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Simulation of Fiber Bragg Grating Characteristics and Behaviors as Strain and Temperature Sensor

Muhammad Arif Bin Jalil
Physics Department, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.

Abstract: ***Optical Fiber Sensor (OFS) has come quite considerable and famous in world of sensor technology where it has been used widely to detect for a changeable environment and responds to some output on other system such as in industrial, chemical analysis and monitoring. A Fiber Bragg Grating (Fiber Bragg Grating) is a kind of appropriated where the short fragment of optical fiber which certain and specific wavelength is reflected with light and the Bragg reflector started developed and transmits all others. The current project is concerned with the development characteristics and behaviors of strain and temperature sensors acting on Fiber Bragg Grating by a computer simulation. This study focuses on analyzing the performance of the characteristics and behavior of strain and temperature sensors acting on Fiber Bragg Grating. A strain sensor is used to measure strain on an object of which the resistance varies range with applied force. Meanwhile,for the temperature sensor is used to measure and detect any abnormality of temperature acting on Fiber Bragg Grating such as can lead into fire and accidents. This will found out on how Fiber Bragg Grating can demonstrate strain and temperature sensors. A simulation of the computer program (MATLAB) will be carried out to simulate due to the strain and temperature sensor of Fiber Bragg Grating.***
Keywords Fiber Bragg Grating, sensors; Strain; Temperature; Simulation; MATLAB

I. INTRODUCTION

A fiber-optic sensor is a sensor that utilizes optical fiber as soon one as the other as the detecting component; intrinsic sensors or as a technique that procedure of signals of extrinsic sensors which relaying from the remote sensor of signals to the electronics. An optical fiber consists of three parts; core, cladding, and coating. The originally made of a dielectric material is the cladding layer with an index of refraction n2. The index of refraction of the cladding material is not as much as that of the core material.[1] Optical fiber sensors that have a very high bandwidth, electromagnetic interference of immunity and a strong capability of functioning under difficult environments of temperature, toxic and pressure.[2] In this field of optical fiber sensing technology, the fiber Bragg grating (Fiber Bragg Grating) sensors as an outstanding merit is one of the most exciting developments with multiplexing capability, and applied widely in various SHM paradigms.[3] An Fiber Bragg Grating has a special character to proceed and has been carried out as a sensor. For instance, when the fiber is compacted, the Fiber Bragg Grating will calculated the strain. This take place of the fact that the optical fiber deformation which leads to an adjustment in the time of the micro-structure. Affectability, of the temperature sensitive is likewise natural for a fiber Bragg grating. The strain sensors where the single-point sensors belong to acting in Fiber Bragg Grating and save the highlights the characteristics of mini size, solidness, peak accuracy and elasto-optic (optical strain) meanwhile in temperature sensor acting in Fiber Bragg Grating where the Bragg wavelength shifted due to the change in refractive index is induced by the thermo-optic coefficient and the thermal-expansion coefficient.[4] For the last couple of years, there are a lot of studies on Fiber Bragg Grating (Fiber Bragg Grating) by a lot of researchers of Fiber Bragg Grating as strain and temperature sensor using simulation. The refractive index and grating period are the significant effects of Fiber Bragg Grating. In this paper, Fiber Bragg Grating is given which focuses around the numerical theoretical demonstrating and simulation of Fiber Bragg Grating by using MATLAB with the help of results in simulation which up to give the effects of Fiber Bragg Grating.

II. RESEARCH METHODOLOGY

A. Simulation of Fiber Bragg Grating

The simulation computer program used for this study are MATLAB Software. The MATLAB estimations of Bragg wavelength move are acquired against applied strain. In MATLAB plot, applied strain and Bragg wavelength has been seen in a fine direct reaction among the shifted of Bragg wavelength through the determined calculation.[5] The temperature is varied for different values in an Fiber Bragg Grating Sensor and its corresponding change in wavelength pattern is studied. The simulation is plotted for Change in Temperature vs. Change in Wavelength. Using MATLAB gives a practical diagram of the advancement of coding code that can be utilized to upgrade and build one's comprehension of optics using representation instruments.

