Fiber laser strain sensor based in the measurement of a Sagnac interferometer optical power spectrum

M. Durán Sánchez*[a], R. I. Álvarez Tamayo[a], O. Pottiez[c], E. A. Kuzin[b], B. Ibarra-Escamilla[b] and A. Barcelata Pinzón[a]

[a]Mecatrónica, Universidad Tecnológica de Puebla, Ant. Camino a la Resurrección N°1002-A Parque Industrial, Puebla, Pue.72300, México

[b]Departamento de Óptica, Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro No. 1, Puebla, Pue. 72000, México

[c]Centro de Investigaciones en Óptica, Fiber Optics Department, Lomas del Bosque N. 115, León, Gto. 37150, México

ABSTRACT

In this paper a linear cavity Erbium doped fiber (EDF) laser based in a fiber Bragg grating (FBG) and a fiber optical loop mirror with a high birefringence fiber in the loop (Hi-Bi FOLM) is used as a strain sensor. The Fabry-Perot cavity is formed by the FBG and the Hi-Bi FOLM, used as a measurement system of strain variations produced on the FBG, used as a strain sensor device. Usually, fiber laser sensor experimental setups determine the measured variable magnitude by using of an optical spectrum analyzer (OSA). Hi-Bi FOLM transmission spectrum wavelength displacement by fiber loop temperature variations measurement can be an attractive application exploiting the characteristics of FOLM transmission spectrum behavior due to Hi-Bi fiber loop temperature variations to determine the FBG strain applied through the maximal optical power monitoring by simple use of a photodetector and a temperature meter.

Keywords: Fiber laser sensor, Sagnac Interferometer, fiber Bragg gratings

1. INTRODUCTION

Fiber lasers from its appearance have been applied in different research areas such as medicine, optical communications, sensors, among other applications. Particularly, in their application as sensors recently have been used in various areas of interest, such as chemical, acoustic waves, pressure and temperature measurements [1-10].Moreover design of sensor systems using Bragg grating optical fiber (FBG) as temperature or strain sensors have applications in different areas. FBGs has been widely accepted because of their optical fiber compatibility, construction features that make them lightweight, small and their low sensitivity to electromagnetic interference feature [11,12]. An additional advantage is the sensing of a physical variable associated to the displacement of FBG Bragg wavelength due to temperature or strain applied on the FBG which is an absolute and connector or splice lossless parameter. Usually, fiber laser sensing systems require expensive equipment as an OSA, to determine the laser line emission wavelength displacement [13,14].

In this paper we propose an all-fiber laser based in a Hi-Bi FOLM used as a strain sensor measuring monitoring system. The linear cavity is formed by a FBG in one side and a Hi-Bi FOLM in the other side, both used as optical mirrors. The FBG is also used as sensing device. An experimental setup attractive application consists in take advantage of Hi-Bi FOLM behavior features to determine physical variable variations due to Hi-Bi fiber loop temperature variations by simple use of a photodetector and a temperature meter.

Fiber Optic Sensors and Applications XI, edited by Henry H. Du, Gary Pickrell, Eric Udd, Christopher S. Baldwin, Jerry J. Benterou, Anbo Wang, Proc. of SPIE Vol. 9098, 909817 · © 2014 SPIE
CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2050781

2. EXPERIMENTAL SETUP

Figure 1 shows the proposed fiber laser experimental setup. The linear cavity laser is formed by a Hi-Bi FOLM acting as a periodical spectrum wide band reflector, a 980/1550 WDM, 3m length EDF used as a gain medium and a FBG reflection wavelength centered at 1548 nm. The FBG acts as a narrow band reflector and a as sensing device as well. The EDF is pumped through the WDM with a laser diode at 980nm and 100mW. The Hi-Bi FOLM is designed by an 50/50 single mode optical coupler with output ports connected by a Hi-Bi fiber forming a loop. Through characterization in ref [4] is well known that this device is highly sensitive to temperature changes in the loop, resulting in a periodical reflection spectrum wavelength displacement. The Hi-Bi FOLM fiber loop is placed on a Peltier device to introduce temperature variations by electrical current changes. This Hi-Bi FOLM behavior characteristic is shaped by optical power measurement in function of a temperature scanning to determine sensor FBG wavelength displacement due to strain variations.

