensing, besides the gyroscope application, it has been used in strain and temperature measurement, in liquid level and displacement sensing as well as a spectral filter for fiber Bragg grating demodulation. Moreover, the Hi-Bi fiber loop mirror combined with a Bragg grating or with a long period grating was also demonstrated for simultaneous measurement of strain and temperature. In this paper we will discuss only the measurement of strain, which are the only measurements that we made.

Fabry-Pérot interferometer has been an attractive choice for fiber-optic interferometric sensors and high resolution sensing devices, due to their inherent miniaturization and point sensing capability. Generally, this type of fiber interferometer is created with two fiber ends with an air-gap in between them (also known as low-finesse Fabry-Pérot cavity), whereas it is associated an optical transfer function close to that of a two beam interferometer. The physical quantity to be measured acts on the optical path difference of the interferometer cavity.

To recover the interferometric phase signal that contains the measurand information, the approach we used is based on the generation of two quadrature phase-shifted interferometric signals through the use of dual-wavelength illumination by two optical sources.

In this paper, we propose a simple sensor design for a fibermodal interferometer by using a fiber taper-tip combination, giving a fiber taper interferometer that is very easy to fabricte by the arc-discharge technique and can be used in a reflective configuration, allowing remote interrogation. To demodulate the interferometric phase signal, we used an optical passive generation of two quadrature phase-shifted signals from a broadband source.

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II. THEORY/PRINCIPLES

A. Theory

The interferometric phase of light reflected from a low-finesse Fabry–Pérot cavity is a well-known function of wavelength. If two distinct wavelength discriminators with bandwidth narrower than the spectral response of the Fabry–Pérot cavity are used to analyze backreflected light, we can write the interferometric phase at each wavelength as

$$\Phi_j = \frac{4\pi nL}{\lambda j}, \text{ j=1,2} \quad \textbf{(1)}$$

where:

n- effective refractive índex of the Fabry-Pérot cavity;

L- Length of the cavity;

$\lambda_{1,2}$- resonances of the two wavelength discriminators.

The relative phase between the two correspondent interferometric signals is given by

$$\Delta\Phi = 4\pi nL\left(\frac{1}{\lambda 1} - \frac{1}{\lambda 2}\right). \quad \textbf{(2)}$$

These signals will be in quadrature when the wavelength separation between the resonant wavelengths is an odd multiple of $\frac{\lambda^2}{8nL}$, where the approximation $\lambda_1=\lambda_2=\lambda$ was considered. This approximation is valid within 1% of error for cavity lengths higher than ~20 µm. For a given cavity length, it is always possible to define two resonant wavelengths that watch the above condition.

The interferometric phase recovery can be obtained using the following equation:

$$\Phi \equiv \Phi_1 = tan^{-1}\left(\frac{I2}{I1}\right), \quad \textbf{(3)}$$

where I_1 and I_2 are the normalized intensities measured in the OSA (Optical Spectrum Analyser).

B. Experimental setup

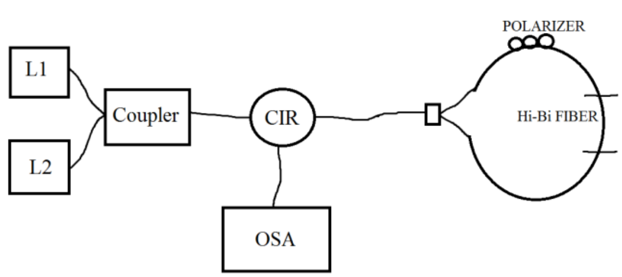

Fig.1– Scheme of experimental setup used on our work

Our experimental setup consists of several instruments, being: 2 lasers, one 50:50 (3dB coupler), one circulator, one polarizer, our Hi-Bi fiber and a OSA.

The lasers are each a large broadband source. The coupler splits the input light into two counter propagating beams, which transverse the loop. These beams then pass through a circulator, which separates the input port from the output port. Therefore, the input port is connected to the coupler, and the final output por tis connected to the OSA. Since we have two beams, they will travel a diferente path: one beam passes through thi Hi-Bi fiber first and then through the polarizer; the other will go through the same, but in the inverse order. Finally, they will pass through the circulator again, this time connected to the OSA for analysising and measuring the data.

