Multi-zone temperature sensor using a multi-wavelength Brillouin fiber ring laser

Carlos A. Galindez[a*], Francisco J. Madruga[a], Angel Ullan[a],
Manuel Lopez-Amo[b] and Jose M. Lopez-Higuera[a]
[a] Photonics Engineering Group, Universidad de Cantabria,
Av Castros s/n, 39005-Santander, Spain
[b] Depto. Ingeniería Eléctrica y Electrónica, Universidad Pública de Navarra,
Campus de Arrosadia s/n, 31006 Pamplona, Spain

ABSTRACT

A simple system for sensing temperature in multiple zones based on a multi-wavelength Brillouin fiber laser ring is presented. Optical fiber reels are serially concatenated and divided in zones (one per sensing area). Setting the Brillouin lasing in each spool of fiber generates a characteristic wavelength that depends on the fiber properties and the temperature in the zone. Thus, it is possible to measure temperature independently and accurately through heterodyne detection between two narrow laser signals. The proposed sensor integrates the temperature along the whole spool of fiber in each zone. These real time measurements were successfully checked in our laboratory.

Keywords: Optical fiber sensors, temperature sensing, Brillouin fiber laser ring.

1. INTRODUCTION

Since the first suggestion of the Brillouin scattering to realize distributed measurements of temperature in 1989 [1], an extensive research work has been invested and now both temperature and strain, along a fiber are obtained by analyzing the Brillouin frequency behavior [2]. In the current distributed fiber sensing field is one of the most remarkable fiber optic sensing technologies thanks to the advantage of use optical fiber as transducer and channel at the same time. Furthermore, Brillouin scattering effect is used to develop gyroscopes [3] and in slow and fast light [4], among others. Additionally, the narrow linewidth of the Brillouin gain effect offers the possibility to use the current fibers as active mediums to build cavities for lasers with narrow bandwidth [5]. Brillouin comb lasers using pump-modulation [6] and ring laser cavity structure within an erbium-doped fiber amplifier (EDFA)[7] have been proposed and demonstrated in order to generate slow light. Otherwise, in this paper we propose to use a multi-line Brillouin laser to measure in real time the temperature in the multiple zones in which each pieces of different fiber are installed. In the next sections the principle and experimental set-up, the results and their discussion and, finally, the conclusions extracted are presented.

2. PRINCIPLE AND EXPERIMENTAL SETUP

Stimulated Brillouin scattering (SBS) can amplify the light that is counter-propagating to the pump light [8], such interaction between pump and stokes light fields can be described by the steady state coupled-intensity equations, without pump depletion and, the Brillouin Gain Scattering (BGS) curve is described by a Lorentzian profile [8]. The Brillouin gain (G) which is the key parameter for amplifiers and Brillouin fiber lasers is given by the expression:

$$G = 10Log\left(\exp\left(g_B L_{eff} P / A - \alpha L\right)\right)$$

Where g_B is the Brillouin gain coefficient, P/A is the power per effective area, α is the fiber transmission loss, L is the fiber length and L_{eff} is the effective fiber length defined by: $L_{eff} = \left(1 - \exp\left(-\alpha L\right)\right)$. This stimulated nonlinear effect in fibers can be use as an active medium to form a resonance cavity to obtain fiber lasers with a narrow line width. Hence, the narrowband Brillouin laser signal is placed around the Brillouin frequency shift (BFS) from the pump wave which is described by $\nu_B = 2nV_a / \lambda$ with n as the refractive index, V_a as the longitudinal acoustic velocity and λ as the pump light

---

[*] galindezca@unican.es; phone +34 942 200877; fax +34 942 200877

20th International Conference on Optical Fibre Sensors, edited by Julian Jones, Brian Culshaw,
Wolfgang Ecke, José Miguel López-Higuera, Reinhardt Willsch, Proc. of SPIE Vol. 7503, 75030J
© 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.835138

wave[8]. The parameters n and V_a are dependent on fiber structure and composition as well as the temperature and strain around the fiber.

