Diyala Journal of Engineering Sciences

ISSN 1999-8716

Printed in Iraq

Vol. 08, No. 03, pp. 116-123, September 2015

TILTED FIBER BRAGG GRATINGS (TFBGs) TEMPERATURE SENSING ELEMENT USING 244NM Ar^+ LASER WRITTEN ON SIDE HOLE FIBER

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(Received: 1/09/2014; Accepted: 5/11/2014)

ABSTRACT: - Tilted Fiber Bragg Gratings (TFBGs) are designed and implemented at the 1550 nm communication window in Institute of Optoelectronic Technology, China Jiliang University, Hangzhou, China. They are experimentally demonstrated to work as high sensitive temperature sensing element. The tilted fiber Bragg gratings of 10 mm were written on the core of 7-cm and 26-cm hydrogen loaded side hole fibers using 244 nm frequency doubled 488 nm Argon ion laser based on phase mask technique. The transmission spectrum of the first TFBG sensing element showed two resonant dips at 1579.614 nm and 1582.502 nm respectively. The transmission spectrum of the second TFBG sensing element showed two resonant dips at 1579.108 nm and 1580.304 nm. The achieved sensitivity is about 10 pm / °C. To the best of our knowledge our finding regarding setup with low cost is very close to the performance of other types of Fiber Bragg Gratings (FBGs) (1).

Keywords: Fiber, Bragg Grating, Sensor, Optics, Side hole fiber, Phase mask.

1. INTRODUCTION

Fiber optic sensors can provide numerous advantages over conventional sensors. These advantages are higher performance, light weight, small and compact size, electromagnetic interference immunity, remote sensing, ability to be multiplexed, and ability to be embedded into various structures and materials. The sensor's sensitivity and selectivity are enhanced by using optical transducers capable of precise detection of surround changes (2). Fiber Bragg Gratings can be used as direct sensing elements for strain and temperature. They can also be used as transduction elements, converting the output of another sensor, which generates a strain or temperature change from the measured. Fiber Bragg Gratings are finding uses in instrumentation applications such as seismology and as down hole sensors in oil and gas wells for measurement of the effects of external pressure, temperature, seismic vibrations and inline flow measurement. As such they offer a significant advantage over traditional electronic gauges used for these applications in that they are less sensitive to vibration or heat and consequently are far more reliable. The Fiber Bragg Gratings can be used for measuring strain and temperature in composite materials for aircraft and helicopter structures. The Fiber Bragg Grating has to be interrogated in order to provide any sensor application. Most significantly, FBGs wavelength-encoding multiplexing capability allows tens of gratings in a single piece of fiber to form an optical data-bus network. The combination of their multiplexing capability and inherent compatibility with fiber-reinforced composite materials permits in-fiber gratings to be embedded in a number of important structural materials for smart structure applications. Indeed, the development of structurally integrated fiber optic sensors, using fiber Bragg gratings (FBGs), represents a major contribution to the evolution of smart structures, leading to improvements in both safety and economics in many engineering fields, including major civil works, road and rail bridges, tunnels, dams, maritime structures, airframe sections, projectile delivery systems, and numerous medical appliances (3-7). Side hole fiber was proposed by Xie (8) as possible sensor for hydrostatic or acoustic pressure. In the presence of hydrostatic pressure acting on fiber surface, anisotropic stress is induced in the core due the geometry of fiber. Through photo elastic effect, the result is a pressure-induced birefringence which is direct measure of the applied pressure. In fibers two orthogonal linear polarization state of guided modes are maintained and desired for use in polarization–dependent optical components and interferometric fiber-optic sensors. It has been shown that intrinsic birefringence results both from residual thermal stresses given to the fiber core.

