IJournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890 Volume 2 Issue 10, October 2014

Experimental Analysis of the Uniform Fiber Bragg Gratings as Temperature Sensor for Environmental Measurements

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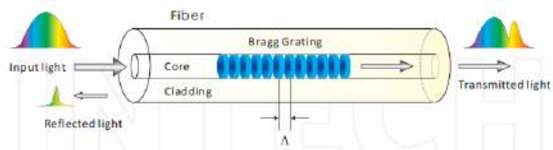
Abstract: *In this paper we analyzed the temperature sensing principle of uniform FBG by using experimental procedures. FBG sensors are based on the fact that any physical parameter which causes change in pitch of the grating and the change in refractive index will change Bragg wavelength shift.By observing the corresponding Bragg wavelength shift with the reference one we can sense the change. The sensitivity of the sensor was found 14.4pm/°C.*

Keywords: ***Fiber Bragg gratings,Reflection,Sensitivity,temperaturesensing, Bragg wavelength.***

1. Introduction

Guided wave optics is the forefront of research in optics nowadays. For modern applications, such as optical telecommunications and optical sensors, optical waveguides are the key components in which generation; modulation, propagation, and detection of light are governed by the principles of guided wave optics. An optical waveguide is a dielectric structure that transports energy at a wavelength in the infrared or visible portions of the electromagnetic spectrum [1].

With the increasing interests in the studies of all-fiber systems, fiber Bragg gratings (FBGs) have been applied in many photonic devices. A FBG is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects specific wavelengths of light and transmits all the other



components as shown in the figure (1).

Figure1 Structure and principle of uniformFiber Bragg Grating

The physical mechanism of inscribing the Bragg grating in a fiber is the photosensitivity of the fiber core. The refractive index of the fiber core is permanently changed[2]. The amount of change in the refractive index varies from 10^{-5} to 10^{-3}. The phenomenon of the change in the refractive index of the fiber upon light irradiation is usually referred as photosensitivity.

2. Fiber Bragg Grating Sensors

Sensors based on FBGs have attracted considerable attention since the early stage of the discovery. FBG sensors exceed other conventional electric sensors in many aspects, or instance, immunity to electromagnetic interference, compact size, light-weight, flexibility, stability, high temperature tolerance, and resistance to harsh environment.

Additional advantages of FBG sensors include very low insertion loss, narrowband wavelength reflection, linearity in response over many orders of magnitude and compatibility with the existing fiber optics system, especially their absolute wavelength-encoding of measureand information, making FBG sensors interrupt immune [3].

FBG sensors can measure many physical parameters, in which strain[4,5] and temperature [6,7] measurements are the major fields of interest. Meltz and Morey propounded that the shift in the Bragg grating wavelength was mainly due to strain and temperature [8]. The strain response is induced due to both the fractional change in a grating period due to the physical elongation of the optical fiber and the change in fiber index due to photo-elastic effects. The thermal response is induced due to both the inherent thermal expansion of the fiber material and the temperature depends of the refractive index. It is apparent that any shift in the Bragg wavelength is the sum of the strain and temperature factors.

Various kinds of methods for temperature measurements have been developed by using optical fibers, which include blackbody radiation and pyrometer, absorption, intrinsic scattering, various forms of interferometry, and fluorescence based techniques [9].

There are numerous applications of FBG sensors for structural health monitoring in civil engineering, including monitoring bridges [10], crack detection [11], and power transmission lines [12]. The FBG sensors can also be used in harsh environments [13].

3. Fiber Bragg Grating Temperature Sensitivity

The Bragg grating resonance wavelengthλ_B, which is the center wavelength of light back reflected from a Bragg grating, depends on the reflective index of refraction of the core (n_{eff}) and the periodicity of the grating (Λ) through the relation $\lambda_B = 2n_{eff}\Lambda$. The effective index of refraction, as well as the periodic spacing between the grating planes, will be affected by changes in temperature and strain. The shift in the Bragg grating wavelength $\Delta\lambda_B$ due to temperature and strain changes is given by [14]:

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

The first term in eq.(1) represents the temperature effect on an optical fiber. The changes in the grating spacing and the index of refraction caused by thermal expansion result in a shift in the Bragg wavelength. This fractional wavelength shift for a temperature change ΔT may be written as [8]:

$$\Delta\lambda_{B,T} = \lambda_B(\alpha + \xi)\Delta T \quad (2)$$

Where $\alpha = (1/\Lambda)(\partial\Lambda/\partial T)$ is the thermal expansion coefficient of the fiber (0.55×10^{-6} °C^{-1} for silica). The quantity $\xi = (1/n)(\partial n/\partial T)$ represents the thermo-optic coefficient, which is 8.6×10^{-6} °C^{-1} for a germanium doped silica-core fiber, the index change is by far the dominant effect.

4. Experimental Details

The experimental set up and the results obtained for temperature sensing of fiber Bragg grating system are indicated in Figure 2.