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The integrates, computation, programming and more clear visualization diagram for Fiber Bragg Grating will showed in MATLAB. The declaration in mathematical and theoretical expressions for temperature and strain sensor will be able to performed the data and graphs which can be generated by MATLAB. The simulation of computer program (MATLAB) used for the Fiber Bragg Grating design are for the simulation of Fiber Bragg Grating, the parameters are set for the Fiber Bragg Grating used in this simulation in temperature and strain sensors are to measure Fiber Bragg Grating strain and temperature with Bragg wavelength shift and spectral reflectivity for both refractive index change and grating length. To perform the simulation in MATLAB, there are some operation that can be take a look at such as mathematical operation, data generated operation and graph generated operation. As for this simulation, parameter was set for all equation as variable. The variables used are defined by using the operator.

B. Identification of Formula

Theoretically, the normalized reflection produced by the Fiber Bragg Grating. The reflected wavelength λ_B, called the Bragg wavelength, is explained in this correlation ;

$$\lambda_B = 2ne\wedge \quad (1)$$

For strain sensor acting in Fiber Bragg Grating ;

$$\varepsilon = \frac{1-L}{L} = \frac{\Delta l}{l} \quad (2)$$

The changes of the wavelength in Fiber Bragg Grating due to temperature and strain can be relate by followed equation :

$$\Delta\lambda_B = \lambda_B(1-\rho_e)\varepsilon \quad (3)$$

For temperature sensor, the thermo-optic coefficient and the thermal-expansion coefficient by followed expression :

$$\Delta\lambda_B = \lambda_B(\alpha+\beta)\Delta T \quad (4)$$

Where α is the thermo-optic coefficient of the grating of the fiber and β is the thermal expansion coefficient of the fiber and expressed by this expressions :

$$\alpha = \frac{1}{n_{eff}}\frac{\partial n_{eff}}{\partial T} \quad (5)$$

$$\beta = \frac{1}{\wedge}\frac{\partial \wedge}{\partial T} \quad (6)$$

The amplitude reflectance spectral of the uniform Fiber Bragg Grating is by the following equation:

$$R(L,\lambda) = \frac{k^2 sinh^2(\gamma L)}{\Delta\beta^2 sinh^2 + k^2 cosh^2(\gamma L)} \quad (7)$$

The spectral reflectivity for Fiber Bragg Grating become as followed equation :

$$R(L,\lambda) = \tanh^2(\gamma L) \quad (8)$$

From equation (8), κ is coupling coefficient and β is wave vector detuning where Δβ is wave vector detuning at Bragg wavelength where Δβ = 0. We use 5 different refractive index change where Δn = 0.0003, 0.0005, 0.0008, 0.0012 and 0.0015. For different grating length, we use 5 different grating length which are L = 1mm, 2mm, 3mm, 4mm and 5mm.

C. Parameter Settings

For the simulation of Fiber Bragg Grating, it is important and most crucial things to set the parameter. In this simulation, the default parameters have been used as main parameter of Fiber Bragg Grating. However, it is crucial to set the specification parameter where it shows the sensor effect after sensing any changes due to changes in strain and temperature.

Parameters	Symbols	Standard
Effective Refractive Index	n_{eff}	1.43535
Grating Period	∧	536 nm
Strain-Optic Constant	ρ_e	0.22
Coefficient	k	0.78
Refractive Index Change	F	0.0003
Thermo-Optic coefficient	α	7.18×10^{-6}
Thermal-Expansion coefficient	β	2.5×10^{-6}

Table 1 : Main Parameters Fiber Bragg Grating

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Parameter	Unit	Standard				
Fiber Bragg Grating wavelength range	nm	1548 - 1552				
Fiber Bragg Grating length	nm	1	2	3	4	5
Peak reflectivity	%	30	70	80	90	90
Strain range	με	± 8000				
Strain sensitivity	pm / με	1.15				
Strain resolution	με	0.40				
Temperature range	℃	25 - 250				
Temperature sensitivity	pm / ℃	17.3				
Temperature resolution	℃	0.05				

Table 2 : Specification Parameters Fiber Bragg Grating

III. RESULTS AND DISCUSSION

A. *Simulation Results*

For the simulation of Fiber Bragg Grating for this project is to demonstrate the Fiber Bragg Grating characteristics and behaviors for strain and temperature sensor. The strain and temperature induces, influenced the changes of Bragg wavelength shift. The spectral reflectivity of Fiber Bragg Grating sensors changes under different refractive index change and grating length. The results are presented as below in table for this simulation of Fiber Bragg Grating act as strain and temperature sensors.

