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CONTACT PRESSURE UNIFORM FIBER BRAGG GRATING (FBG) SENSOR

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ABSTRACT
Analysis of contact pressure Fiber Bragg Grating Sensor was proposed. FBG sensor based optical fiber is one of the best sensors devices to measure the physical parameters with high accuracy compared to the conventional sensors. In this paper, a contact pressure FBG sensor with enhancement of sensitivity was analysis. Applying force on the FBG sensor caused a wavelength shift of the central Bragg wavelength depending on the amount of the applied force. However, the pressure sensitivity measurements can be influenced by the surrounding factors such as temperature. This paper showed a new method to overcome the impact of temperature on the pressure sensitivity readings. The method involved using two FBG sensors written along one optical fiber with 4 cm distance between them and 1550 nm central Bragg wavelength. Nevertheless, the experimental results with one FBG sensor showed pressure sensitivity about $2.61X10^{-2}$ nm/KPa and when two FBG sensors are used, the result showed more accurate sensitivity reading which was about $3.1065X10^{-3}$ nm/KPa. Some recommendations to enhance the setup and working are briefly outlined.

KEYWORDS: contact pressure, FBG, fiber optic sensor, pressure sensitivity

1. INTRODUCTION
In the last decade, researches had shown the wide range of optical fiber technologies, not only in data communication but also in sensing technology [1]. Fiber optic sensing FOS technology is a combination of optoelectronics devices and optical fiber [2]. The optoelectronics field has given compact devises and the fiber optic industry has brought a high performance, less loss and low cost [3]. As a result, FOS has the capability to displace the conventional sensors for physical and chemical parameters measurements [3]. Depending on how FOS system measures the required measured, FOS technologies are classified into two essential categories: Intrinsic and extrinsic [4]. Firstly, in an intrinsic type the light and the measured are interacted internally to the optical fiber, therefore the modulated characteristic of the light can be effected, for instance, intensity, phase, wavelength and polarization [5]. Secondly, in an extrinsic type the light and the measured are interacted externally to optical fiber [6]. However, according to the modulated light FOS technologies can be divided into [7]:

- Intensity modulated sensor
- Phase modulated sensor
- Spectrum modulated sensor
- Time and frequency modulated sensor

The FOS has many advantages such as, light weight and small size, immunity to electromagnetic interference and high sensitivity reading. These benefits can be used to neglect the disadvantages of FOS such as high cost maintenance and professional setup skills [8]. During the past decades, new FOS technologies developed, for example: “FBG sensors”, “interferometric sensors” and “Brillouin scattering distributed sensors”. However, these technologies have significantly improved the practical function of the FOS. Although these mechanisms have many advantages, FBG sensors technology has been dominated over the others, because of its advantages. For instance: small size and light weight, easy integrated to other techniques, immune to electrical signal, electromagnetic interference and radio frequency interference, resistive to harsh environments, high and accurate sensitivity, suitable for remote sensing technologies, finally capability of power transmission, pressure and underground temperature monitoring. [8].

FBG sensor has been used in different application because of high and accurate sensitivity to several environmental measured, for example: 'physical', 'biomedical', 'chemical' and electrical' parameters [9]. Additionally, FBG sensor has a wide range of application in: optical telecommunications sensor, fiber lasers, amplifiers, filters, wavelength division multiplexers, monitoring of dispersion compensation, static and dynamic strain, humidity sensors and an optical layer, and finally, length measurements technique. FBG sensor showed a high sensitivity to strain, temperature, transverse load, pressure, vibration and displacement [9]. In this paper, a spectrum modulated based Fiber Bragg Grating FBG sensor was presented in terms of contact pressure measurements.

