International Journal on Emerging Technologies **5**(2): 110-113(2014)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Cost-Effective Fiber Bragg Grating Temperature Sensor Using Power Measurement

B.B. Padhy*, S.N. Kale**, R.B. Sharma and A.D. Shaligram*******

**Armament Research & Development Establishment, Pashan, Pune (MH), INDIA*
***Defence Institute of Advanced Technology, Girinagar, Pune, (MH), INDIA*
****DRDO Hqrs, DRDO Bhawan, New Delhi, INDIA*
*****Dept. of Electronic Science, Savitribai Phule Pune University, (MH), INDIA*

(Corresponding author: B.B. Padhy)
(Received 05 August, 2014 Accepted 11 October, 2014)

ABSTRACT: A cost-effective fiber Bragg grating (FBG) based temperature sensor has been studied and the experimental results are presented in this paper. Power measurement scheme has been implemented for temperature sensing using matched pair of FBGs and use of Optical Spectrum Analyzer is thus avoided. Maximum sensitivity of 545 nW/°C has been obtained.

Keywords : Fiber Bragg grating, Bragg wavelength, Temperature sensitivity, Power measurement.

I. INTRODUCTION

Fiber Bragg gratings have been very successfully used through spectral modulation scheme by many researchers for temperature and strain sensing apart from other parameters like acceleration, pressure and vibration etc [1-6]. Further, multipoint or distributed sensing has been made possible by measuring the wavelength shift on the Bragg wavelength with respect to the change in the measurand [7-10]. However, these methods require an Optical Spectrum Analyzer (OSA) or other wavelength interrogation scheme making it a complex and costly sensor system. In this work, we present a simple, low-cost and effective temperature sensor using a matched pair of FBGs and employing power measurement technique. The power measurement scheme enables temperature sensing without the use of OSA or any other wavelength interrogation, thus making the sensor simple, less bulky and cost-effective.

A. Temperature Sensing Using FBG

A fiber Bragg grating consists of fiber core refractive index modulation in a periodic manner. These gratings are photo-inscribed in a length of few centimeters of the fiber core, with different techniques to induce changes in the refractive index of the core. When probed with a broadband source, the grating reflects a spectral peak called as the Bragg wavelength (λ_B). The Bragg wavelength is a function of the inscribed grating pitch (period) and effective refractive index along the grating and is given as :

$$\lambda_B = 2\,\eta_{eff}\,\Lambda \qquad \ldots(1)$$

where η_{eff} is the effective refractive index of the fiber and Λ is the period of the grating. Each reflection from the index perturbation is in phase with the next one at λ_B and any change in fiber properties, such as strain, temperature, or pressure, which varies the modal index, or grating pitch leads the change in Bragg wavelength [4].

The temperature response of the Bragg wavelength is due to two factors namely, the change in the effective refractive index of the glass due to the thermo-optic effect and the thermal expansion of the glass resulting in a change in the grating pitch. The Bragg wavelength shift due to temperature can be expressed as [11] :

$$\frac{\Delta\lambda_B}{\lambda_B} = \left[\frac{1}{\Lambda}\frac{\partial\Lambda}{\partial T} + \frac{1}{n_{eff}}\frac{\partial n_{eff}}{\partial T}\right]\Delta T \qquad \ldots(2)$$

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha + \xi)\Delta T \qquad \ldots(3)$$

where α is the thermal expansion coefficient, ξ is the thermo-optic coefficient due to the temperature dependence of the refractive index of the fiber and ΔT is the change in temperature. Both these coefficients are functions of temperature and for silica fiber, the thermo-optic effect is the dominant factor contributing to the observed shift in the Bragg wavelength due to change in temperature [12].

II. EXPERIMENTAL SETUP

The experimental set up is shown in Fig. 1. Two uniform FBGs written separately on two different fibers are used here. For implementing the power measurement scheme, it is required that the reflection spectra of the two FBGs are either identical or slightly overlapping. Also, the pair of FBGs is to be placed in such a manner that FBG1 (sensor FBG) is subjected to temperature variations while the FBG2 (reference FBG) is insusceptible to temperature effects. In this work, both the FBGs having the same temperature sensitivity have been used to achieve maximum accuracy in measurement. To implement the power measurement scheme, the FBG1 (sensor) has been kept in a controller based crystal temperature oven and FBG2 (reference) has been isolated by keeping it free from temperature effects.

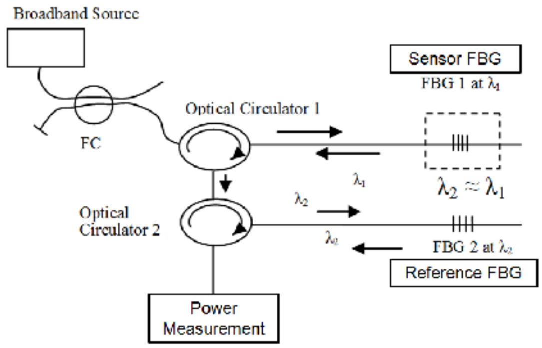

Fig. 1. Schematic of Setup for power measurement scheme.