1) *Strain:* The strain was measured when there are any change in fiber length from its original length. When the fiber length changes from its original length, it means the fiber detects the strain in the fiber. Therefore the strain increase with the increment of the changes of fiber length. It increased to 272411 με when the change in fiber was $\Delta l = 0.45$.

Change of length, Δl (± 0.05 mm)	Strain, (με)
0.00	0
0.05	2500
0.10	5000
0.15	7500
0.20	1000
0.25	1250
0.30	1500
0.35	1750
0.40	2000
0.45	2250

Table 3 : Strain applied from change of fiber length

2) *Bragg Wavelength Shift:* The graph of Bragg Wavelength Shift with applied strain can be plotted from the table and plotted in MATLAB.

Strain, Ɛ	Bragg wavelength, λ_B (± 0.10nm)	Bragg wavelength shift, $\Delta\lambda_B$ ($\pm 0.00001nm$)
0	1548.60	0
2500	1549.00	3.02055
5000	1549.40	6.04266
7500	1549.80	9.06633
1000	1550.20	12.09156
1250	1550.60	15.11835
1500	1551.00	18.1467
1750	1551.40	21.17661
2000	1551.80	24.20808
2250	1552.20	27.24111

Table 4 : The Bragg wavelength shift with applied strain

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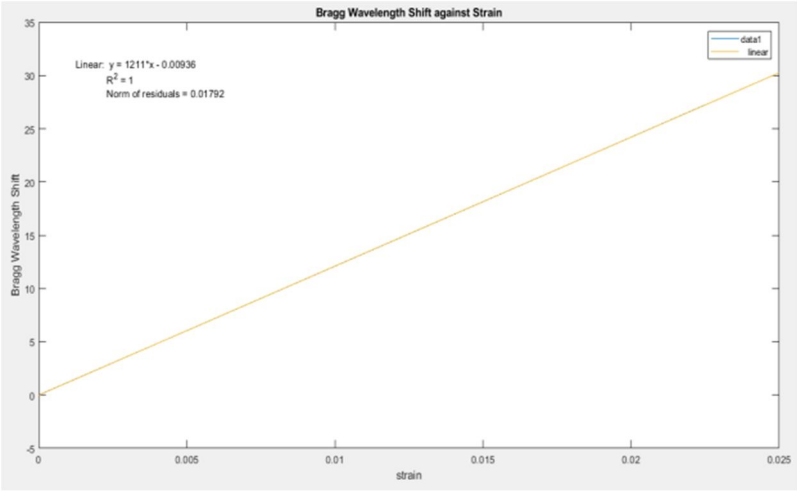

Figure 1 : Graph Brag wavelength shift against strain in MATLAB

B. Temperature

The Bragg wavelength shift was measured when the temperature is increase. The Bragg wavelength shift shows an increment if the changes of temperature increase. The change of temperature increased to 250 ℃ when the Bragg wavelength shift keep increasing to 12.48745. The graph was plotted from the table.

Temperature change, ΔT (±1°C)	Bragg wavelength, λ_B (±0.10nm)	Bragg wavelength shift, $\Delta\lambda_B$ (±0.00001nm)
25	1548.60	1.24584
50	1549.00	2.49234
75	1549.40	3.73947
100	1549.80	4.98725
125	1550.20	6.23567
150	1550.60	7.48474
175	1551.00	8.73445
200	1551.40	9.98481
225	1551.80	11.23580
250	1552.20	12.48745

Table 5 : Change of Temperature with Bragg wavelength shift

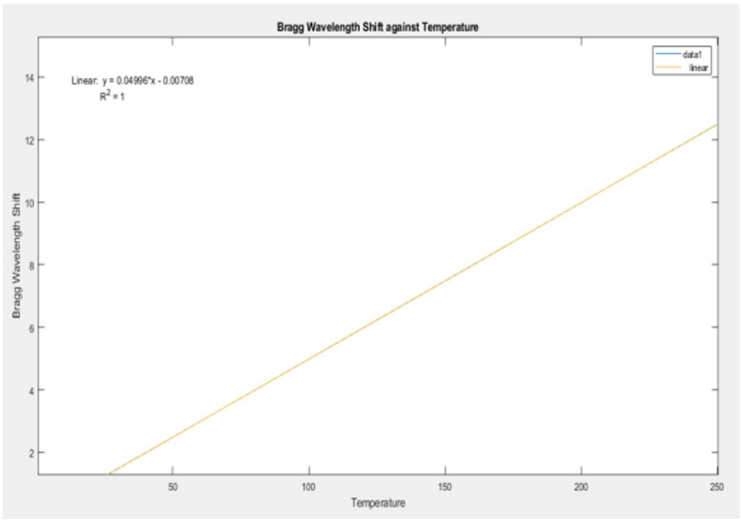

Figure 2 : Graph Temperature against Bragg Wavelength Shift in MATLAB

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C. Spectral Reflectivity

The spectral reflectivity are dependence towards the refractive index change and the grating length.

