Human body high resolution and accurate temperature FBG sensor

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Abstract. A fiber Brag grating-based temperature sensor FBG together with high accuracy, resolution and compact size interrogation system using a short period grating was presented in this work. The designed sensor measures the temperature from 35 °C temperature to 41 °C which is represented the ranges of human body temperature for use in medical applications. In this paper, we present some results obtained from experiments within a measurement range from (35°C to 40°C) which is from hypothermia to hyperthermia) that the sensor has high sensitivity and high resolution of (85.9%) for FBG sensor. After the results we obtained and the features that the sensor enjoys, such as small size, immunity from electrical influence, and the ability to work in environments Magnetic Resonance Imaging (MRI) environments. The sensor can be used in hospitals and clinics for improvement and monitoring of patients. The importance of this work increases due to the COVID-19 pandemic we are going through, so this work can be proposed to contribute to monitoring patients’ cases and considered as a new equipment in studying temperature sensor in human.

Keywords— fiber Bragg grating, fiber optic temperature sensor, optical wavelength, modulation, high accuracy sensors, health monitoring system.

1. Introduction

The development of optical fiber communication technology has contributed to the development and intensification of studies of optical fiber sensors [1]. The sensor Optical fiber gives more advantageous over other sensors, in high sensitivity and variety of form factors. For the many important features of fiber optic sensors, its has led to the replacement of well-known traditional sensors to optical fiber sensors in a broad range of applications [1]. By introducing and modulation of the refractive index of the fiber core Produces the fiber Bragg grating optical device [2]. Fiber Bragg grating (FBG) have wide attracted attention because of many of their inherent advantages, such as small size, cylindrical geometry, immunity to electromagnetic interference or optical power fluctuations, its weight is light, no zero-temperature drift, and the fact that multiple FBGs can be arrayed along in a single fiber [3]. The Bragg wavelength ($\lambda_B$) shift reflected by the grating from FBG is the operation principle includes as a function of the monitored parameter, through by the relation equation no.(1) the grating period ($\Lambda$) and the effective refractive index of the fiber core ($n_{eff}$) are effective on The Bragg wavelength [4]:

$$\lambda_B = 2n_{eff} \Lambda$$

(1)

Therefore, By variations in the grating period or optical fiber core effective refractive index They change the Bragg wavelength. So, the strain and temperature are affects on the FBG wavelength [4], can be translated by :

$$\Delta \lambda_B = \lambda_B (1 - \rho_A) \Delta \epsilon + \lambda_B (\alpha + \xi)$$

(2)
Where the strain is effect on the first term on the $\lambda_B$ while the temperature effect on the second term. Hence, in Eq. (2), $\Delta \lambda_p$ is represents the shift of the Bragg wavelength, while $\xi$ thermal expansion, $\alpha$ is thermo-optic coefficients, and $\rho$ is the photoelastic of the fiber, ($\Delta T$ and $\Delta \varepsilon$) change directly with temperature and pressure changes respectively. The mechanism of FBG sensing consists of spectral broadband optical signal launched into the fiber and to monitor the Bragg wavelength shifts use an optical spectral analyzer. At the grating region The Bragg wavelength component of the spectrum will be expressed in the grid area, while the same Bragg wavelength component will be absent in the transmitted optical signal, shown in figure 1 below.

Figure1. Schematic representation of the principal work of an FBG [5]

Based on the described mechanisms, FBG sensors have a wide field of applications that range from their use for structural health monitoring, biomedical sensors, and medical applications, also as in oil, aeronautic industry [5].

In the medical field, there are several research articles of FBGs used especially, e-health monitoring, heart rate monitoring, and vital sign measurements such as heart rate, body temperature, pulmonary condition respiratory, blood pressure, and respiratory rate (RR). [5,7,8]

These are sensors interested with an important aspect of resistance of electromagnetic interference, which makes sensors a valid in magnetic resonance imaging (MRI) environment.

In recent years, FBG has more research interest because it’s considered as an excellent sensor element. The reflected wavelength from the FBG depends on physical properties such as strain and temperature. The FBG attracts wide attention for its wavelength based algorithms, which make the sensor self-referring with less power/conductor loss [9].

The temperature sensing of Bragg grating occurs principally through the temperature effect on the index of refraction and to a lesser extent through the expansion coefficient. That means the temperature sensitivity can be enhanced or mulled by proper bonding to other materials. While the strain its depends on changing in spacing between pitch [10].

