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Modeling and Simulation of Fiber Bragg Grating (FBG) as a Strain Sensor for in Vivo Body Monitoring

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Abstract: Malaysia is a well-known country to have the best healthcare in the world. However, the number of deaths is increases annually due to heart disease. As a preventive measure against this disease, cost-effective technology must be introduced. The current project is concerned with the development of cardiovascular assessment sensor systems. The determination of aortic pressure in the carotid artery is by using fiber Bragg Grating (FBG) in in-vivo measurements. For this project, the strain response of the optical FBG sensor uses MATLAB R2133 software to simulate the reflected spectrum from the strain applied. By using the simulation, the characteristic of FBG can also be analyzed such as the spectral reflectivity and bandwidth. It were analyzed with grating length and refractive index change. Thus, simulation results demonstrated the strain, Bragg wavelength shift, spectral reflectivity and bandwidth as grating length and refractive index change is varies. It is affirmed that this model system can be used as a cardiovascular assessment device and the simulation result satisfy with the previous research.
Keywords: Fiber Bragg Grating, strain sensor, reflectivity, simulation, in vivo body monitoring

I. INTRODUCTION

According to the New Strait Times website [1], Malaysia has ranked the first Best Healthcare in the World category of 2019 International Living Annual Global Retirement Index. However, from the Department of Statistic Malaysia website [2], a total of 162 201 deaths were recorded in 2016. It increases 4.1 per cent compared to 2015 (155 786). Ischemic heart disease was the principal cause of death in 2016. Besides, from World of Health organization (WHO) website [3], Malaysian probability of dying from cardiovascular diseases (CVDs) stood at 17.2 per cent in 2018 compared to 2016. This pattern indicates increment of number of death due to heart disease every year. In response to this problem, this study proposes to develop an option for making a cost-effective device for cardiovascular assessment. For a low-cost device, FBG was used as a strain sensor to measure heart activity. FBG has always been used for the higher frequency range and various applications for optical fiber sensors [4]. It is a type of Bragg reflector that is built into a short fiber optic segment. It reflects the specific wavelength of light and sends out the other. This reflection can be found by adding a periodic variation to the fiber core refraction index. This periodic variation will create a wave-specific dielectric mirror. As a result, it can be used as an optical filter to prevent specific wavelengths [5]. Apart from low-cost, FBG sensors are also well-known for their features such as electromagnetic immunity, long distance sensing, selection of wavelengths, environmental resistance, reduced size and multiplexing capabilities [6]. For the effectiveness of the device, in vivo measurement is considered. FBG is made from glass and is highly resistant to the organic and chemical deterioration [7]. Hence, making it suitable for human and animal biology. Reliability, stability, and high accuracy are an essential factor in many medical applications, particularly during long-term measurement. This feature is useful in medical diagnosis. These sensors can, therefore, be inserted in vivo for several hours in patients [8]. It produces no bad biological response from the human defense system and minimizes the risk of infection. This risk is usually associated with invasive surgical procedures [9]. For the FBG strain response, the simulation program will also be considered. The program has to be able to plot the reflected or transmission spectrum from the Bragg wavelength.

II. METHODOLOGY

In this study, the design of this Fiber Bragg grating sensor system was developed using only the main components, while the illustration was designed for cardiovascular assessment. The specification of the FBG used in the system is listed in Table 1. This optical FBG sensor for strain measurement is then simulated in Mathworks Software MATLAB R2016a. The simulation has been performed with certain fixed values of the parameters as in Table 2. The simulation program can be used to analyze the characteristics of fiber Bragg grating such as bandwidth and reflectivity by varying the grating length and refractive index change.

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III. RESULTS AND DISCUSSION

A. Schematic Model and Illustration of FBG System

The FBG model system and illustration for blood stress measurement are shown in Figure 1 and 2. The model system consists of a commercial FBG, an optical spectrum analyzer (OSA) as detector, a tunable laser source that can control the wavelength, a Single Mode Fiber SMF-28, 9/125 µm fiber optic cable for connecting FBG to OSA and laser source, a metal plate and a pressure gage. While for illustration, the FBG was inserted into the left carotid artery to sense the aortic pressure or blood stress. The stress in the blood is then is translated into OSA and therefore provide the information about heart activity.

B. Strain

From data in Table 4, the strain is induced when there is a change in the initial fiber length. The more changes of initial fiber length, the more strain is induced.

C. Bragg wavelength Shift

From the data in Table 5, the graph of Bragg wavelength shift against the strain applied is plot as in Figure 3. The more strain is applied to FBG; the more Bragg wavelength will be shifted.

D. Spectral Reflectivity

From data in Table 1, the graph of FBG spectral reflectivity for different changes of refractive index and different grating length is plot as in Figure 4 and Figure 5. The FBG spectral reflectivity increase with increase in refractive index change at a constant grating length. It also increases with increase in grating length for a fixed refractive index.

E. Bandwidth

From the data in Table 1, the graph of bandwidth is plot in Figure 6. It is observed that the bandwidth decrease as the grating length is increased. However, it increases as the refractive index change is increased.