Grating Length (L), mm	Δn = 0.0003	Δn = 0.0005	Δn = 0.0008	Δn = 0.0012	Δn = 0.0015
	R (%)				
1.0	29.450	58.847	85.527	96.953	99.089
2.0	70.300	93.288	99.2703	100	100
3.0	90.103	99.089	100	100	100
4.0	96.959	100	100	100	100
5.0	99.089	100	100	100	100

Table 6 : Dependence of spectral reflectivity of Bragg wavelength on refractive index changes and grating length

1) *Spectral Reflectivity dependence on various Refractive Index Change:* The graph of spectral reflectivity of Fiber Bragg Grating with 5 different refractive index change, = 0.0003, 0.0005, 0.0008, 0.0012 and 0.0015 are plotted. It has been shown that the reflectivity of Fiber Bragg Grating varies with different refractive index changes. Spectral reflectivity increases with increasing of refractive index changes. It increases to 99.09% with Δn = 0.0015 when the grating length was 1.0 mm.

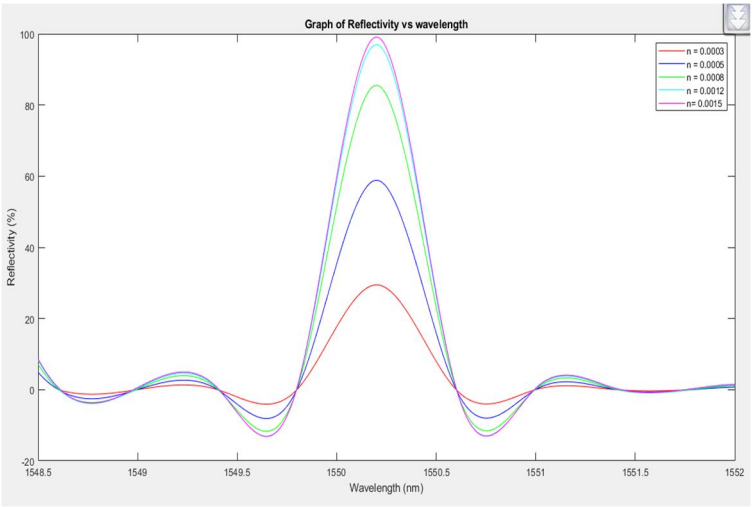

Figure 3 : The reflection spectrum of Fiber Bragg Grating with different refractive index change at grating length, L = 1mm

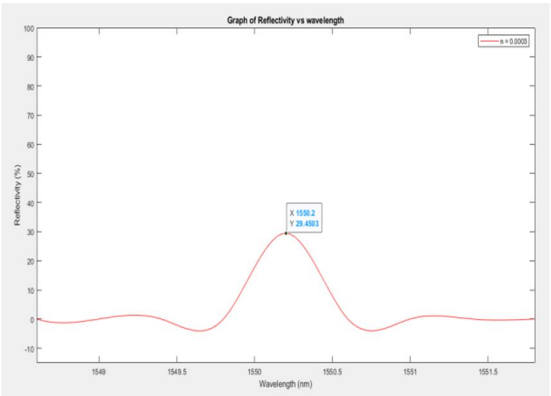

Figure 4 : The reflection spectrum of Fiber Bragg Grating for refractive index change of Δn = 0.0003 at grating length of L = 1mm with peak reflectivity, R = 29.45%

