Stretching light. An interferometric measure.

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Abstract

A strain sensor based on an optical fiber loop mirror unbalanced Mach-Zehnder interferometer is demonstrated. The magnitude of deformation is obtained through interferometric interrogation with origin in two quadrature phase-shifted signals from two tunable lasers. A sensitivity of4.54 rad/nε(nanostrain) is achieved.

Keywords: Fiber loop mirror, unbalanced Mach-Zehnder, strain sensor

1 Introduction

Optical fiber interferometric sensors are a systematic choice for low cost, high resolution devices. FLM (fiber loop mirror) devices are attractive both for use in optical fiber communications or as sensors. The loop mirror is formed when the output ports of a directional coupler are spliced, in such case the two waves have the same optical path but travel in opposite directions and interference is assured when both waves reenter the coupler. A FLM with a section of Hi-Bi fiber built in it has the advantage of becoming a polarization independent interferometer, another advantage is the fact that the formed spectral filter only depends on the length of this fiber section, and not on the total FLM.

2 Principles and theory

2.1 Birrefringence

The birrefringence (β) of an optical fiber depends on the difference of refraction indices between the fast axis (n_y) and slow axis (n_x).

$$\beta = n_y - n_x \tag{2.1}$$

Hi-Bi fibers are polarizing maintaining fibers where the linear polarization states are maintained. It is because of this property that one can implement an interferometer based on a FLM.

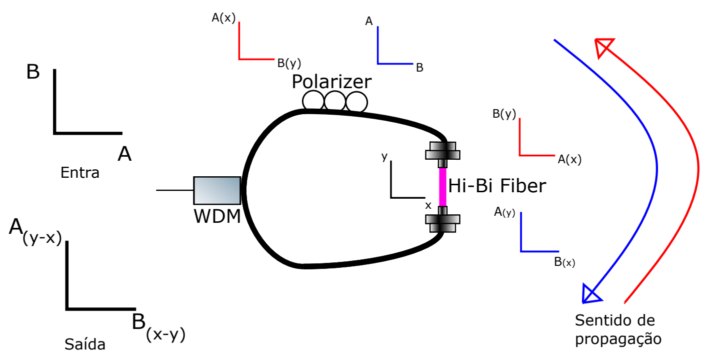

Figure 2.1: The two paths of light in the interferometer

2.2 FLM

In Figure 2.1 is shown a FLM. Transversing the loop are two counter propagating beams. They propagate through the Hi-Bi fiber with different velocities which is translated by a variation in their individual polarization directions and the two beams will interfere at the output port.

This characteristics are those of an unbalanced Mach-Zehnder interferometer (one arm Mach-Zehnder). The phase difference between the fast and slow beams in the Hi-Bi fiber is given by:

$$\Delta\phi = \frac{2\pi\beta L}{\lambda} \tag{2.2}$$

In this equation, β, L and λ, are the birrefringence, the length of Hi-Bi fiber and the wavelength at which one is working, in our case we will do the media between the two wavelengths that we use in our quadrature phase-shifted lasers.

To the response one can show that the transmission spectrum of the loop is approximately periodic with the wavelength, namely:

$$T = [sin\frac{\beta L}{\lambda}cos(\theta_1 + \theta_2)]^2 \tag{2.3}$$

where the ϑ are the angle between the light and the fast or slow axis at the both ends of the Hi-Bi fiber. Reflectivity response is given by $R = 1 - T$. The spacing of wavelengths is inversely proportional to the length and the birrefringence of the Hi-Bi fiber. This tells us that this sensor depends only on the characteristic of the Hi-Bi fiber, we have:

$$\Delta\lambda = \frac{\lambda^2}{\beta L} \tag{2.4}$$

where λ is the wavelenght of operation, and Δλ is te spacing of the fringes of the resulting interferometer.

This way one can imply that for small wavelength spacing, it is need larger beta fiber or a longer length of fiber. more so this spectral characteristic is independent of the polarization of the input light.

It is known that for an interferometer, holds up the relation:

$$\phi = atan(\frac{V1 - G1}{V2 - G2}) \tag{2.5}$$

where V and G are the signal and gain respectively. It is through this relation that we obtain the phase shift as a function of the microstrain.

3 Experiment and results

The schematic of the experimental setup is shown in Figure 3.1. Two tunable lasers are connected to a 3dB coupler which is the input of a circulator whose outputs are an OSA (optical spectrum analiser) and the FLM which is a Hi-Bi fiber connected to a polarizer and both to a WDM (wavelength division multiplexer). The principle of operation is the one described above since we have a FLM, the only additions are the circulator to get light to the OSA and the WDM to control the light that enters the loop.

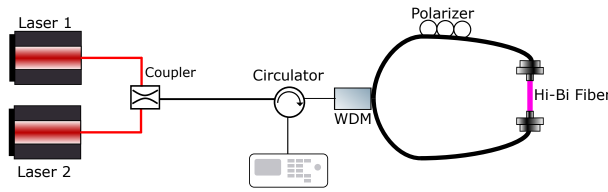

Figure 3.1: Experimental Setup

The light emitted by the lasers enters the FLM where it interferes, interaction that is changed when we stretch the Hi-Bi fiber, and we can see the power of each of the lasers that is leaving it, this power changes according to the strain that is applied, as we apply strain the balance between the detected power of laser 1 and laser 2 changes as we can see in Figure 3.2. As expected this power reflect the quadrature phase-shifted pattern of the incoming signals. To obtain the two λ at which the lasers must be working to obtain a quadrature phase-shift pattern we first need to use a broadband light source connected to the FLM to detect the pattern of interference and obtain two λ that are phase-shifted by $\frac{\pi}{4}$, this is easily detected with the OSA.

