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Dual Measurements of Pressure and Temperature With Fiber Bragg Grating Sensor

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Abstract

The fiber Bragg grating (FBG) technology has been rapidly applied in the sensing technology field. In this work, uniform FBG was used as pressure sensor based on measuring related Bragg wavelength shift. The pressure was applied directly by air compressor to the sensor and the pressure was ranged from 1 to 6 bar.

This sensor also was affected by the external temperature so as a result it could be used as a temperature sensor. This sensor could be used to monitor the pressure of dams. It has been shown from the result that the sensor is very sensitive to the pressure and the sensitivity was (67 pm\bar) and is very sensitive to temperature and the sensitivity was (10pm\ ^{o}C).

Keywords: *fiber Bragg grating (FBG), fiber Bragg grating analyzer (FBGA), pressure sensor, Effective refractive index.*

1. Introduction

Fiber Bragg grating (FBG) sensors have been widely used in an increasingly large number of sensing applications due to their especially attractive characteristics such as intrinsical safety, immunity to electromagnetic fields, remote sensing, and large multiplexing capabilities [1]. These sensors can be widely found in medicine as well as in different experimental, developmental, and diagnostic processes. One of the FBG sensors is the pressure sensor which presents key technology for the safe operation of different technical products, systems, and technologies [2]. FBGs are spectral filters fabricated within the segments of optical fibers. They typically reflect light over a narrow wavelength range and transmit all other wavelengths, but they also can be designed to have more complex spectral responses [3]. Figure (1) shows the structure and the spectrum of the FBG.

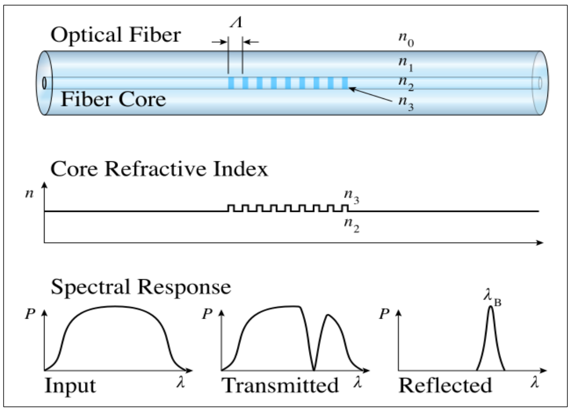

Fig. 1. Structure of FBG and the reflection and transmission spectrum [4].

FBGs are formed by a periodic change of the fiber cored refractive index in direction of propagation of optical radiation. The Bragg resonant wavelength is given by [2]:

$$\lambda_{\boldsymbol{B}} = 2n_e\Lambda \quad \text{... (1)}$$

Where λ_B is the Bragg resonant wavelength, n_e is the effective refractive index and Λ is the periodic variation (pitch) of the FBG.

The formation of FBG is generally based on the photo-sensitivity of silica fiber doped with germanium. When illuminated by UV radiation, the fiber exhibits a permanent change in the refractive index of the core [5].

The Bragg resonant wavelength is determined by various factors applied on the FBG, which affect effectively refractive index or grating periodic variation; therefore, it is an indirect measurement resulting from modifying physical or geometrical properties of the FBG. Pressure measurement is always based on the deformation of some sensing part (typically the membrane). Applied stress on the FBG in the direction of the fiber axis results in the extension of its physical dimensions and in the change of the periodic variation [2]. A lot of research is done on FBG sensors, especially concerning pressure measurement, but since FBG intrinsic pressure sensitivity is not very high, those sensors are always designed to amplify the pressure measurement indirectly by sensing the strain instead .Our approach consists of mounting the FBG sensor in cylindrical assemblies so that increased pressure sensitivity is achieved though mechanical amplification schemes [6]. The wavelength variation ($\Delta\lambda$) caused by the axial strain change ($\Delta\varepsilon$) and the temperature change (ΔT) could be given by [1]:

$$\Delta\lambda/\lambda = (1-\rho_e)\,\Delta\varepsilon + (\alpha_f + \xi)\,\Delta T \quad \text{... (2)}$$

Where λ is the initial wavelength of FBG, ρ_e, α_f and ξ are the effective photoelastic coefficient, the thermal expansion coefficient, and the thermal-optic coefficient of fused silica fiber respectively.