The body temperature of human beings arranged from (35°C to 40°C) which is from (hypothermia to hyperthermia), and the normal human temperature is typically stated as (36.5 °C – 37.5 °C) [11]. This research article was concluded as a sober medical institutes because one of the signs of infection with the
Coronavirus is the high temperature of the infected person. Therefore, FBG sensor had been designed for studying its performance as a temperature sensor for humans without the need to traditional equipment.

2. Experimental work
The FBG Temperature sensor had been characterized through the experimental setup shown in figure 2 and 3 respectively. The source was laser diode type single-mode fiber-pigtailed, FC/PC, the center wavelength was (1540 nm-1560 nm), the power output around 1.6 mW, the current approximation 29.3 mA was joint into the input port of optical fiber circulator, when the input port of FBG was connected to the transmitted port. The FBG region had been immersed into water bath boiler microprocessor-controlled, temperature Range from 0°C to 100°C, for a submitted application the temperature range was 35 °C to 41 °C with step 0.5 °C. The reflected signal was read through the third port of the optical fiber circulator, this port connected to a high-resolution Optical Spectrum Analyzer (OSA- Thorlabs 203).

Figure 2: Schematic of FBG temperature sensor diagram
First, the spectrum of laser source had been recorded. Then, we recorded the FBG spectrum at room temperature. Then the FBG had been immersed into water bath temperature had been raising by step 0.5 °C and recorded the spectrum. Then we record the spectrum for the cooling cases. This steps had been repeated several time to test the repeatability of the sensor.
**Figure 3:** photographic image of FBG temperature sensor: (1) light Source, (2) optical circulator, (3) FBG, (4) water bath, (5) OSA, (6) Digital Multimeter

| Component         | Values and using                                      |
|-------------------|-------------------------------------------------------|
| White light source| Power = (0.001 mwatt), peak wavelength = (1550 nm)    |
| optical circulator| three ports. The first port input port, the second port fiber is the output port that connects to OSA, the third port fiber is the bidirectional port connected to the FBG |
| FBG               | Bragg wavelength (1550 nm), reflectivity (0.99), bandwidth (125 GHz) |
| water bath        | Thermostatic Water Bath                                |
| OSA               | (Thorlabs-203 OSA) with wavelength range (1000-2500 nm), resolution (0.1) nm |
| Digital Multimeter| Used for reading temperatures                          |

3. **Results and Discussion**

By using the spectrum analyzer to recognize the sensor's response to the change in wavelength when changing temperature as shown in figure (4). We took the center of the zero spectral transmission area and changed the temperature, we noticed that the change is clear. This indicates that the sensor is working fine and has high sensitivity. But in case of raising the temperature led to the change of the Bragg resonance wavelength shift.

**Figure 4:** Spectrum of Shifted Bragg wavelength due to increase applied temperature.

In Figure 5, the sensitivity was (-)16 pm/°C while in figure 6, we recorded the spectrum for each degree and the results showed that the Bragg wavelength had been shifted towards the higher wavelengths.

The Figure 7 showed the sensitivity was 22.86 pm/°C. This indicated is due to the change of effective refractive index and spacing between gratings due to applied temperature.
Figure 5. The relationship between shifted $\lambda_B$ and applied temperature in case of raising degrees.

Figure 6. Spectrum of Shifted Bragg wavelength due to decrease applied temperature.
Figure 7. The relationship between shifted $\lambda_B$ and applied temperature in case of decreasing temperature degrees.

4. Conclusion
The temperature sensor which has been used as FBG was identified to read the reflection spectrum. The FBG properties make them very useful to measure the human temperature (35 – 41)°C in special and critical cases depends on health and mental case of the patient as measuring it due to MRI or PET SCAN. The main advantage of this work is its high sensitivity and responsiveness when changing temperature range from 35 oC to 41 oC, the high sensitivity were in both cases increasing and decreasing temperature when FBG used. The relation between the range of temperature degrees ($\Delta T$) used and the Bragg wavelength shift ($\Delta\lambda_B$) were linear. The change in a refractive index of the FBG caused by the change in temperature that affects the sensitivity of the Bragg wavelength, That’s why the change happens Shifted Bragg wavelength .

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