After doing this test we decided that the lasers would be working at λ_1=1543.6nm and λ_2=1547.5nm. Both lasers were tuned to this wavelengths and fixating the two ends of the Hi-Bi fiber we made the graph that can be seen in Figure 3.2, as one can see the $\frac{\pi}{4}$ phase shift is clearly there. This when plotted x/y, according to the phase shift would result in a circle, after normalization we obtained Figure 3.3, as can be seen, the experience does not differ much from a perfect circle, this deviation can be because of poor measure of power since the values float a lot since the environment of the experience was not controlled (fiber was left on the table, and was probably touched during the experience which affects the

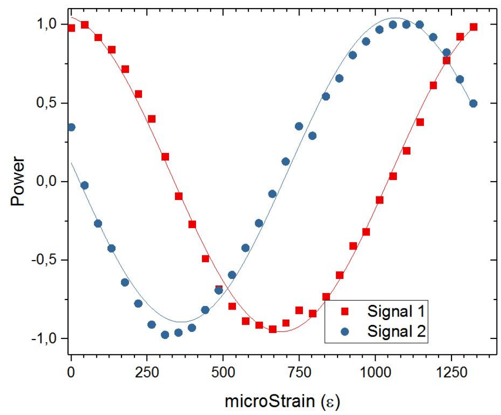

Figure 3.2: Detected signals versus strain

phase), additionally the two ends of the Hi-Bi fiber were glued to a support, this glue has some strain of it's own and the measure that the support makes is not the true measure.

In Figure 3.4 one can see the phase change versus the strain applied, this had to be normalized since the phase jumps every 90 degrees. The sensibility of the sensor is simply the slope of this line which corresponds to 4.54 rad/nε(nanostrain).

In order to further test the sensor we used equation 2.4 to obtain the lenght (L) of the sensor from the experimental values measured in the OSA and compare with the lenght of the sensor we measure in the lab. Using the measures from the OSA we have:

$$\Delta\lambda = \frac{\lambda^2}{\beta L} \Longrightarrow L = \frac{\lambda^2}{\beta \Delta\lambda} \Longrightarrow$$

$$\Longrightarrow L = \frac{1571.32^2}{5.1 \times 10^{-4} * 16.987 * 10^{-9}} = 28.4cm$$

Which is congruent with the experience since we measured a lenght of 27.3cm for the Hi-Bi fiber, this measurement has an associated estimate because part of the fiber was enclosed in a splice protector.

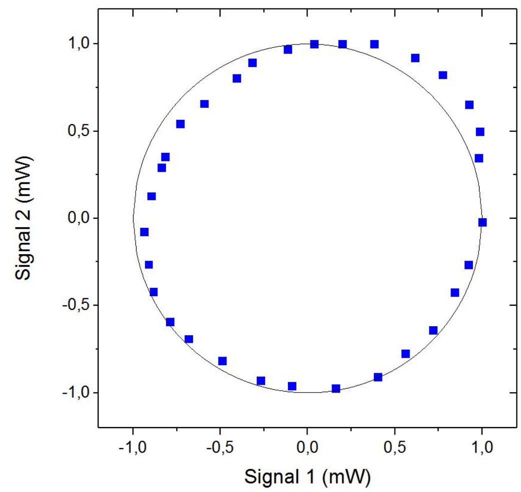

Figure 3.3: x-y signal representing the quadrature condition

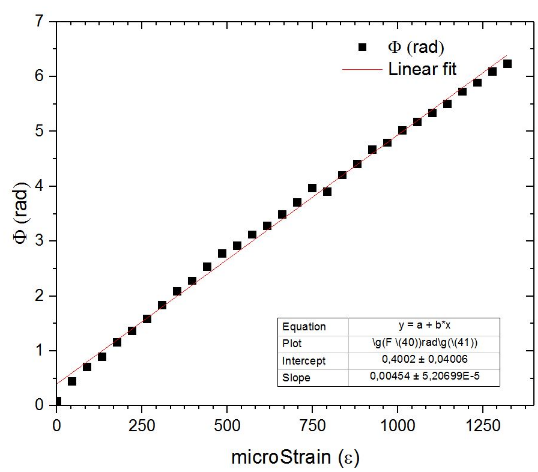

Figure 3.4: Interferometric phase change versus strain

4 Conclusion

A strain sensor based on a optical fiber loop mirror unbalanced Mach-Zehnder interferometer, was successfully demonstrated. The low cost and ease of operation make of this kind of sensors a tool for many applications, from pressure sensing to sensing of buildings and structures. They are highly portable and can be miniaturized. It was achieved, with a basic setup, a sensibility of 4.54 rad/nε(nanostrain) which is very good compared to more traditional strain sensors, it might be a good replacement for some applications. It is needed further research in this area, specially with new kinds of fiber per example PCF to improve some of its characteristics, as well to make a device that can sense more with just a fiber.

5 References

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