Table 1. The dependence of reflectivity and bandwidth on the grating length and refractive index change

Grating Length (L) mm	$\Delta n = 0.0003$		$\Delta n = 0.0005$		$\Delta n = 0.0008$		$\Delta n = 0.0012$		$\Delta n = 0.0015$		$\Delta n = 0.0020$	
	R(%)	Band Width (BW) nm	R(%)	Band Width (BW) nm	R(%)	Band Width (BW) nm	R(%)	Band Width (BW) nm	R(%)	Band Width (BW) nm	R(%)	Band Width (BW) nm
1.0	29.46	1.68	58.86	1.73	85.53	1.85	96.96	2.08	99.09	2.29	99.88	2.69
3.0	90.10	0.63	99.98	0.76	99.98	1.01	100	1.39	100	1.68	100	2.19
5.0	99.10	0.46	99.98	0.63	100	9.11	100	1.32	100	1.63	100	2.15
7.0	99.92	0.40	99.99	0.58	100	8.81	100	1.30	100	1.61	100	2.14
9.0	99.99	0.37	99.99	0.56	100	8.69	100	1.29	100	1.60	100	2.13

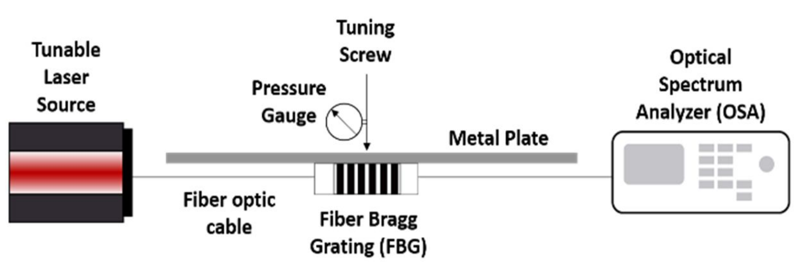

Figure 1. The schematic model of FBG for strain measurement

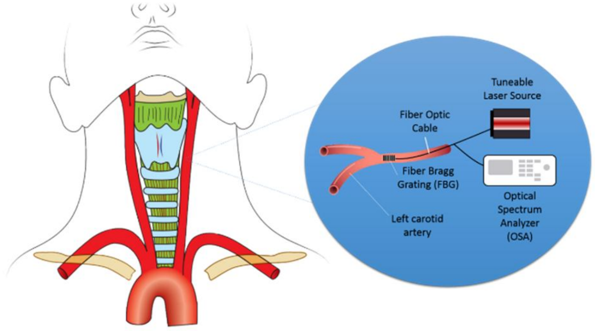

Figure 2. The illustration of the FBG system for determination of stress in blood

Table 2. The main parameter of Fiber Bragg Grating use in the simulation

Parameters	Values
Effective refractive index, n_{eff}	1.46
Bragg wavelength, λ_B	1550 nm
Grating period, Λ	530 nm
Strain-optic constant, p_e	0.22

Table 3. The specifications of the Fiber Bragg Grating use in the simulation

Parameters	**Standard**
Centre wavelength	1528 – 1609 nm
FBG Length	1 -10 mm
Peak Reflectivity	50 – 80 %
3 dB Bandwidth	1.5 – 0.3 nm
SLSR single sensor	15 dB
Strain range	±9000 µstrain
Strain sensitivity	1.2 pm/µstrain
Strain resolution	0.4 µstrain
Fiber type	Single Mode SMF-28, 9/125 µm

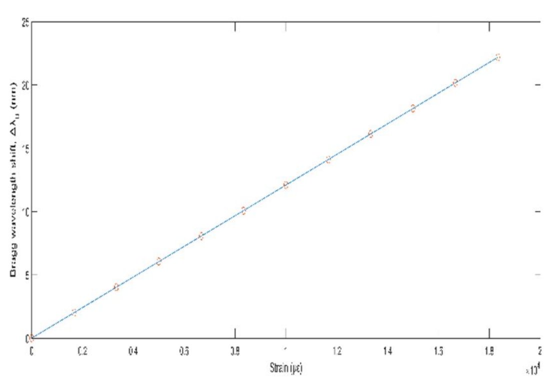

Figure 3. The graph of Bragg wavelength shift against the applied strain

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Table 4. The strain applied from the change of fiber length

Δl $(\pm 0.05\ mm)$	Strain $(\mu\varepsilon)$
0.000	0.00
0.050	1666.67
0.100	3333.33
0.150	5000.00
0.200	6666.67
0.250	8333.33
0.300	10000.00
0.350	11666.67
0.400	13333.33
0.450	15000.00
0.500	16666.67
0.550	18333.33