FBG Pressure Sensing Technology

Recently, FBG technology has shown a wide range of applications. Nevertheless, the FBG sensor has the ability to measure different physical parameters with high accuracy [6]. FOS based FBG has been used in different measurements parameters such as, physical, chemical, biomedical and electrical [7]. The sensitivity of these parameters was encoded by wavelength shift. Furthermore, using FBG sensor has many advantages for example, high response time, high accuracy measurements, small size and small weight. However, FBG sensor is a periodic refractive index perturbation written within the optical fiber. This perturbation of refractive index is made by focusing a high intense illumination on a specific part of core [10]. Additionally, this refractive index perturbation will cause a wavelength shift according to the measurements of the measured [11]. Therefore, the Bragg condition can be expressed as [12]:

$$\lambda_B = 2n_{eff}\Lambda \qquad \text{(i)}$$

Where λ_B is the reflected Bragg wavelength, n_{eff} is the effective refractive index of the core and Λ is the grating period. It is clear from equation (i), that the Bragg wavelength depends on the effective refractive index and the grating period. As a consequence, any external force will cause a change in the grating period because of the grating pitch increasing and refractive index due to the impact of the photoelastic coefficient [13].
In this paper, the analysis of contact pressure FBG sensor is presented. It demonstrates the impact of applying pressure on FBG which induce a wavelength shift of FBG. This shift occurs because of the impact of the pressure on the refractive index and grating period of FBG. It can be given by the following expressions:

$$\Delta\lambda_B = \lambda_B\left(\frac{1}{\Lambda}\frac{d\Lambda}{dP} + \frac{1}{n_{eff}}\frac{dn}{dP}\right)\Delta P \qquad \text{(ii)}$$

ΔP is the change in contact pressure. If E is Young's modulus, ν is the Poisson ratio of the fibre, p_{11} and p_{12} are the strain-optic tensor components and $\Delta n/n$ and $\Delta L/L$ are the changes in refractive index and length respectively, then[14]:

$$\frac{\Delta n}{n} = \frac{n^2 P}{2E}(1-2\upsilon)(2p_{12}+p_{11}) \qquad \text{(iii)}$$

$$\frac{\Delta L}{L} = -\frac{P-2P\upsilon}{E} \qquad \text{(iv)}$$

$$\frac{1}{\Lambda}\frac{d\Lambda}{dP} = (1-2\upsilon)E^{-1} \qquad \text{(v)}$$

$$\frac{1}{n}\frac{dn}{dP} = \frac{n^2}{2E}(1-2\upsilon)(2p_{12}+p_{11}) \qquad \text{(vi)}$$

Finally, we can substitute equation (v) and (vi) into equation (ii), yield:

$$\Delta\lambda_B = \frac{1}{E}\left(\frac{n^2}{2}(2p_{12}+p_{11}) - 1\right)\Delta P\lambda_B(1-2\upsilon) \qquad \text{(vii)}$$

Applying a force on a certain part of FBG sensor will induce a change in the refractive index of the core of the optical fiber as a shown in the figure (1). The figure illustrates the two parts of the FBG sensor, the first one with influenced refractive index and the second one without applying force [15].

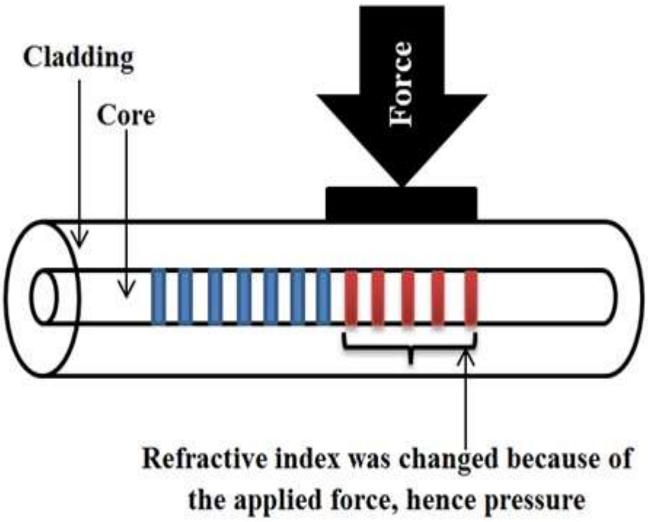

Fig. 1. The applied force on the FBG sensor

However, this will cause two Bragg peaks as shown in figure (2). These peaks will be broadening by increasing the applied force, until they split [16]. Nevertheless, the contact pressure can be estimated from the relation: pressure= force/area.

