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Simulation of Fiber Bragg Grating (FBG) as a Strain Sensor for Rodent Threat Detection

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Abstract: The characterization of Fiber Bragg grating such as strain, Bragg wavelength shift, spectral response and its bandwidth are provided and also discussed by means of its parameter setup namely effective refractive index, Bragg wavelength, grating period and strain-optic constant with varying the grating length and refractive index change. Analyzing and obtaining the data works are referred based on the coupled mode equations. In this paper, FBG spectral responses are simulated through the help of a high -level programming language such as GNU Octave software.
Keywords: Fiber Bragg Grating, Simulation, Strain, Bragg Wavelength Shift, Spectral Reflectivity, Bandwidth

I. INTRODUCTION

Since in the beginning of 1970 , optical fiber sensors (OFS) has already been developed and some optical devices namely optical fibers, photodetectors and laser were used to replace the ancient communication network of saturated copper telephone. As time goes by, the value of these optoelectronic devices become cheaper which makes them more favorable in the use of OFS [1]. Apart of that, fiber optic sensors bring some additional advantages compared to the other sensing technologies for having higher sensitivity [2].

The exploitation in OFS offers great exposure towards replacing traditional sensors in terms of applications for example temperature, vibration, magnetic fields, strain, humidity and also pressure. In addition, OFS is also applicable under rough environments such as high voltage, high temperature and corrosive materials presence [3]. Nowadays, Fiber Bragg grating (FBG) sensors are most commonly used for current studies for their special features like small in size, light and immune towards electronic magnetic devices [4]. The basic principle of FBG sensing is that this sensor is able to have wavelength alternation due to changes in strain or temperature [5].

II. METHODOLOGY

A. Parameter Setup

Table 2.1: Main Parameter of FBG

Parameters	Symbols	Values
Effective Refractive Index	n_{eff}	1.46
Bragg Wavelength	λ_B	1550 nm
Grating Period	Λ	530 nm
Strain-optic Constant	ρ_e	0.22

B. Identification of Formulas

1) *Strain:* From physical perspective, strain is a tensor quality which can be disintegrated to both shear and normal component. Shear component can be described as component that takes account to the cross section of a material, meanwhile normal component is related to the compression or stretch of fibers or elements in a material used. Consecutively, normal strain (tensile strain) reduces as the body length of the element increases; compressive strain [6]. Strain unit is dimensionless and can be expressed as below:

$$\varepsilon = \frac{\ell - L}{L} = \frac{\Delta L}{L} \tag{2.1}$$

where ε is strain, L is the initial length followed by ℓ as the final length and ΔL is the changes of length that occurs.

2) *Bragg Wavelength Shift:* In relation towards the applied strain ε, the Bragg wavelength shift can be derived as follows [7]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - \rho_e) . \varepsilon \quad (2.2)$$

where $\Delta\lambda_B$ is the Bragg wavelength shift, λ_B is the unstrained Bragg wavelength and ρ_e is the elasto-optic coefficient assumed to be at value of 0.22 and the typical strain value is approximated at 1.2 pm/με.

3) *Spectral Reflectivity:* To investigate the spectral reflectivity, R of the proposed model can be expressed as in equation below [8]:

$$R = \frac{sinh^2\left(kL\sqrt{1-\left(\frac{\delta}{k}\right)^2}\right)}{cosh^2\left(kL\sqrt{1-\left(\frac{\delta}{k}\right)^2}\right)-\left(\frac{\delta}{k}\right)^2} \quad (2.3)$$

where L is the grating length, k is coupling coefficient and δ is the detuning factor.

4) *Bandwidth:* In this study, the defined bandwidth of the FBG is given by [9]:

$$\Delta\lambda = \frac{{\lambda_B}^2}{\pi {n_{eff}}^2}\left(k^2L^2 + \pi^2\right)^{\frac{1}{2}} \quad (2.4)$$

where $\Delta\lambda$ is the FBG bandwidth, λ_B is Bragg wavelength, n_{eff} is the effective refractive index, k is coupling coefficient and L is FBG length.

5) *Simulation Tool:* The length of fiber used in this study is L = 40 mm with increment of 0.050 mm. In this study, the $\Delta\, L$ used is in the increment of 0.050 mm ranges from $(0.000\ to\ 0.500)\ mm$. In the simulation, the values of grating length, L studied are (L = 1,3,5,7,9 mm) under the influence of different refractive index ($\Delta n\ = 0.0003, 0.0005, 0.0008, 0.0012, 0.0015, 0.0020$). All the formulas from equation (2.1) to (2.4) have to be inserted into the Octave software for further mathematical operation and related data and graphs will be initiated by Octave with additional implementation of software, SRS1 Spline to fit the curves.