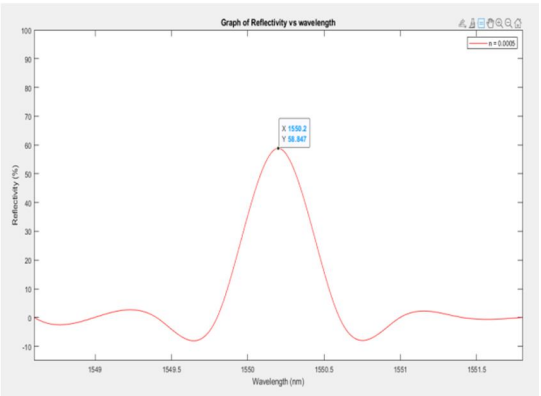

Figure 5 : The reflection spectrum of Fiber Bragg Grating for refractive index change of Δn = 0.0005 at grating length of L = 1mm with peak reflectivity, R = 58.85%

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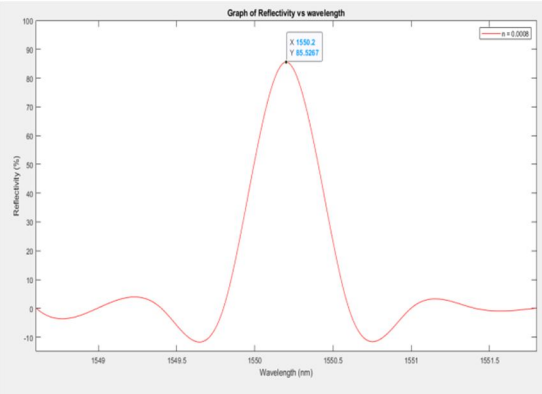

Figure 6 : The reflection spectrum of Fiber Bragg Grating for refractive index change of $\Delta n = 0.0008$ at grating length of L = 1mm with peak reflectivity, R = 85.53%

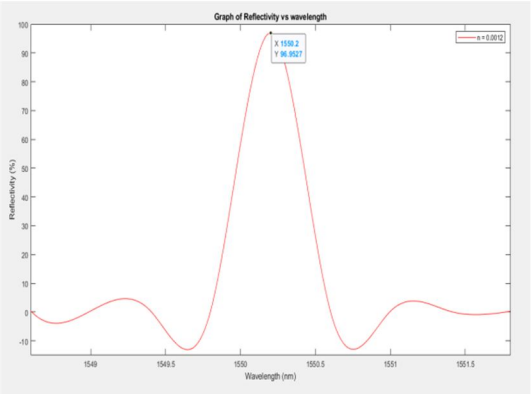

Figure 7 : The reflection spectrum of Fiber Bragg Grating for refractive index change of $\Delta n = 0.0012$ at grating length of L = 1mm with peak reflectivity, R = 96.95%

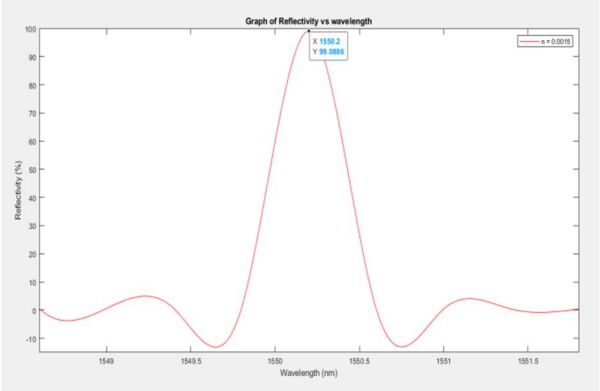

Figure 8 : The reflection spectrum of Fiber Bragg Grating for refractive index change of $\Delta n = 0.0015$ at grating length of L = 1mm with peak reflectivity, R = 99.09%

2) *Spectral Reflectivity dependence on various Grating Length:* Spectral Reflectivity dependence on different grating length, L = 1mm, 2mm, 3mm, 4mm and 5mm graph are plotted. Result shows the spectral reflectivity changes with different grating length which are L = 1mm, 2mm, 3mm, 4mm and 5mm , and the refractive index changes were fixed at $\Delta n = 0.0003$. The reflectivity was observed with the increasing of grating length. When grating length is increasing to 5mm, the spectral reflectivity is increasing to 99.08% when the refractive index changes was set to be constant at $\Delta n = 0.0003$.