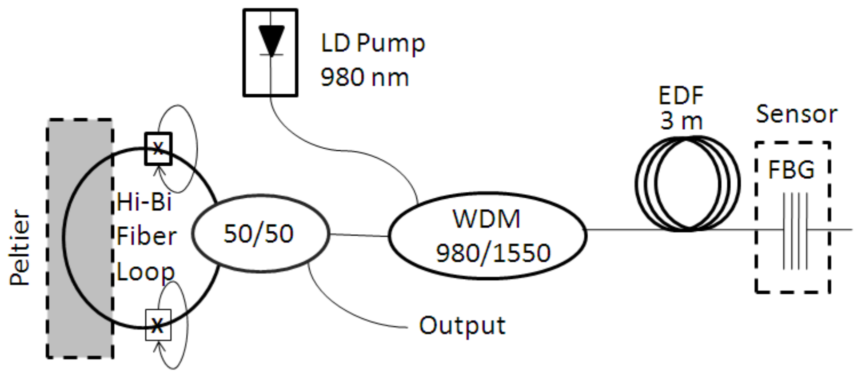

Figure 1.Fiber laser based on a FBG and a Hi-Bi FOLM experimental setup.

3. RESULTS DISCUSSION

The Hi-Bi FOLM fiber loop is placed on a Peltier device introducing temperature variations by electrical current changes, used to obtain Hi-Bi FOLM transmission optical power spectrum at 50/50 coupler Output port. Peltier device is controlled by an electronic system designed on our own to allow control and display of temperature changes in centigrade centesimal precision. The Hi-Bi fiber loop length of 28 cm allows obtaining of a Hi-Bi FOLM wavelength transmission periodical spectrum of 20nm. Figure 2 shows the 20nm Hi-Bi FOLM transmission spectrum with optical power pump bellow the laser threshold, measured at Output port by using an OSA in an 1520nm to 1565nm scanning range. As can be seen, the experimental Hi-Bi FOLM transmission period obtained is around 19.73 nm, near to the 20nm calculated period.

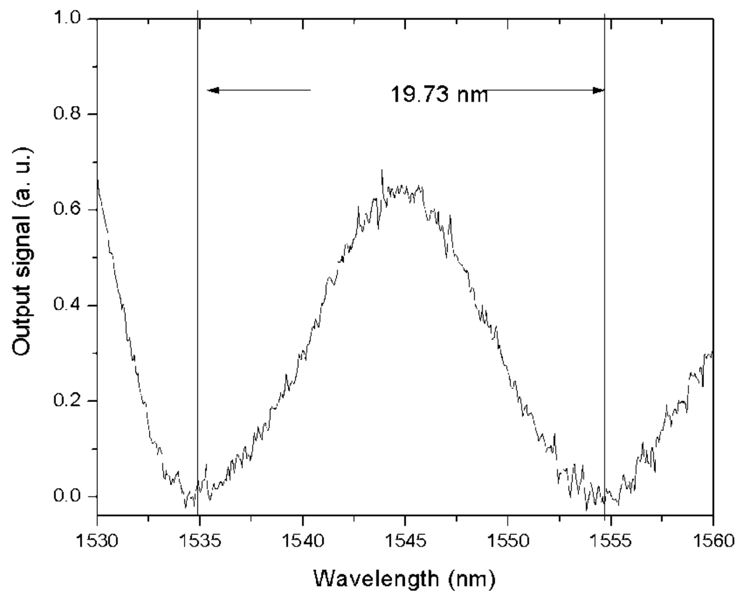

Figure 2. Hi-Bi FOLM transmission spectrum on wavelength scanning.