FBGs wavelength λ_B can be written in terms of the effective refractive index n_{eff} and the grating optical pitch Λ as (9);

$$\Delta\lambda_B = 2(\Lambda\, \partial n / \partial l + n\, \partial\Lambda / \partial l)\, \Delta l + 2(\Lambda\, \partial n / \partial T + n\, \partial\Lambda / \partial T)\, \Delta T \qquad (1)$$

The second term in equation (1) represents the temperature variation effect on an optical fiber. The Bragg wavelength shift as a consequence of thermal expansion changes the grating spacing and changes the effective index of refraction. The Bragg wavelength shift for temperature change ΔT can be written as;

$$\Delta\lambda_B = \lambda_B\, (\alpha - \zeta)\, \Delta T \qquad (2)$$

where $\alpha = (1/\Lambda)\, (\partial\Lambda/\partial T)$ represents the thermal expansion coefficient of the optical fiber ($\approx 0.55\times10^{-6}$ for silica), $\zeta = (1/n)\, (\partial n/\partial T)$ represents the thermo-optic coefficient and it is approximately equal to 8.6×10^{-6} / ºC for germanium-doped silica core fiber. The TFBG induces two types of coupling: the first is coupling the light from forward propagating core mode to backward propagating core mode, the second is coupling the forward propagating core mode to backward propagating cladding modes.

2. EXPERIMENTAL WORK

The setup shown in Figure (1) depicts a schematic diagram of the sensing system involving the home made tilted fiber Bragg grating written on a side hole fiber using 244 nm Ar^+ laser. The setup involves a light source, an interrogator and a circulator. The broad band source has a peak emission at 1550 nm. It was supplied by HAYATEK. The BBS has 200 nm operating bandwidth, a 3-dB bandwidth of 62 nm. The Circulator is of a 3 port type supplied by thorlabs. The Broad band source is connected to port 1 of the circulator. To the second, the prepare sensing element is connected. The Optical Spectrum Analyzer in our setup was supplied by Yokogawa model Ando AQ6370B It included modifications to the monochromator in comparison with Ando AQ6317B and AQ6370. The OSA has a wavelength resolution of 0.02 nm. Ando AQ6370B was well suited for C-band and L-band measurements as it covers from 600 to 1700nm.

A scanning electron micrograph (SEM) of the Side hole fiber is shown in Figure (1).The two symmetrical air holes located in the cladding and in parallel to the fiber core are clearly indicated in this figure .The diameter of the core of the side hole fiber is 8um with 125 um cladding in diameter. The two symmetrical air holes are of 28 um in diameter. The distance between the core and the center of each air hole is 32 um. The side hole fiber core refractive index differs by 0.0056 from that of the cladding. The TFBG was manufactured using phase mask method. This method employs a diffractive optical element (DOE) to spatially modulate the UV writing beam. The 10-mm long with a tilt angle of 4°TFBG was achieved with a uniform phase mask of 1074 nm period. The transmission spectrum of the TFBG written on 7-cm side hole fiber is shown in Figure (2) .The Bragg mode resonance of the two TFBG dips are located at 1579.614 nm and 1582.502nm with wavelength difference 2.888 nm between them.

Figure (3) shows the transmission spectrum of the second TFBG which was manufactured for new side hole fiber length 26 cm, grating length 10mm , tilted angle 4°and two dips 1579.108 nm,1580.304 nm .The wavelength difference 1.196 nm between them.

3. RESULTS & DISCUSSION

When the first TFBG was fixed into an oven bath with controllable temperature from 42 °C to 56°C by 1°C for each step , the wavelength of the two dips are changed with respect to temperature change as shown in Figure (4). The temperature was monitored by a thermo-couple with accuracy of 0.1 ◦C. The data are saved and plotted by Optical Spectrum Analyzer (OSA).The monitored temperature and corresponding wavelength are recorded. The fitting curves can be expressed by y= 0.009x+1579 and y=0.010x+1582 have exhibited a sensitivity of 9 pm/ °C for dip 1 and 10 pm / °C for dip 2. The R-squared values are 0.993 and 0.989 which mean that the response of the wavelength shift to temperature is quite linear When the second TFBG was fixed into an oven bath with controllable temperature from 32 °C to 78 °C by 4°C for each step, the wavelength of the two dips are changed with respect to temperature change as shown in Figure (5). The temperature was monitored by a thermo-couple with accuracy of 0.1 ◦C. The data are saved and plotted by Optical Spectrum Analyzer (OSA).The monitored temperature and corresponding wavelength are recorded. The fitting curves can be expressed by y= 0.009 x+1578 and y=0.009 x+1580 have exhibited a sensitivity of 9 pm/ °C for dip 1 and dip 2. The R-squared values are 0.995 and 0.988 which mean that the response of wavelength shift to temperature is quite linear. In conclusion , we think that tilted Fiber Bragg Gratings (TFBGs) temperature sensing element using 244 nm Ar^+ laser written on side hole fiber possess a potential in building the temperature sensor with acceptable sensitivity.

