Micro-structured fiber as temperature sensor in a loop architecture

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***Abstract*— A temperature sensor built by a micro-structured fiber (MSF) into a Sagnac interferometer scheme is reported. The optical waveguide is provided by a two-hole fiber (THF) which are located asymmetrically from the core. A linear response to thermal effects is observed and the sensitivity ~ 2.22 nm/°C was reached using a 2m-long of THF. The main advantage of the system proposed is a linear response, the use of a MSF with a simpler transverse geometry, non-use a special filled mechanism for the holes and a simple experimental array.**

Keywords—fiber optic, fiber sensors, micro-structured fiber, temperature sensor.

I. Introduction

The special optical fibers (SOFs) have been studied for at least 3 decades in terms of the fiber properties, fabrications, and potential applications, being their main impact is in telecommunications field. Besides communications, there are also an important interest in other applications for the development of SOF. These fibers are special due to their different structures, materials, dopants compared to normal single mode fibers (SMFs) and play a relevant role in several photonics devices [1].

A kind of SOF are the microstructured fibers (MSF), which are formed by an array of air columns implanted within a silica matrix extend along the z-axis of fiber. Size and shape holes, distribution, insertion of materials into the cavities and interferometric arrangements are parameters in the design process to permits to build different MSF structures. These features are an attractive component due to fabrication technology and physical properties.

The presence of air holes in MSF and the possibility to be filled with other materials, gives some substantial engineering advantages such as increase the birefringence, dispersion, and the response to external thermal effects [2]. In this sense, liquid materials have been inserted into the MSF holes such as ethanol [3] or refractive index matching oil [4]. In this paper, we report a temperature sensor built by MSF using a two-hole fiber (THF) in a Sagnac interferometer (SI) architecture. The operation principle is based on the birefringence changes on the TFF induced by the temperature difference between the air-holes and the silica fiber when the fiber is heated. Thus, a spectral shift of the SI pattern is observed and used to measure the external temperature changes. The experimental results exhibit a sensor sensitivity around 2.22 nm/°C, which is on the comparable order of similar reported systems.

II. Theoretical Considerations

The SI in fiber is typically fabricated using a 50/50 fiber coupler, which splits the input signal in two equal parts. These two output fibers coming from the coupler are spliced with the birefringent fiber to create a closed loop (see Fig.1). When a beam is propagated at the input of the fiber coupler, the optical beam is equally divided and propagates in opposite directions in the loop. Later, both signals arrive back to the fiber coupler output terminals to be recombined.

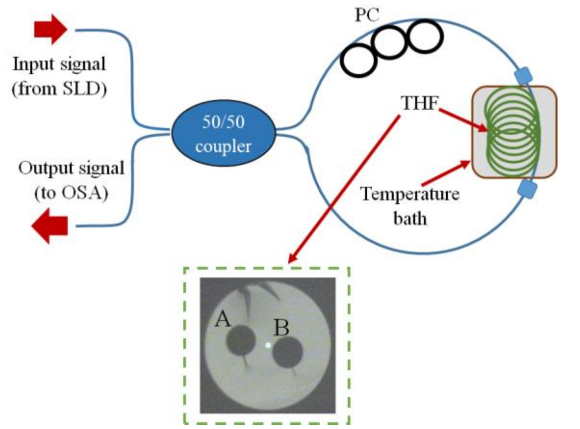

Fig. 1. Experimental architecture to build SI with birefringent fiber (PC, polatization controller; THF, two-hole fiber; SLD, superluminiscense laser diode; OSA, Optical Spectrum Analizer). Inset, transversal view of THF.

For this system, the periodical transmission spectrum is given by a well-known expression [5]:

$$T = \left[\sin \frac{\beta L}{\lambda} \cos\left(\theta_1 + \theta_2\right) \right]^2 \tag{1}$$

where L is the length of the birefringent fiber, λ is the wavelength of the input beam, θ_1 and θ_2 are the angles between the light at both ends of the birefringent fiber with respect to the fast or slow axis of the fiber, respectively. The birefringence β, expressed by the difference in refractive indexes along the fast axis (n_y) and the slow axis (n_x), also can be related in terms of the wavelength spacing spectrum ($\Delta\lambda$) is related by:

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

In this case, equation (2) relate changes in wavelength spacing or spectral shift when the birefringence is modified. These variations can be reached by external effects as the temperature changes.

III. Experimental Set-up and Results

The temperature measurements were performed using the experimental set-up shown in Fig. 1. The system consists in a Super-luminescent laser diode (SLD, centered in 1545nm) which emitting an optical field into the interferometer. The fiber interferometer was built by 50/50 splicer connected to the THF segment (length L= 2 m) by fusion splicing and a manual polarizer controller PC incorporated into the loop. The measurement of the transmission spectrum was performed with an Optical Spectrum Analyzer, OSA. The THF segment is situated into a temperature chamber. The cross section of the THF used as the sensing element is shown in the in-set of Fig. 1. The diameter of the cladding is 125 µm and 5.6 µm for the core. Two holes (with diameters A=29 µm ; B=27 µm), are asymmetrically located into the fiber: the center of hole A is located at 27 µm from the center of the fiber core while the center of hole B is located 20 µm away from the center of the fiber core. The splicing to standard single mode fibers (SMF) was performed using typical splicing mechanism. In Figure 2, we observe the response of the transmission spectra with the temperature (from 20°C to 40°C).

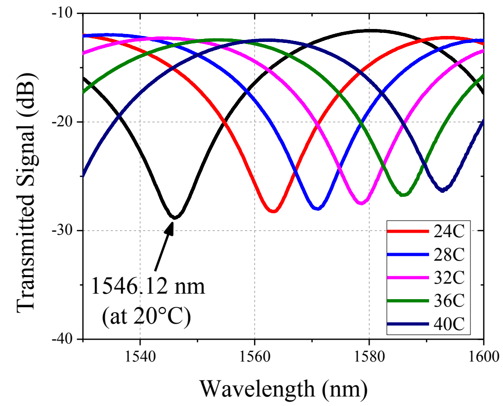

Fig. 2. Curve of interference pattern spectrum at room temperature (at room situated in 1546.12 nm , black line). When the temperature is growing up, the position of the dip shifts to larger wavelengths.

From Fig. 1, we can observe the transmittance pattern shifts when the temperature increases. Following one of the dip pattern, the shift versus the temperature applied can be considered as a good linear approximation. Under this assumption, we obtain a slope around a 2.22 nm/°C in a 20-40°C range. The system exposed suggest the option to increase significantly the thermic sensitivity by filling the side-holes with a suitable thermo-optic material.

IV. Conclusions

We show a fiber optic temperature sensor based on SI architecture incorporating a THF segment. The wavelength response as a function of the applied temperature exhibits a linear response with similar MSF structures reported. The scheme proposed suggests the possibility of increasing the thermal sensitivity if the holes are filled with a suitable thermo-optic material.

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