In this work, the capability of the FBG sensor to be used as pressure and temperature sensor was investigated and at different sets of powers from the source. The relationship between the shift of the Bragg wavelength of FBG and the applied pressure and temperature can be expressed as [7]:

$$\frac{\Delta\boldsymbol{\lambda}}{\boldsymbol{\lambda}} = k_p\,\Delta p + k_T\,\Delta T \quad \text{… (3)}$$

Where k_p is the pressure sensitivity and k_T is the temperature sensitivity. This equation is a general expression that describe the amount of shifting that caused by pressure and temperature while eq. 2 described the amount of shifting due to strain and temperature. The effects of pressure and temperature on FWHM of Bragg wavelength were discussed. A general expression for the approximate FWHM bandwidth of a gratings that inscribed inside a core of fiber with n_o refractive index is given by [8]:

$$\Delta\lambda = \lambda_{\boldsymbol{B}}\, s\sqrt{\left(\frac{\Delta n}{n_o}\right)^2 + \left(\frac{1}{N}\right)^2} \quad \text{... (4)}$$

Where N is the number of the grating planes and Δn is the amplitude of the induced refractive index perturbation. The parameter s is ~1 for strong gratings (for grating with near 100% reflection) whereas s ~ 0.5 for weak gratings.

2. Experimental Setup

The measurement setup consists of an optical signal source which is superluminescent diode with temperature controller TED200C and laser diode controller LDC210C (both TED and LDC are made from Thorlabs Company). The laser mount is the main part of the source. IC Chipset (Covega Company) is fixed on it. IC Chipset is connected to a single mode fiber (SMF) that is terminated by an FC connector to the first port of a 3-port circulator (Thorlabs Company). The second port is connected by an FC connector to the FBG sensor and the third port is connected to the fiber Bragg grating analyzer (FBGA) (Bay Spec Company).

The FBG sensor (Welltech Instrument Company) is designed to measure fluid pressure or levels. There are double FBGs that inscribed on SMF inside stainless steel housing named as FBG1 with λ_B = 1545.748 nm and FBG2 with λ_B = 1550.710 nm. The reflectivity and the gratings length for both FBGs are 99% and 3cm respectively. FBG2 is used to measure the pressure. Simultaneously, as temperature is compensated, FBG1 is used to monitor temperature. The pressure was applied by air compressor with pressure ranged from (1 to 6) bar. The FBG sensor was also affected by change of external temperature when it was immersed in water and heated. The reflected signal from the sensor is analyzed by FBGA and the program (sense20\20) analyzed the reflected data. Figure (2) shows the FBG sensor and the experimental setup was shown in figure (3).

Fig. 2. FBG sensor head.

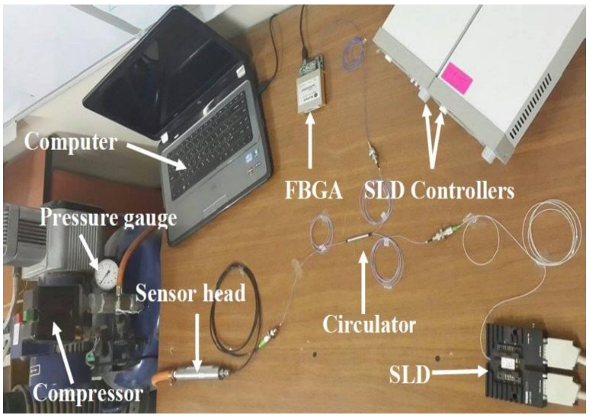

Fig. 3. Experimental setup.

Next figure shows the light source which consist of laser mount that including the IC Chipset, and also TDC and LDC.

(a) (b)

Fig. 4. Light source: a. TDC and LDC. b. Laser mount and IC chipset.

3. Results and Discussion

At the first the two peaks of the FBG sensor that analyzed by the FBGA through the software program Sense (20/20) that connected to the FBGA with no pressure applied and with 30 ˚C the temperature of the water with 280mA applied to the FBG sensor from LDC are shown in figure (5).