In order to show and validate the proposed multi-line laser sensor configuration, we show in Fig. 1 the experimental setup and sensor; in which the fiber transducer constitute part of a typical ring laser cavity. The fiber transducer is integrated by three spools of fiber (F1, F2 and F3) coiled without mechanical strain and with a length of 1000m, 1100m and 550m, respectively. F1 is an Alcatel TERALIGHT fiber, F2 is a commercial single mode fiber SMF-28 and F3 is an all-silica-core Sumitomo fiber.

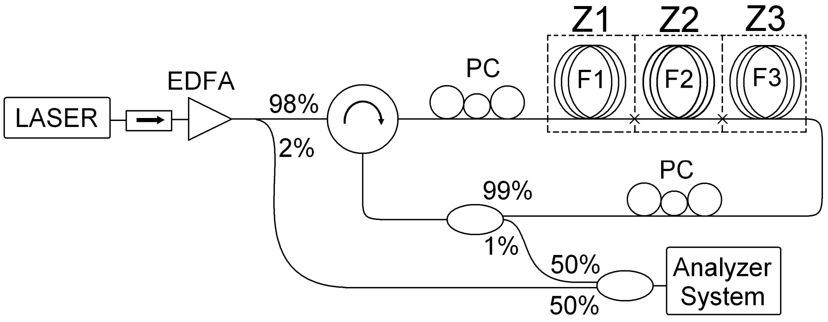

Fig. 1. Experimental setup used for Brillouin fiber laser ring. EDFA is an Erbium Doped Fiber Amplifier and PC is the Polarization controller. Every spool of fiber (F1 to F3) is placed in an environmental zone (Z1 to Z3). The Fiber 2 is put into a climatic chamber, this system is denoted as zone 2 (Z2).

A tunable laser source HP8168F set at 1550nm with a typical linewidth of ~100 KHz is used as the pump source. It is amplified by an erbium-doped fiber amplifier (EDFA) and split in two different beams by means of a 3dB coupler. The coupler output one (2%) is used as the local oscillator (OL); the other output (98%) is used as pump power signal. The pump is launched into a set of three spools of different fibers spliced serially, each one is placed in a different zone (three in total), in which the temperature will be later measure (Z1, Z2 and Z3). An spontaneous backscatter signal is generated in the set of fibers and goes from port 2 to port 3 of an optical circulator; it is launched back into the spools of fiber in the opposite direction of the pump light (by means of the 99% output of a coupler) to close the ring cavity laser. Hence, the Brillouin signal is reinforced and properly amplified, reaching the lasing conditions in the ring cavity. Two polarization control devices (PC) are inserted inside the ring cavity to control properly the polarization of the optical signals. The Brillouin laser signals (one per spool of fiber) are taken out from the ring by using the 1% output of a coupler. This signal is mixed with the LO signal within a 3dB coupler, and a heterodyne signal is obtained. This frequency is measured using an analyzer system. It is formed by an opto-electric converter (HP11982) and an electrical spectrum analyzer (ESA-HP8592L). We measure a set of three independent electrical signals that are observed in the display of the ESA. They are proportional to the laser output that comes from each spool of fiber and their corresponding frequencies also are proportional to the temperature in each zone.

3. EXPERIMENTAL RESULTS

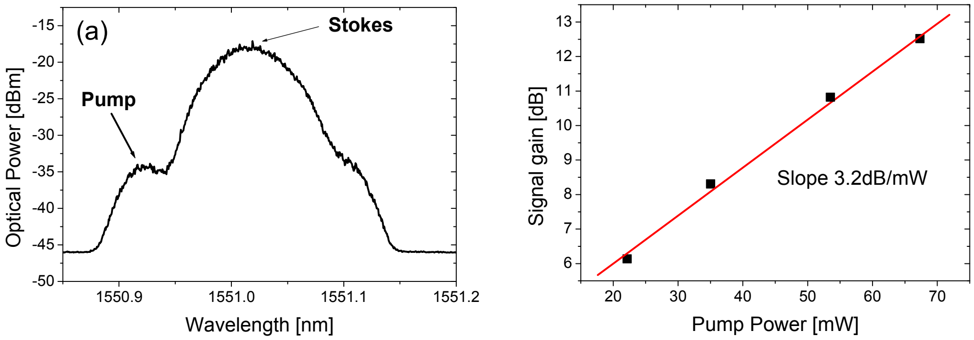

Fig. 2. (a) Emission spectrum of the Brillouin fiber laser ring pumped at 1551nm. (b) Brillouin fiber ring laser gain.