III. EXPERIMENTAL PROCEDURE

Once our setup was assembled, we started to measure the output data in the OSA, in order to find the 2 wavelengths used in our LASERs. To do so, we connected the large broadband source to the OSA, and we changed the setup of the polarizer until a image like Figure 2 appeared. The goal here was to find the 2 wavelengths to use in the LASERs, by measuring the minimum and maximum of the signal amplitude using the markers available in the OSA. Then, we would divide the differences in wavelength by two, which left us with the wavelength difference required for the two quadrature phase-shifted signals to be used by the LASERs.

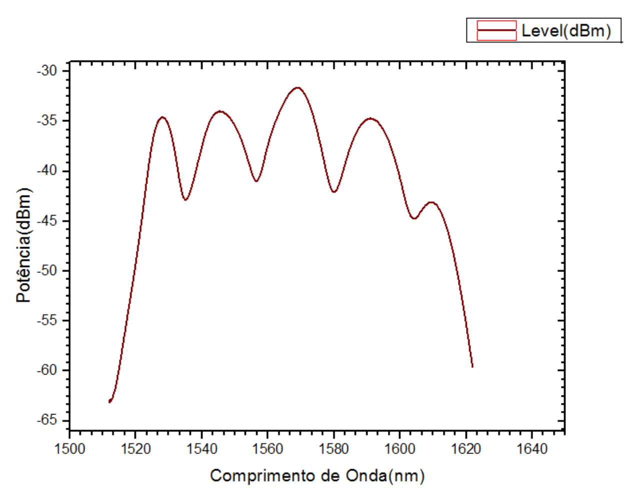

Fig. 2- Image obtained by the OSA for estimate of the difference in wavelength, for the two quadrature phase-shifted signals.

We measured λ_1=1555.900 nm and λ_2=1562.300. the difference is of 6.7 nm, therefore $\Delta\lambda$=3.35 nm. The wavelengths we used were then λ_1=1555.900 and λ_2=1559.250. this difference in wavelength is associated with a phase-shift between the 2 signals of 90º.

We then proceeded to the measurement of the data, by applying stress on the Hi-Bi fiber and reading the corresponding output intensity signal in the OSA.

By applying stress on the fiber, the core effective refractive index will change, and therefore the output signal will be "phase-shifted". We collected enough data for one full cycle, or period, of the sinusoidal change of the signal intensity. We obtained this by placing both markers in the same place in the wavelengths axis, measuring the corresponding intensity as we stretched the fiber.

IV. RESULTS

After the data was retrieved, we analysed the results.

Figure 3 shows the intensity of the two beams of light, normalized.

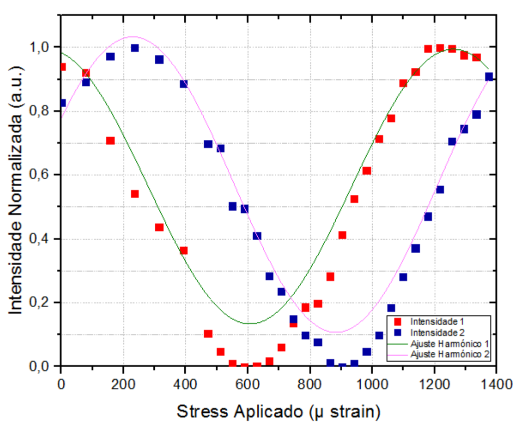

Fig. 3- Normalized intensity vs. applied stress, expressed in micro-strains

Using these results, we can construct a Lissajous figure, which consists of representing the intensity of one beam vs. the second beam of light. For a perfect phase-shift, the image must be a circle. Therefore, the closest we get to a circle, more the results are in agreement with the expected results. Figure 4 illustrates the image we obtained.