Acknowledgments

This work was designed and implemented in Institute of Optoelectronic Technology, China Jiliang University, Hangzhou, China. I owe my most sincere thanks to the staff for sharing their extensive knowledge with me

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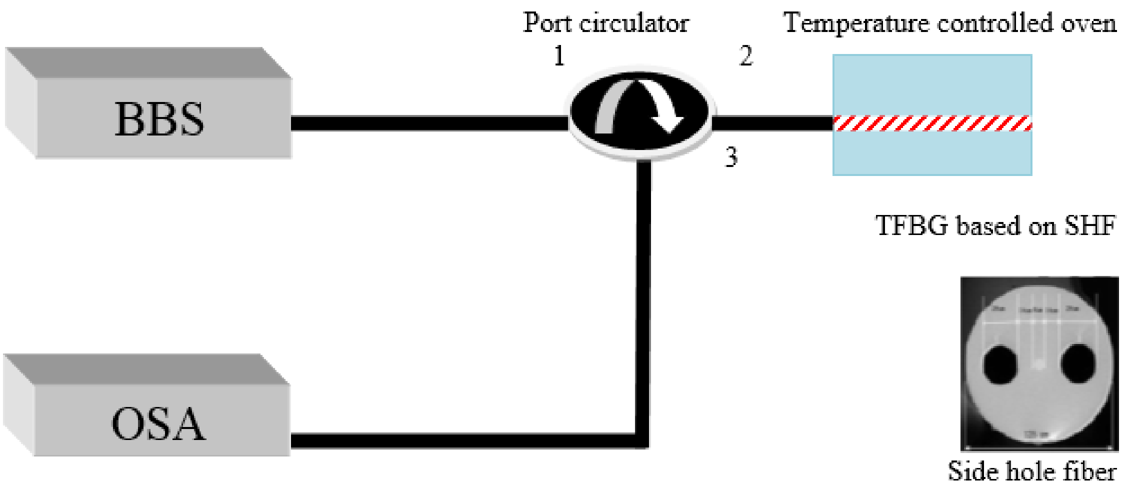

Figure (1): A schematic diagram of the sensing system involving the home made tilted fiber Bragg grating

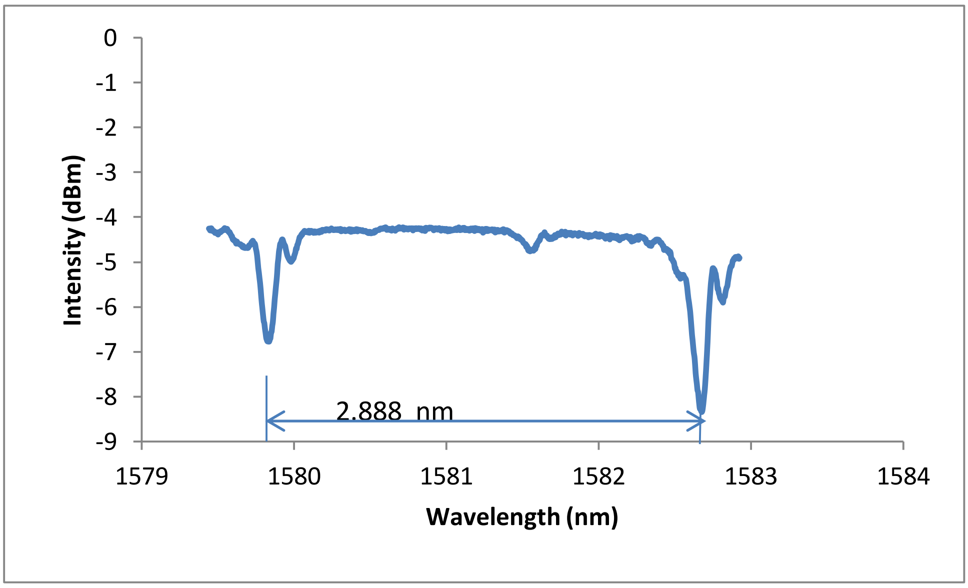

Figure (2): Transmission spectrum of the TFBG written on 7cm side hole fiber.