The 100% reflection FBG at 1548nm is attached to a flexible metal girder, part of a mechanical device used to apply compression/strain in the FBG affecting Bragg wavelength by curvature deformation through a micrometrical screw. To perform an experimental optical power laser line wavelength displacement measurement, a fiber loop temperature variations in the range of 10^{-2} is required.

Figure 3 shows eight normalized laser line spectrum measurements with the same pump power above the amplification threshold, for different laser line wavelength due to sensor FBG strain applied, measured at Output port with an OSA. As can be seen, laser emission wavelengths are shown in a range from 1548 to 1544 nm due to strain applied from 0 to 6.1 mm in the same order. As a result it can be seen that strain application in the sensor FBG produce a laser line displacement to shorter wavelengths.

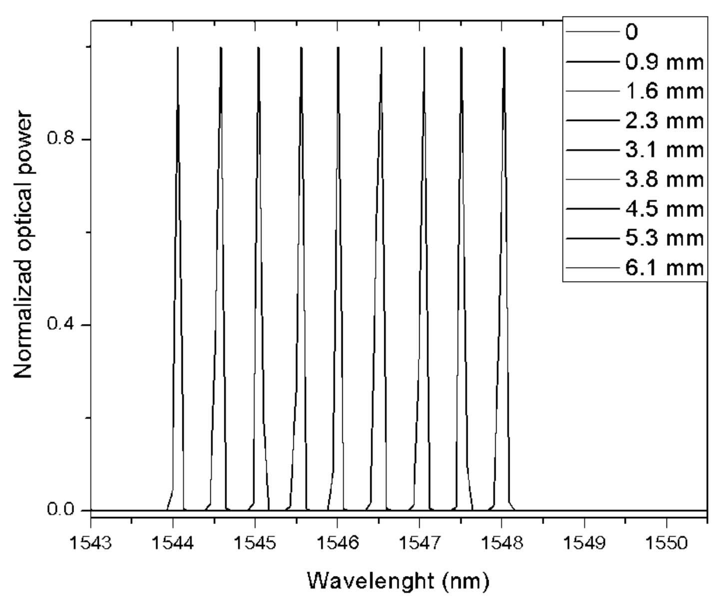

Figure 3. Laser wavelength spectrum on sensor FBG strain applied.

In Figure 4 is shown the plotting of maximal laser lines optical power points at central wavelength emission due to strain applied at sensor FBG results shown in Figure 3. As can be seen, the maximal curvature by 6.1 mm of strain applied on the FBG results in a laser line wavelength displacement of 4nm. The dependence of laser line wavelength displacement on strain applied can be fitted by a linear dependence with a slope of 0.65 nm/1 mm.

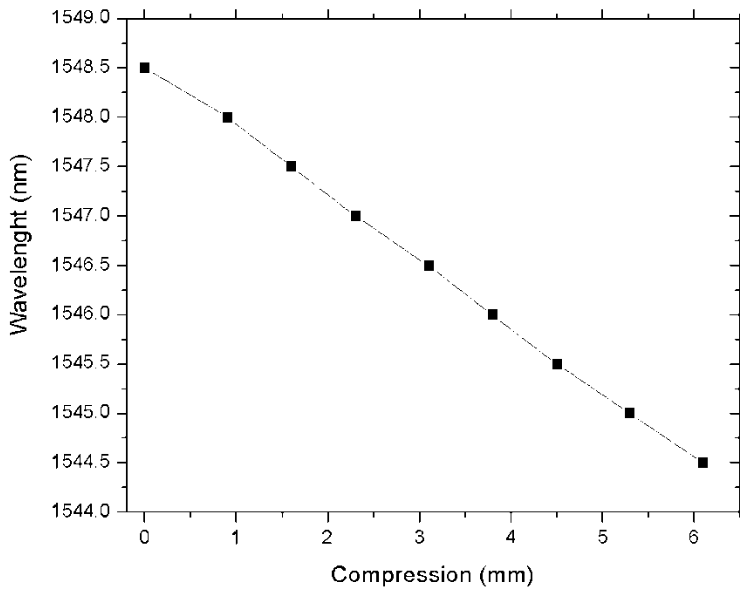

Figure 4. Laser wavelength displacement on sensor FBG different strains applied.