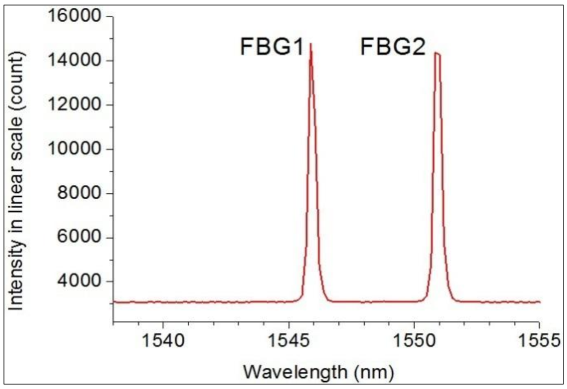

Fig. 5. The spectrum of the sensor.

The wavelength spacing between the two peaks is about 5 nm. When the FBG sensor is connected to the air compressor and the pressure start to increase, the characteristics curve of the pressure sensor can be measured. Figure (6) shows the spectral response of the FBG sensor with different sets for the power of the optical signal that goes to the FBG sensor. The power was varied by varying the LDC and TDC. The pressure sensitivity was calculated to be 67 pm/ bar for the pressure range from (1 to 6) bar with step of 1 bar.

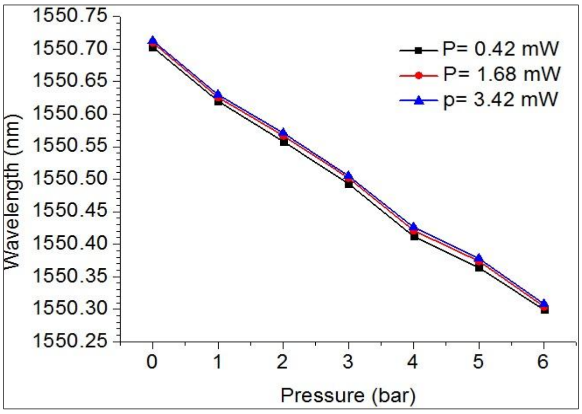

Fig. 6. Bragg wavelength shift against pressure at different sets of powers.

According to eq.1 the pressure will affect the pitch of the grating. Table (1) shows the value of pitch of grating with different sets of pressure with I=240mA, TEC=40℃, Pin=1.68mw. Pressure applied on FBG sensor will affect its physical dimensions and changes the grating period [2].

Table 1,
pressure with grating period.

Pressure (bar)	Bragg wavelength (nm)	Grating period (nm)
1	1550.620	545.914
2	1550.558	545.892
3	1550.493	545.869
4	1550.412	545.840
5	1550.364	545.824
6	1550.299	545.801

Figure (7) shows the relation between the grating period and Bragg wavelength.

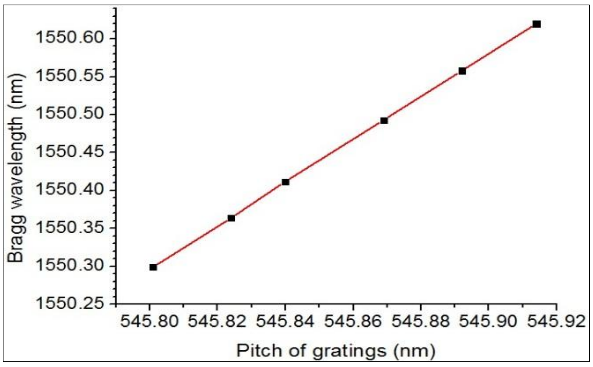

Fig. 7. Grating period against Bragg wavelength.

When the FBG sensor was immersed in water and the water was heated and the temperature was varied, the thermal expansion of the stainless steel will add another thermal effect on the second FBG of the pressure, thus the two FBGs respond to the thermal effect differently. In figure (8) there will be no pressure applied and the temperature increased from (20 to 70) ˚C with step of 5 ˚C and this figure shows the peak of temperature (FBG1).

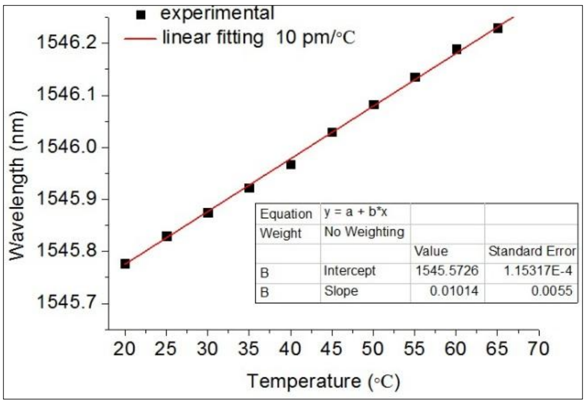

Fig. 8. First peak shift (FGB1) with temperature increased.