Table 5. The Bragg wavelength shift with applied strain

Strain $(\mu\varepsilon)$	Bragg wavelength, λ_B $(\pm 0.10nm)$	Bragg wavelength shift, $\Delta\lambda_B(\pm 0.10nm)$
0.00	1549.40	0.00
1666.67	1549.60	2.01
3333.33	1549.80	4.03
5000.00	1550.00	6.05
6666.67	1550.20	8.06
8333.33	1550.40	10.07
10000.00	1550.60	12.10
11666.67	1550.80	14.11
13333.33	1551.00	16.13
15000.00	1551.20	18.15
16666.67	1551.40	20.17
18333.33	1551.60	22.19

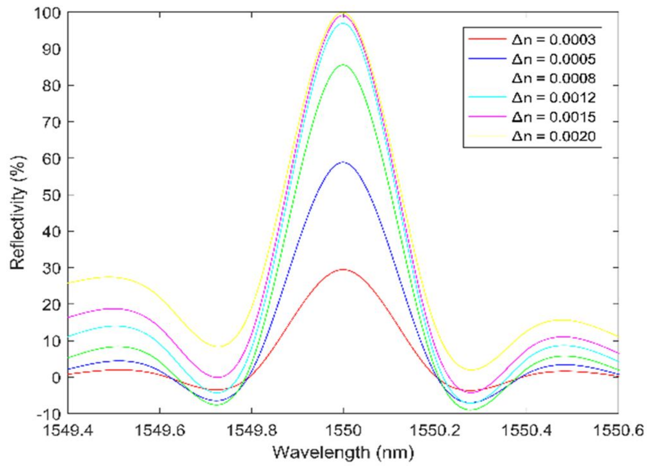

Figure 4. The reflection spectrum of FBG for various reflective index change at the grating length of L = 1 mm

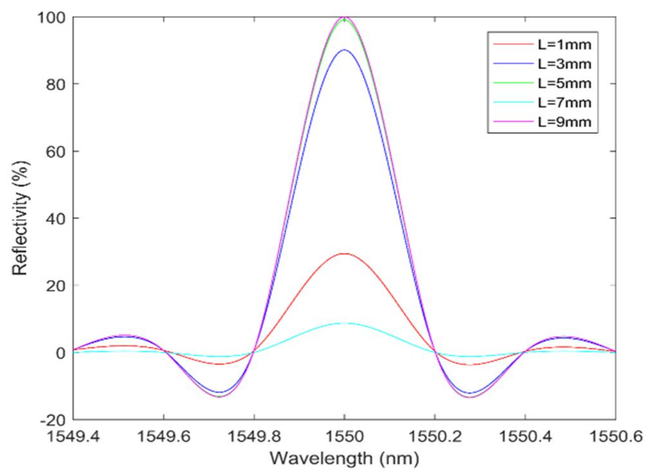

Figure 5. The reflection spectrum of FBG for various grating length at reflective index change of Δn = 0.0003

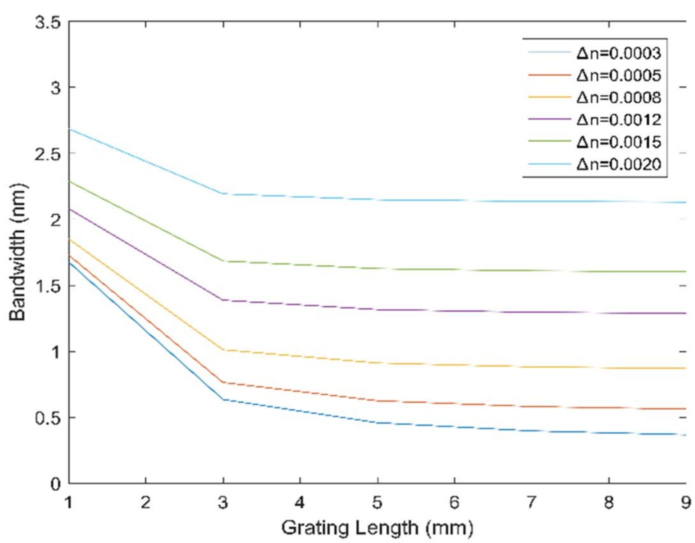

Figure 6. The relationship between FBG bandwidth and grating length for different refractive index

IV. CONCLUSION

The present work has proposed a model system incorporating FBG for in vivo body measurement. The designed model construct was in line with the essential requirement for an optical system. This system can be used to measure heart activity by detecting the aortic pressure which is required for heart assessment. Present work also has shown the success of using MATLAB software to develop coding and simulate the strain of FBG sensing system. The results obtained from the simulation process are very close to other researcher's simulation. By using the simulation, FBG characteristic can be analysed such as strain, spectral reflectivity and bandwidth were analyzed with changes in the grating length and refractive index. From the simulation, the strain is generated when the length of the fiber changes from its original length. When the strain increase, the Bragg wavelength will also increase. Thus, with the increase in grating length, the reflectivity of FBG increases. It became 100 % above 10.0 mm grating length and maintained this value for longer grating length. The reflectivity also increases with the increase of refractive index changes. 100% reflection may be achieved with higher refractive index changes. Also, the FBG sensor bandwidth decreases with increased grating length and increases with increased refractive index changes.

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