Figure 5 shows the Hi-Bi optical power transmission spectrum due to Hi-Bi fiber loop temperature variations scanning from 24°C to 40°C each 0.2°C, by the simple use of a photodetector, without strain applied on the sensor FBG, therefore, FBG central reflection wavelength is at 1548nm. The maximal output power measured is 9.8 mW at 28°C. As can be seen, the measured Hi-Bi FOLM transmission spectrum rebuilt point by point is similar to the cosine transmission spectrum on wavelength scanning obtained in Figure 2. The Hi-Bi FOLM transmission spectrum period is around 12°C.

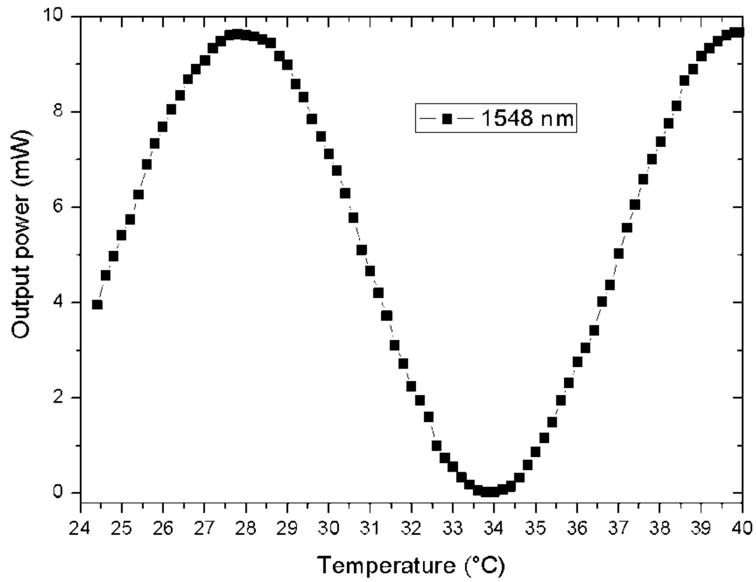

Figure 5. Hi-Bi FOLM transmission spectrum on temperature scanning.

Figure 6 shows the Hi-Bi FOLM transmission optical power spectrum with 100mW of pump power. Results show point to point rebuilt of Hi-Bi FOLM spectrum on temperature scanning from 25°C to 40°C with 0.2°C step measurements of output power. Multiple Hi-Bi FOLM transmission spectrum are Hi-Bi fiber loop temperature displaced due to different strain applied on the sensor FBG by the micrometric screw. As is observed, for each change of wavelength in the FBG there is a different Hi-Bi FOLM transmission spectrum displaced to higher temperatures. This method can identify changes in wavelength of the laser as the maximum optical power and the temperature at which it was generated.