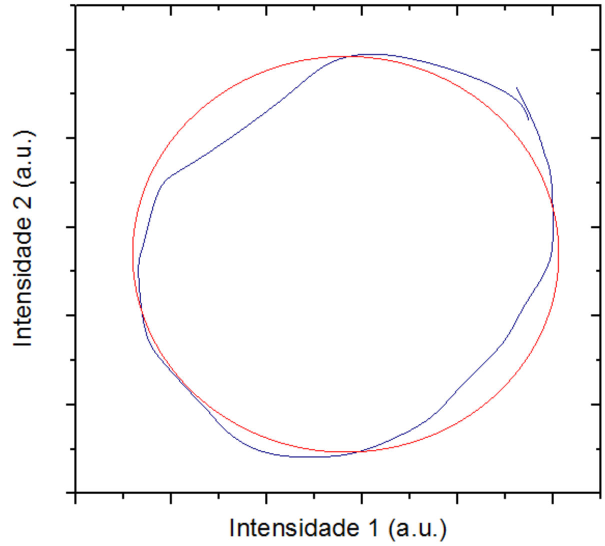

Fig. 4- Lissajous figure. The blue line represents the connecting curve between the points of I_1 vs. I_2, and the red line represents the circular fit.

Figure 4 shows a almost circular fit of the values obtained. This means that the beams weren´t completely synchronized. We obtained a coefficient of determination (R^2) of 0.99352 for the circular fit, although many points are outside the fit line. We can also see this in Figure 3, where the values of both beams are clearly not equal for the same phase.

We can still represent our data with a more accurate point of view. If we use equation (3), we get the phase-shift vs. the stress applied. Figure 5 will illustrate such graph.

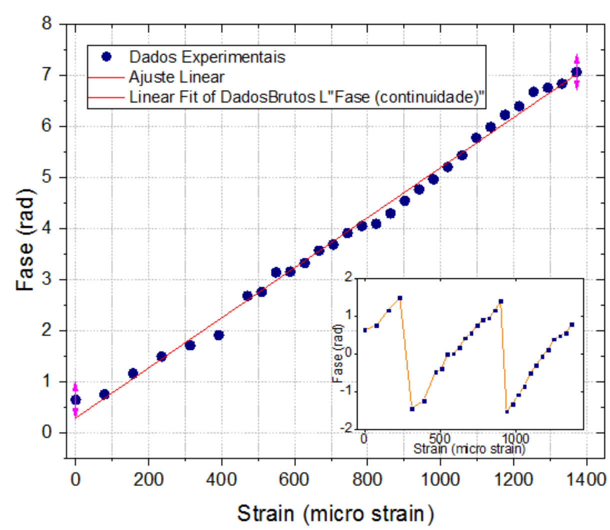

Fig. 5- Phase vs. stress applied. The smaller image within shows the image before data treatment.

Figure 5 is a better way of viewing the display of the data obtained. The smaller image inside shows the initial values obtained after using eq. (3). As expected, there are descontinuities in the function. After “aligning” the lines, by translating by π and 2π, we obtain a straight line. This is the best display of the data, because from here we can obtain the slope of the line, which represents the sensitivity of the fiber, which is the main objective in this work. The slope we obtained was of $4.91*10^{-3}$ rads/με (radians/microstrain). We discussed this value with one of our teachers in charge, and he agreed that this was a rather good value for the sensitivity of this particular fiber. We also obtained a better coefficient of determination (R^2) for this linear fit, that was about 0.99415.

V. CONCLUSION

In this work, me and my collegues could learn more about and have experience working with optical fibers and its properties. Also, a sensor of reduced size and complexity was presented. The concept was tested by applying stress in the Hi-Bi fiber and measuring the corresponding optical intensity, related to the core effective refraction index change. We obtained a sensitivity of $4.91*10^{-3}$ rads/με, which in overall is a rather good result.

VI. REFERENCES

[1] M. Dahlem, J. L. Santos, L. A. Ferreira, and F. M. Araújo, “Passive Interrogation of Low-Finesse Fabry-Pérot Cavities Using Fiber Bragg Gratings”

[2] L. M. N. Amaral, O. Frazão, J. L. Santos, and A. B. Lobo Ribeiro, “Fiber-Optic Inclinometer Based on Taper Michelson Interferometer”

[3] Edurdo Velosa, Carlos Gouveia, Orlando Frazão, Pedro A. S. Jorge, and José M- Baptista, Member, IEEE, “Digital Control of a White Light Interrogation System for Optical Fiber Interferometers”

[4] Orlando Frazão, José M. Baptista, and José L. Santos, “Recent advances in High-Birefringence Fiber Loops Mirror Sensors”.