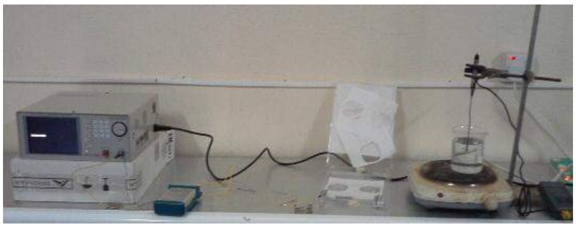


Figure2 Experimental setup for temperature sensing of FBG sensor

Light from laser source 1550 nm was launched into one end of the fiber containing the Bragg grating and the other end connected to the fiber coupler (2x1), and traveled to be detected the Bragg wavelength (λ_B) by the optical spectrum analyzer (OSA).The FBG sample was immersed in the water bath for which the temperature has been kept constant for at least half an hour before measurement in order to ensure that the transmission spectrum of the FBG sample was immovable and the system was in a stable condition.

5. Results &Analysis

Monitoring the spectral characteristics of Bragg gratings helps us to investigate the spectral profile of the Bragg resonance away from the peak wavelength (reflection spectrum).The transmission and reflectionspectrum of uniform Bragg grating at room temperature are shown in the Figures (3&4).

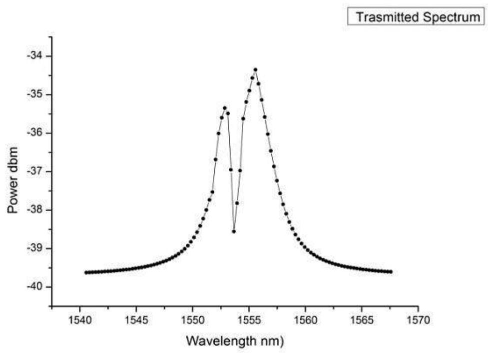


Figure 3 Transmission spectrum of FBG at room temperature

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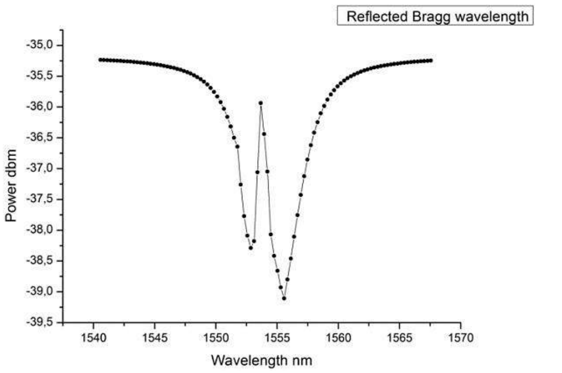

Figure 4 Transmission spectrum of FBG at room temperature

Experimental results due to the temperature change are listed in theTable 1, we plot the data as Temperature vs. Bragg wavelength and we got linear curves.Figure 5 shows the effect of temperature while the applied is used temperature from 25ºC to 80ºC.

Table 1Experimental Results of Temperature Change on FBG

Temperature (˚C)	Wavelength shift (nm)
25	1553.764
30	1553.836
35	1553.908
40	1553.980
45	1554.04
50	1554.114
55	1554.184
60	1554.244
65	1554.316
70	1554.388
75	1554.460
80	1554.520

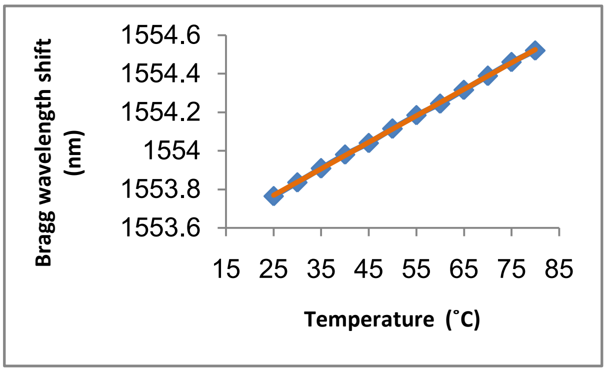

Figure 5Experimental results of the Bragg wavelength dependence on temperature

This implies that with the temperature change the Bragg wavelength shifts linearly. So by observing the Bragg wavelength shift with the reference Bragg wavelength we can sense the temperature through this sensor. The good linear relationship between temperature and Bragg wavelength has shown the potential of using for a device sensing applications.Theexperimental sensitivityof the sensor was found 14.4 pm/˚C while thetheoretical Sensitivitywas 14.21 pm/˚C.

6. Conclusions

From the results, it is observedthat when there is a change in optical properties of a material (FBG) because of heat radiation the effective refractive index (as well as the grating period) is changing as a result the Bragg wavelength shifts.There is a linear relationship between the Braggwavelength shift and the temperature. So,when we comparing the shifted Braggwavelength due to the temperature with the reference Braggwavelength at room temperature and without any stresses, it is possible to sense the temperature. Thus FBG work as a sensor for temperature.

7. ACKNOWLEDGEMENTS

Authors are grateful to Salahaddin University-Erbil-Office of General Directorate for Scientific Research for their cooperation in carrying out this work.Also we would like to express our thanks to Dr. DaraMohamedAmeen and Dr. NahlaQader forvaluable guidance.

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