III. WORKING OF THE MEASUREMENT SCHEME & EXPERIMENTAL RESULTS

Two different combinations of sensor and reference FBGs have been experimented to study the power measurement scheme. In the first combination, a sensor FBG having Bragg wavelength of 1549.88 nm with FWHM of 0.41 nm and a reference FBG having Bragg wavelength of 1550.04 with FWHM of 0.31 nm have been used.

At room temperature, because of the difference in the Bragg wavelength of the sensor and the reference FBG, lesser output power is obtained from the reference FBG. As the temperature is increased, the Bragg wavelength of the sensor FBG shifts towards higher values from 1549.88 nm and hence approaches towards the Bragg wavelength of the reference FBG at 1550.04 nm. Accordingly, the output intensity from reference FBG increases with increase in the temperature. The temperature at which the Bragg wavelength of both the FBGs match, corresponds to the maximum overlapping spectrum and this gives the maximum observed power. If the temperature is further increased then Bragg wavelength of the sensor FBG crosses the Bragg wavelength of the reference FBG and hence there is a decrease in the measured power at the reference FBG. The result is shown in Fig. 2.

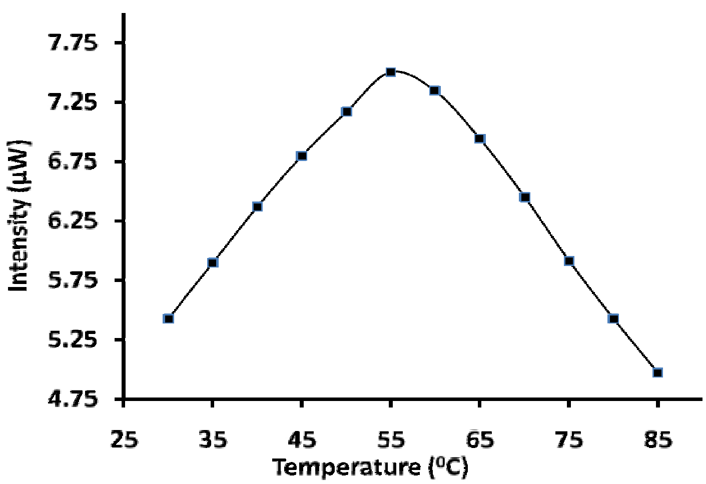

Fig. 2. Variation in power with temperature for first combination

The front and back slopes of the above graph are separately plotted in Fig.3 to analyze the sensitivity for each case. It is observed that the front and back slopes have a sensitivity of 83.6 nW/°C and 99.5 nW/°C respectively. In the second combination, a sensor FBG having Bragg wavelength of 1550.04 with FWHM of 0.31 nm and a reference FBG having Bragg wavelength of 1549.83 nm with FWHM of 0.45 nm have been used. The result for measured power versus temperature is shown in Fig. 4.

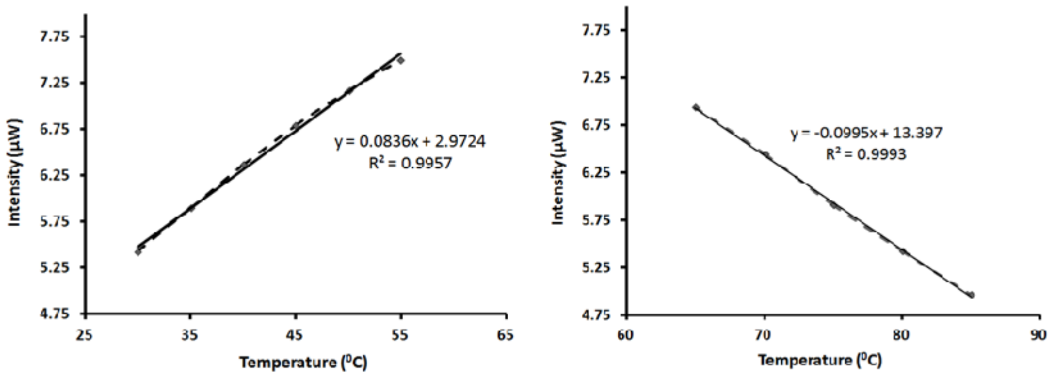

Fig. 3. Front and back slope sensitivity.