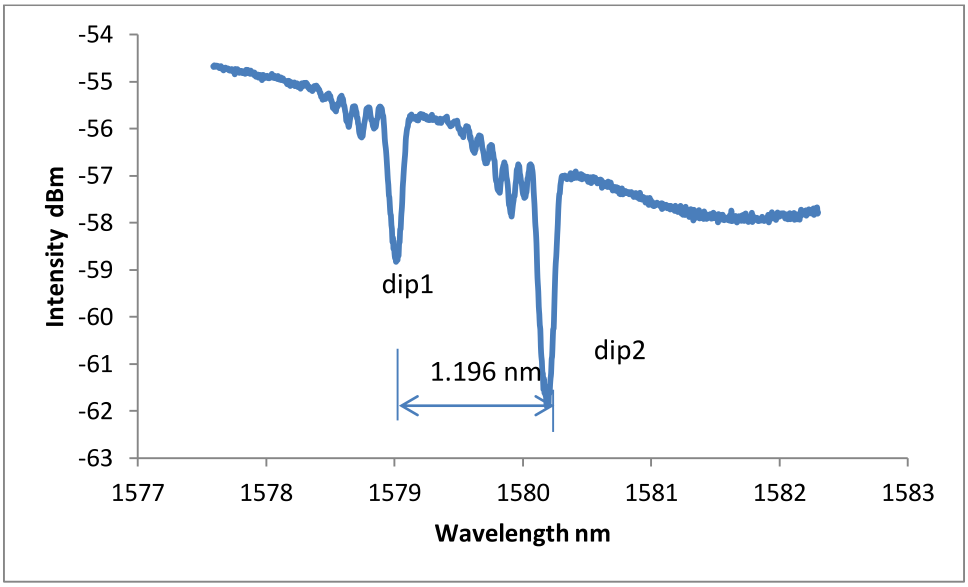

Figure (3): Transmission spectrum of the TFBG written on 26 cm side hole fiber.

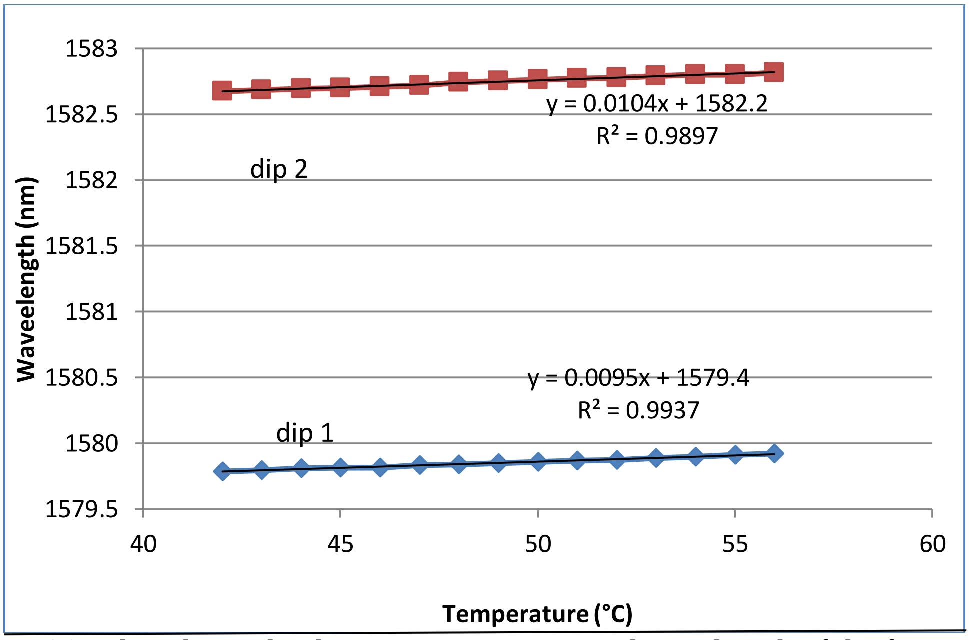

Figure (4): The relationship between temperature and wavelength of the first TFBG