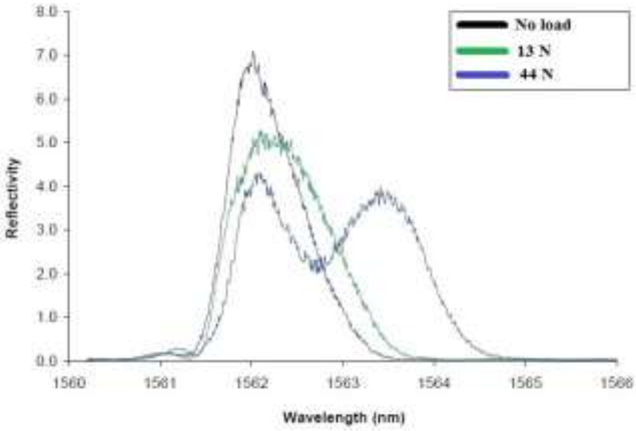

Fig. 2. The reflection spectrum under different load values

2. MATERIALS AND METHODS

The fiber used in this work was Coring Single Mode Fiber 28 (SMF-28), refractive index of core 1.45 and for cladding 1.46 with 1550 nm central Bragg wavelength with 5 mm FBG sensor. The FBG sensor covered within epoxy resin patch to protect the grating from the applied force. The second model design was two FBG sensors with 4 cm distance between them as illustrated in figure (3). Figure (4) shows the setup used. A container was used in order to increase the amount of applied force on the FBG sensor by filling it up with water. However, the weight represents the applied force. It can be estimated by using balance. As a consequence, the pressure was calculated as following:

$$pressure = \frac{force}{area} = \frac{mXg}{area} \qquad \text{(viii)}$$

Where m is the mass, g = 9.81 m/s2 is the effective gravitational acceleration of earth and area is the area of the patch.

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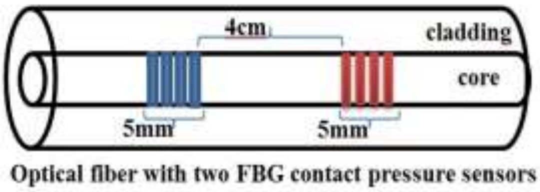

Fig.3. Two FBG pressure sensors

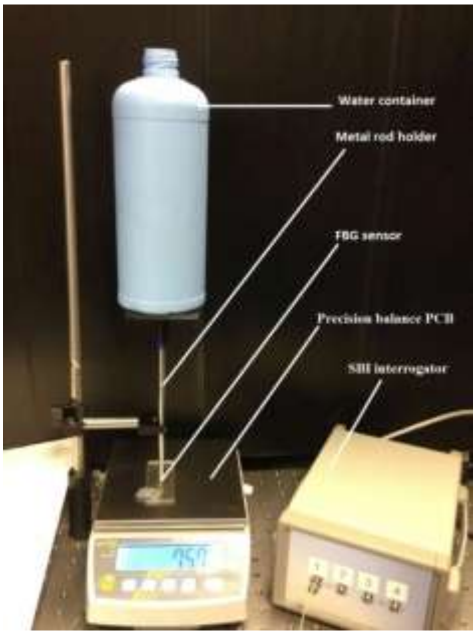

Fig. 4. The experimental setup of the contact pressure measurements

3. RESULTS AND DISCUSSION

By applying equation (7), figure (5) shows the reflection spectrum of FBG sensor with different applied pressure values from zero Pa to 500 MPa caused a wavelength shift of 0.0109 µm of a central Bragg wavelength.