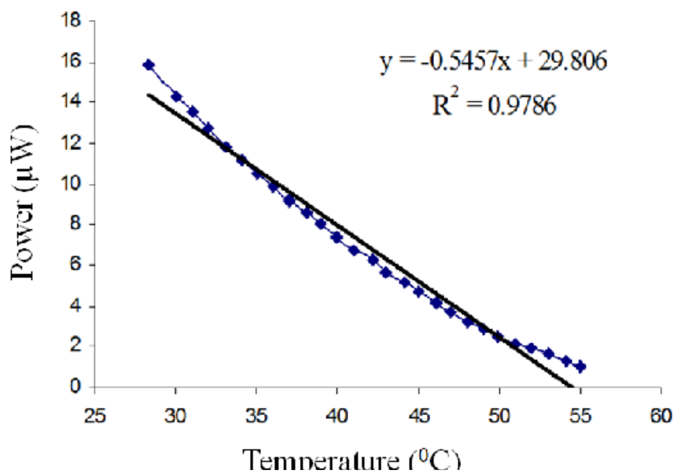

Fig. 4. Variation in power with temperature for second combination.

It is observed that the initial measured power corresponds to the maximum overlap of spectrum between the two FBGs. Here, since the sensor FBG has a higher Bragg wavelength than the reference FBG, as the temperature is increased, the Bragg wavelength of sensor FBG shifts further away from the Bragg wavelength of reference FBG. This results in a decrease in the measured power at the reference FBG. This combination offers a limited temperature range compared to the first combination but offers much higher sensitivity of 545 nW/^{0}C.

IV. CONCLUSION

Power measurement scheme has been successfully employed for temperature sensing with FBGs. Minimum sensitivity of 83.6 nW/^{0}C and maximum sensitivity of 545 nW/^{0}C has been obtained by the set up for two different combinations of FBG pairs. The use power measurement instead of wavelength shift measurement ensures a cost-effective alternate and eliminates the use of bulky optical spectrum analyzer. The range of temperature measurement can be increased by using reference FBG with maximum possible FWHM. One limitation of this scheme is that the accuracy of measurement is limited by the stability of input power.

ACKNOWLEDGEMENT

The authors wish to thank DIAT for providing the experimental facilities.

REFERENCES

[1]. Amelia L. Ricchiuti, David Barrera, Koji Nonaka, and Salvador Sales, "Temperature Gradient Sensor Based on a Long Fiber Bragg Grating and Time Waveform Analysis", Proc. Conf on Optical Sensors, Barcelona Spain, July 27-31, 2014.

[2]. A.L. Ricchiuti, D. Barrera, K. Nonaka, and S. Sales, "Temperature gradient sensor based on a long-fiber Bragg grating and time-frequency analysis", *Optics Letters*, Vol. **39**, pp. 5729-5731, 2014.

[3]. Mingyao Liu, Erlong Zhang, Zude Zhou, Yuegang Tan, and Yi Liu, "Measurement of Temperature Field for the Spindle of Machine Tool Based on Optical Fiber Bragg Grating Sensors," *Advances in Mechanical Engineering*, Volume 2013, pp.1-6.

[4]. K.O. Hill and G. Meltz, "Fiber Bragg grating technology fundamentals and overview," *J. Lightwave Technol*., Vol. **15**(8), pp. 1262-1276, 1997.

[5]. A. Othonos and K.Kali, Fiber Bragg Gratings: Fundamentals and Applications in Telecommunications and Sensing. Artech House, Boston & London, 1999.

[6]. A.D. Kersey, M.A. Davis, H.J. Patrick, M. LeBlanc, K.P. Koo, C.G. Askins, M.A. Putnam, and E.J. Friebele, "Fiber grating sensors," *J. Lightwave Technology*, Vol. **15**(8), pp.1442-1463, August1997.

[7]. Chunguang Lan, Zhi Zhou and Jinping Ou, "Monitoring of structural prestress loss in RC beams by inner distributed Brillouin and fiber Bragg grating sensors on a single optical fiber", *Struct. Control Health Monit.* **21**, pp. 317-330, 2014.

[8]. Jiulin Gan, Yunqi Hao, Qing Ye, Zhengqing Pan, Haiwen Cai, Ronghui Qu and Zujie Fang, "High spatial resolution distributed strain sensor based on linear chirped fiber Bragg grating and fiber loop ringdown spectroscopy", *Optics Letters*, Vol. **36**, No. 6, pp.879-81, 2011.

[9]. Remco Nieuwland, Lun Cheng, Peter Harmsma, Martin Lemmen, Raoul Oostenbrink, and Jan Schreuder, "A fiber Bragg based semi distributed pressure sensor system for in-vivo vascular applications", *Proc. Conference on Optical Sensors, Barcelona Spain, 2014.*

[10]. Yasukazu Sano and Toshihiko Yoshino, "Fast Optical Wavelength Interrogator Employing Arrayed Waveguide Grating for Distributed Fiber Bragg Grating Sensors", *J. Lightwave Technology*, Vol. **21**, No. 1, pp.132-139, 2003.

[11]. B.D. Gupta, Fiber Optic Sensors. New India Publishing Agency, New Delhi, 2006.

[12]. F..T.S. Yu and S. Yin, Fiber Optic Sensors. Marcel Dekker Inc., New York, 2002.