III. RESULTS AND DISCUSSION

Table 3.1: Strain Applied due to Fiber Length Changes

$\Delta\ell$ ($\pm$ 0.05 mm)	Strain (με)	Bragg Wavelength Shift, $\Delta\lambda_B$ ($\pm 0.10nm$)
0.000	0	0.00
0.050	1 250	1.51
0.100	2 500	3.02
0.150	3 750	4.53
0.200	5 000	6.05
0.250	6 250	7.56
0.300	7 500	9.07
0.350	8 750	10.58
0.400	10 000	12.09
0.450	11 250	13.60
0.500	12 500	15.11

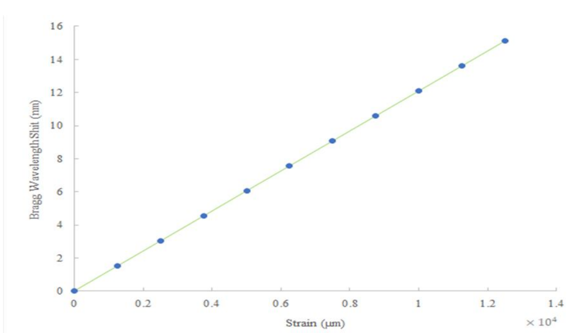

Figure 3.1: Graph of Bragg Wavelength Shift Against the Applied Strain

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Table 3.2: Spectral Reflectivity Dependence of Bragg Wavelength Shift on Grating Length and Refractive Index Changes

Grating Length, L (mm)	Δn = 0.0003	Δn = 0.0005	Δn = 0.0008	Δn = 0.0012	Δn = 0.0015	Δn = 0.0020
	Reflectivity (%)					
1.0	29.46	58.86	85.53	96.96	99.09	99.98
3.0	90.11	99.09	99.98	100.00	100.00	100.00
5.0	99.09	99.98	100.00	100.00	100.00	100.00
7.0	99.92	100.00	100.00	100.00	100.00	100.00
9.0	99.99	100.00	100.00	100.00	100.00	100.00

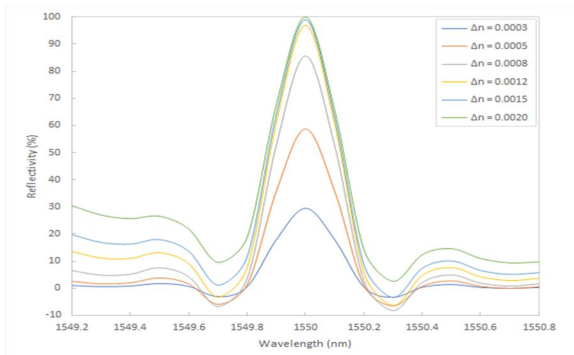

Figure 3.2: The Reflection Spectrum of FBG for Various Refractive Index Change at fixed Grating Length, L = 1 mm

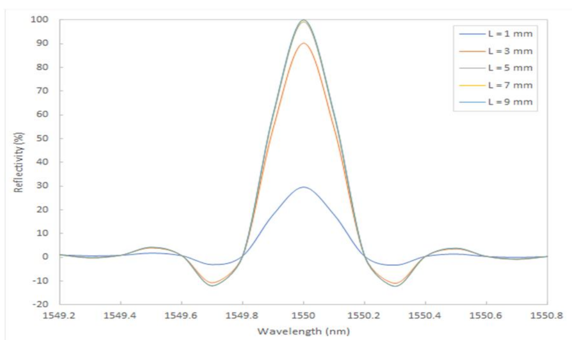

Figure 3.3: The Reflection Spectrum of FBG for Various Grating Length at Fixed Refractive Index Change, Δn = 0.0003

Table 3.3: Bandwidth Dependence on Grating Length and Refractive Index Changes.

Grating Length, L (mm)	Δn = 0.0003	Δn = 0.0005	Δn = 0.0008	Δn = 0.0012	Δn = 0.0015	Δn = 0.0020
	Bandwidth (nm)					
1.0	1.68	1.73	1.85	2.08	2.29	2.69
3.0	0.63	0.76	1.01	1.39	1.68	2.19
5.0	0.46	0.63	0.91	1.32	1.63	2.15
7.0	0.40	0.58	0.88	1.30	1.61	2.14
9.0	0.37	0.56	0.87	1.29	1.60	2.13

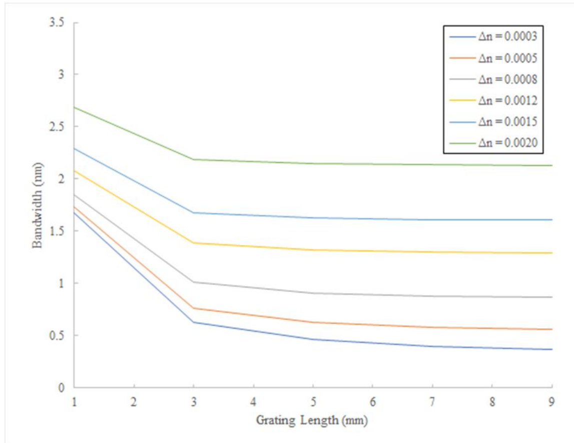

Figure 3.4: Relationship between FBG bandwidth and Grating Length for Different Refractive Index

IV. CONCLUSION

Based on the simulation results, the strain is simulated by means of fiber length changes. When the strain increases, the Bragg wavelength shift increases. Therefore, grating length also increases which causes the FBG reflectivity to increase. The reflectivity of FBG reaches its highest point (full reflection) at grating length of above 9.0 mm. FBG reflectivity also increases as refractive index change increases. 100% of reflection can occur when refractive index change is above $\Delta n = 0.0020$. Furthermore, FBG sensor bandwidth shows decrement with increasing of grating length and refractive index change.

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