Fig. 2-a. shows the amplified stokes optical wave that is generated in the ring cavity. It is observed using an Optical spectrum Analyzer (OSA). The slope efficiency of the multi-line laser set corresponds to 32.15% (see Fig. 2-b). We set our multi-line Brillouin laser to work with a pump power of 13.45dBm and initial conditions of 20ºC of temperature and 50% RH.

As shown in figure 3 the three laser lines are detected in real time with an ESA. Besides, whether the temperature is changed only in the second zone, we can observe a shift of tens of mega Hertz in the BFS reference. Reference values for the three Brillouin laser lines are also shown in Fig. 3. The Brillouin laser signals for Fiber1, Fiber2 and Fiber3 are shifted 10.69GHz, 10.86GHz and 11.07GHz, respectively, from the pump optical wave. From Fig. 3 we point out that the narrow linewidth, which corresponds to the spectral convolution between linewidth of the pump and the Brillouin signal, is approximately 5MHz. It allows the measuring of small variations in the central Brillouin frequency. The measurement range of temperature is delimited by the gap between Brillouin signals, i.e. the characteristic Brillouin shift in the fibers.

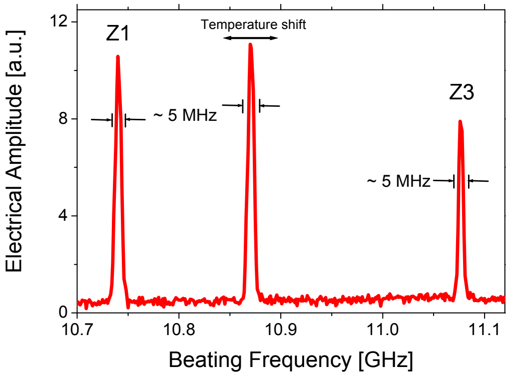

Fig. 3. Electrical spectra, heterodyne signal displayed in the ESA. Beating frequency between pump signal and each Brillouin laser signal at laboratory conditions (20ºC and 50% of RH, no strain along fibers).

To calibrate the sensor, we modified the temperature in the zone 2 using a climatic chamber HYGROS15. We set variations between 10ºC to 50ºC at constant relative humidity. The zones 1 and 3 are kept with their initial conditions of temperature and RH. Thus, we observe the variation in the Brillouin frequency laser in the spool of fiber 2 (See Fig. 4-a) and monitored the fiber 1 to test its invariance. The data for the variation in the Brillouin laser signal in fiber 2 are plotted in Fig. 4-b, the linear fit shows the expected proportional dependence with the temperature, which is about 1.1MHz/ºC. Also, we observe the Brillouin laser signal from Fiber 1 as a reference constant value to control the temperature in the zone 1.