In figure (9) the peak of the pressure (FBG2) will be shifted too but the Bragg wavelength here will increase as shown figure (9) for the same range of temperatures.

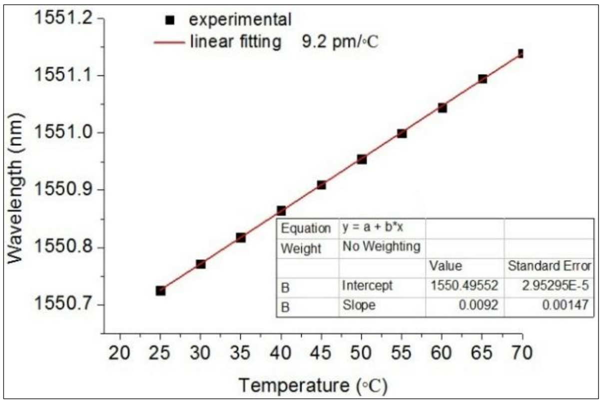

Fig. 9. Second peak shift (FBG2) with temperature increased.

The two peaks were shifted to higher wavelengths with increasing the value of temperature. Under the influence of strain or temperature changes, the effective refractive index and the grating period of FBG will change that result in the change of center wavelength of FBG [9] and that showed in eq.(2). The FWHM for the two FBGs were changed during the heating process and figure (10) shows the change of FWHM for the two peaks with I=240mA, TEC=50℃, Pin=1.68mw.

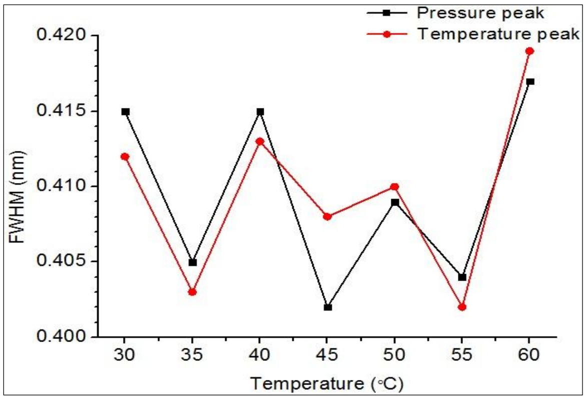

Fig. 10. FWHM change with temperature increased for FBG1 and FBG2.

When only pressure was applied the FWHM for the two peaks was not affected.

4. Conclusions

1. Simultaneous measurements of temperature and pressure were achieved for dual peaks sensor setup. FBG1 and FBG2 were sensitive to the variation of temperature with sensitivities of 10 pm/ ˚C and 9.2 pm/ ˚C for the temperature range from (20 to 65) ˚C as shown in figures (8 and 9).
2. FBG2 was sensitive to the variation of pressure with 67 pm/ bar sensitivity for the pressure range from (1 to 6) bar as shown in figure (6).
3. The FWHM was changed for the two peaks during the heating process but its relation was nonlinear with temperature as shown in figure (10). FWHM was not affected when only pressure was applied.

5. References

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القياس المزدوج للحرارة والضغط باستعمال متحسس الليف البصري المحزز نوع براغ

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الخلاصة

استخدم مؤخراً وبصورة متسارعة الليف البصري المحزز نوع براغ في تقنية بناء المتحسسات . في هذا العمل استعمل الليف البصري المحزز نوع براغ منتظم الترتيب بوصفه متحسساً للضغط عن طريق قياس ازاحة طوله الموجي . تم تسليط الضغط بصورة مباشرة باستعمال ضاغط الهواء بضغط يتراوح من (١-٦) بار . تاثر هذا المتحسس ايضا بالحرارة الخارجية لذلك استعمل متحسسا للحرارة ايضاً. بعد انجاز العمل وجد ان تحسس هذه المنظومة ذات الفايبرين المحززين نوع براغ قد تحسست للضغط بحساسية (٦٠pm /bar) والتي تعد حساسية جيدة وحساسيته للحرارة هي (١٠pm/C°) .