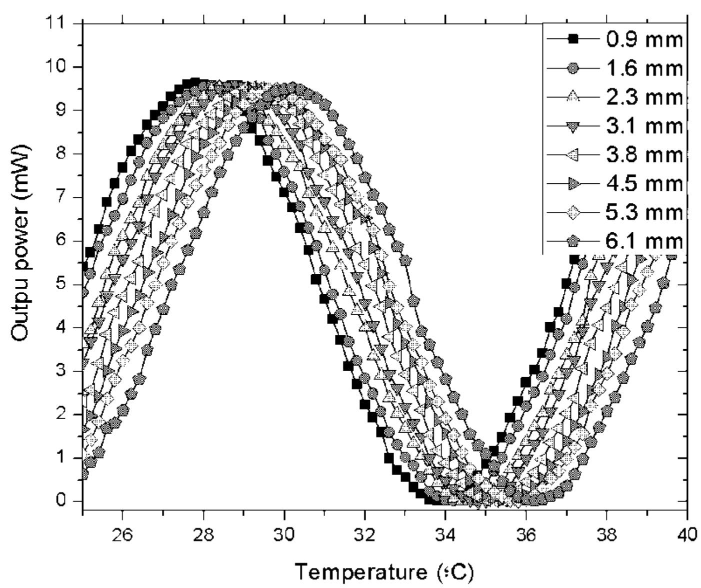

Figure 6. Hi-Bi FOLM transmission spectrum measurements on sensor FBG strain variations.

Figure 7 shows the plotting of wavelength on Hi-Bi fiber loop temperature points in which Hi-Bi FOLM transmission maximal optical power is reached for each strain variation applied on the sensor FBG. As can be seen, for the maximal strain applied of 6.1nm, the fiber loop temperature and the wavelength in which Hi-Bi FOLM transmission optical power is maximal was obtained around 30.2°C and 1544.5 nm respectively. The dependence of maximal Hi-Bi FOLM transmission spectrum optical power on Hi-Bi fiber loop temperature in which this wavelength is present, due to strain applied on the sensor FBG can be fitted by a linear dependence with a slope of -1.6 nm/1°C for each 1.5mm of strain applied on the sensor FBG.

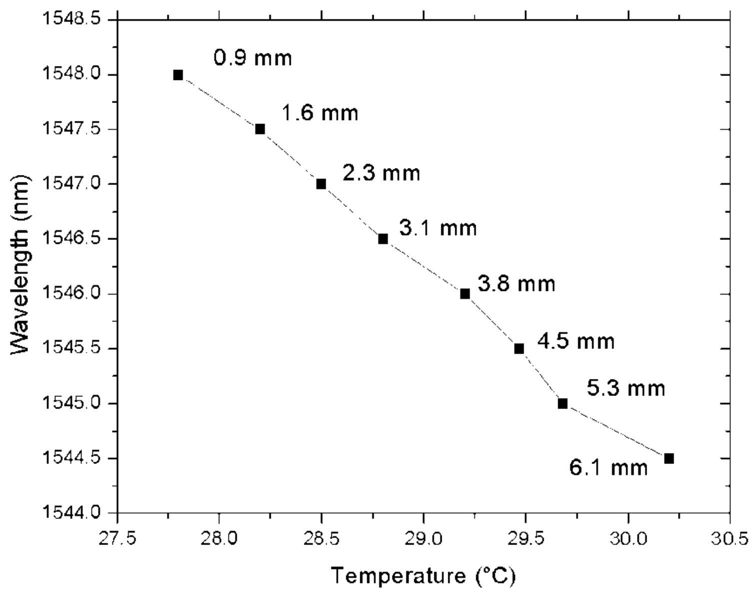

Figure 6. Hi-Bi FOLM maximal optical power wavelength and Hi-Bi fiber loop displacement due to strain applied on the sensor FBG.

4. CONCLUSION

In this paper a linear cavity EDF laser based in a FBG and a Hi-Bi FOLM used as a strain sensor has been presented. The FBG strain variations measurement system relates the Hi-Bi FOLM transmission spectrum maximal optical power or laser emission wavelength with the Hi-Bi fiber loop temperature in which optical power output is maximal due to the strain applied on the sensor FBG. The strain on the FBG can be determined experimentally by the simple use of a photodetector and a fiber loop temperature scanning. By measuring of the laser optical output power through the Hi-Bi FOLM temperature monitoring, we have a novel measurement system which can be useful for strain discrete range sensing measurement at low costs by seeking of maximum optical power and the temperature at which it was generated by determining of wavelength spectrum displacement.

ACKNOWLEDGEMENTS

This work has been supported by CONACYT grant CB-2010-151434.

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