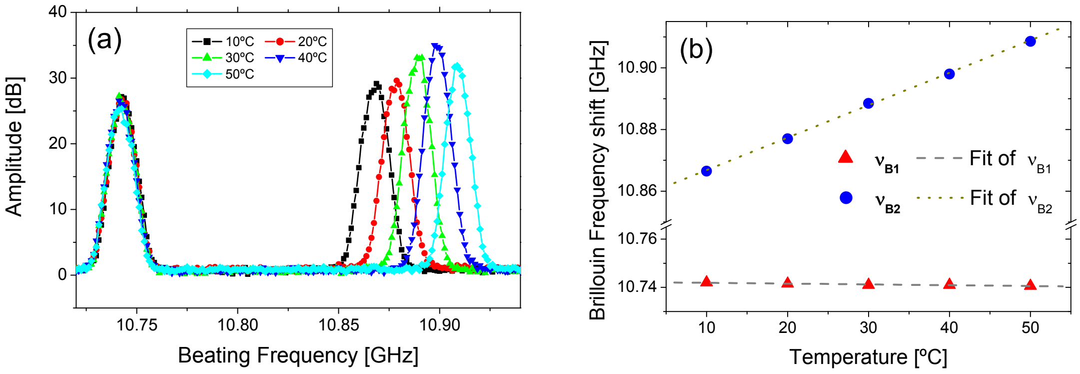

Fig. 4. (a) Experimental data of beating between pump and Brillouin laser signal with temperature variations in Zone 2 (Z2). (b) Brillouin laser signal versus temperature. Data (▲) shows the temperature in Zone 1 and (●) Zone 2.

These results confirm the expected behavior of the multi-line Brillouin laser with the temperature in each spool of fiber. Also, the temperature measurement can be made in real time as proposed by Dakin et all [9]. The number of spools of fiber depends on the pump power, the Brillouin gain coefficient of each fiber, the Brillouin threshold and the fiber length. So, the zones are limited by these parameters. However, it is a simple method to sense the temperature within several zones.

4. CONCLUSIONS

In this paper we proposed and experimentally validated a simple system for sensing temperature in multiple zones based on Brillouin fiber laser ring. Optical fiber reels are serially concatenated and separated in zones. Each spool of fiber generates a characteristic Brillouin wavelength that depends on the fiber properties and the temperature in the zone. The different temperatures are independently and accurately measured through heterodyne detection between two narrow laser signals. This method avoids the usage of electro-optic modulators and allows the use of strong signals to determine the frequency variations. Also, the power intensity threshold can be set to improve the signal amplitude by choosing diverse fiber lengths. This active sensor system shows a good accuracy and can be used in rough environments.

ACKNOWLEDGMENTS

The authors acknowledge the support from the Spanish Government under the research the two coordinated projects TEC2007-67987-CO2-01 and 02.

REFERENCES

[1] D. Culverhouse, F. Farahi, C.N. Pannel and D:A: Jackson, " Potential of stimulated Brillouin Scattering as sensing mechanism for distributed temperature sensors," Electronic Letters 25, p913-914, 1989.

[2] J.M. Lopez-Higuera, E., *Hand book of fibre optics sensing technology*. 2002: Wiley & Sons.

[3] S. P. Smith, F. Zarinetchi, and S. Ezequiel, "Narrow-linewidth stimulated Brillouin fiber laser and applications," Opt. Lett. Vol 16, p 393-395, 1991.

[4] K. Y. Song, M. G. Herraez, and L. Thevenaz, "Observation of pulse delaying and advancement in optical fibers using stimulated Brillouin scattering," Opt. Express, vol. 13, p 82-88, 2005.

[5] Y. J. Song, L. Zhan, S. Hu, Q. H. Ye, and Y. X. Xia, "Tunable multiwavelength Brillouin-Erbium fiber laser with polarization-maintaining fiber Sagnac loop filter," IEEE Phot. Tech. Lett., vol. 16, 9 2015-2017, 2004

[6] C. Jauregui, P. Petropoulos, and D. J, Richardson, "Periodic signal processing using a Brillouin gain comb," OFC/NFOEC, article OMH3, 2008.

[7] G. Qin, H. Sotobayashi, M. Tsuchiya, A.Mori, T. Susuki, and Y. Ohishi, "Stimulated Brillouin scattering in a single-mode Telluride fiber for amplification, lasing and slow light generation," J. lightwave Tech., vol. 26, p 492-498, 2008.

[8] Boyd, R.W., *Non linear Optics*. Second ed. 2003, USA: Academic Press; Elsevier Science.

[9] J.P. Dakin, S. Chin and L. Thévenaz, "A multiplexed CW Brillouin system for precise interrogation of a sensor array made from short discrete sections of optical fibre, " OFS-19th, Perth, Australy, 2008.