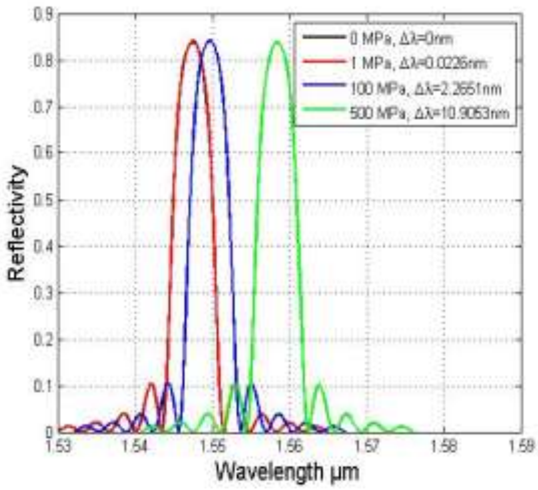

Fig. 5. The reflection spectrum under different values of pressure.

Moreover, figure (6) shows the pressure as a function of the wavelength shift. It is clear from the data that the relation is linear since the pressure has an impact on the refractive index, hence the wavelength shifts as Bragg condition shown. Nevertheless, temperatures had affected the pressure measurements. This fluctuation was removed by using dual FBG sensors written on the same optical fiber. One of them was sensitive to the temperature and the second one was sensitive to both temperature and pressure. The temperature impact on the first FBG was subtracted from the second FBG as the following expression:

$$\Delta\lambda(P)_{FBG2} = \Delta\lambda(T,P)_{FBG2} - \Delta\lambda(T)_{FBG1} \qquad \text{(ix)}$$

This method gave a high accuracy of pressure sensitivity. Similarly, this technique gave good results as shown in measurements of strain and temperature [17]. However, the researchers have shown a different way to overcome the impact of the external force. For instance, two FBG sensors coating with Al_2O_3 substrate, polymer package Double FBG, arc-shaped steel strip FBG, one FBG written in grapefruit microstructure fiber, broadened reflection spectrum single FBG, FBG emended in a tapered polymer, FBG coated with metal and FBG wrote in birefringence fiber [18]. In addition, new technologies combined FBG with other technologies to reduce the effect of temperature. For example, regular FBG combine with long period FBG, with a Fabry-Perot interferometer, and with thermo-chromic material [19].

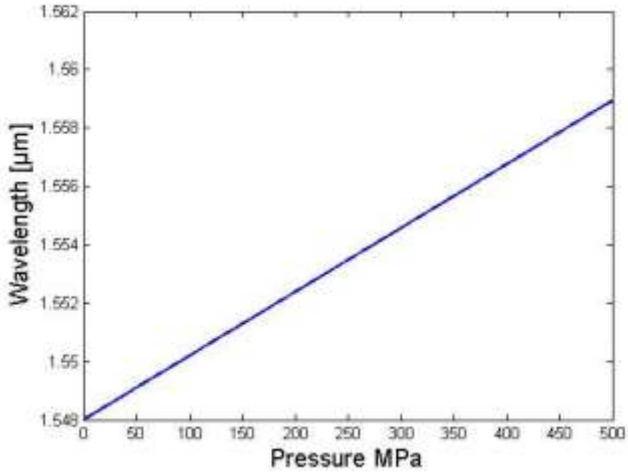

Fig. 6. Pressure as a function of wavelength

It is clear from figures above that the applied pressure was increased by approximately 5 KPa up to 500 MPa. At the pressure of 150 KPa the wavelength shift was 0.0606 nm, the estimated wavelength shift was good enough to induce a reliable accuracy in sensitivity reading. The FBG pressure sensitivity was calculated $2.61X10^{-2}$ nm/KPa. However, using two FBG sensors was a good method to increase the accuracy of the contact pressure sensitivity reading which made it equal to $3.1065X10^{-3}$ nm/KPa. However, using two FBG sensors gave high contact pressure sensitivity. Even the data obtained was accurate enough, improving the setup is recommended. The setup used could be enhanced by adjusting the applied force directly to the FBG sensor taking into account that the FBG sensor will be protected well.

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