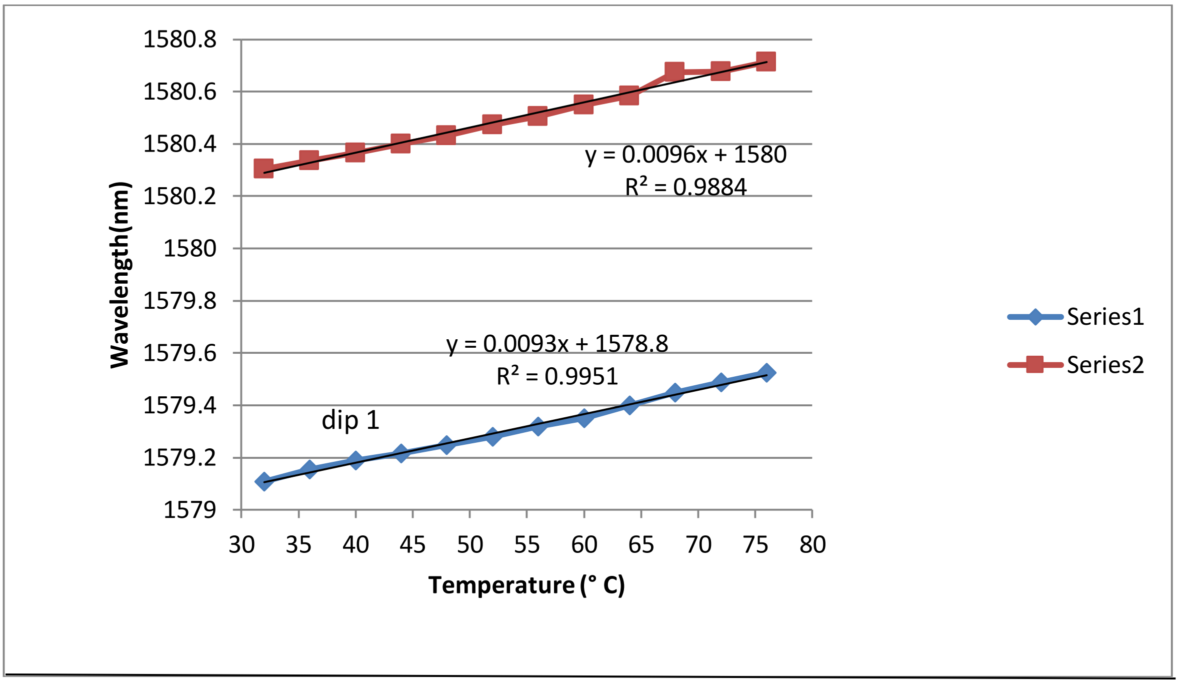

Figure (5):.The relationship between temperature and wavelength of the second TFBG.

عنصر تحسس حرارة لمحزز براغ الليفي المائل مستخدما ليزر ايون الاركون 244 نانومتر مكتوب على ليف ذو ثقوب جانبية

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الخلاصة:

محززات براغ الليفية المائلة تم تصميمها وتنفيذها في اطار حزمة الاتصالات 1550 نانومتر. تم تجريب المتحسسات ان تعمل كعنصر تحسس حرارة ذو استشعارية عالية. كتب محزز براغ الليفي المائل بطول 10 ملي متر على نواة الليف ذو ثقوب جانبية وبطول 7سم و26 سم المحملين بالهيدروجين مستخدما ليزر ايون الاركون 244 نانومتر لمضاعف التردد 488 نانومتر باستخدام طريقة القناع الطوري. اظهر طيف الارسال لمحزز براغ الليفي المائل الاول انخفاضات عند 1579.614 نانومتر و1582.502 نانومتر. اظهر طيف الارسال لمحزز براغ الليفي المائل الثاني انخفاضات عند 1579.108 نانومتر و 1580.304نانومتر. ان الاستشعارية المنجزة حوالي 10 بيكومتر/ م°. الى حد معرفتنا ان الاستشعارية المنجزة لهذا التصميم المنخفض الكلفة قريب جدا من اداء الانواع الاخرى من محززات براغ الليفي [(1)].