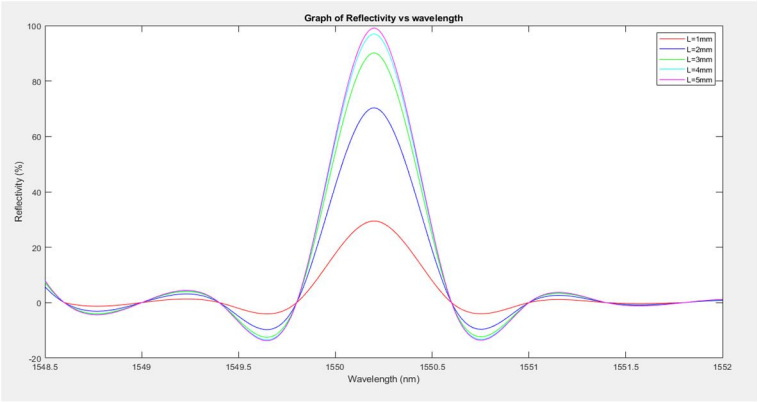

Figure 9 : The reflection spectrum of Fiber Bragg Grating with different grating length at refractive index change of $\Delta n = 0.0003$

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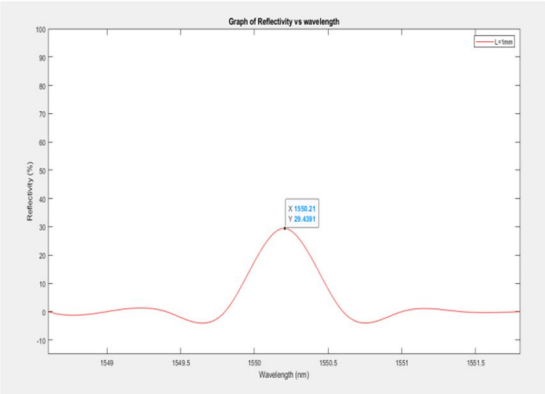

Figure 10 : The reflection spectrum of Fiber Bragg Grating with grating length, L = 1mm at refractive index change of Δn = 0.0003 with peak reflectivity, R = 29.44%

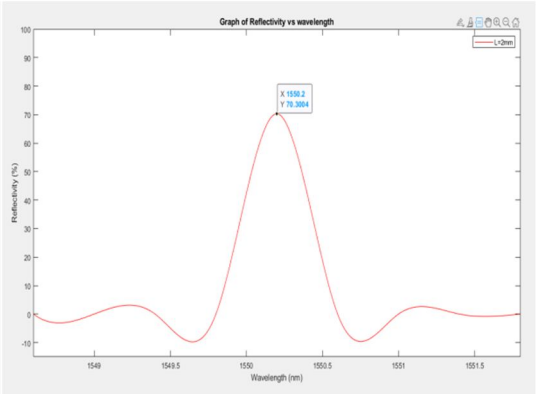

Figure 11 : The reflection spectrum of Fiber Bragg Grating with grating length, L = 2mm at refractive index change of Δn = 0.0003 with peak reflectivity, R = 70.31%

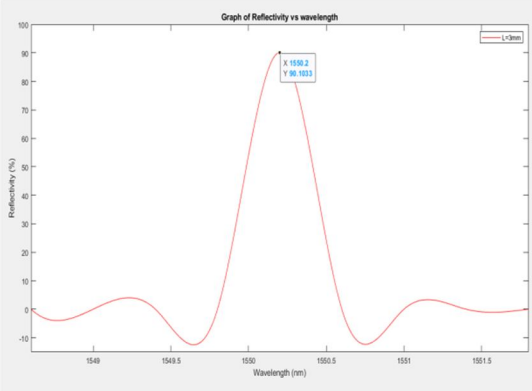

Figure 12 : The reflection spectrum of Fiber Bragg Grating with grating length, L = 3mm at refractive index change of Δn = 0.0003 with peak reflectivity, R = 90.10%

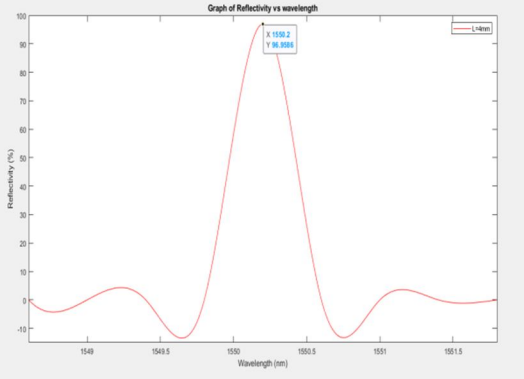

Figure 13 : The reflection spectrum of Fiber Bragg Grating with grating length, L = 4mm at refractive index change of Δn = 0.0003 with peak reflectivity, R = 96.96%

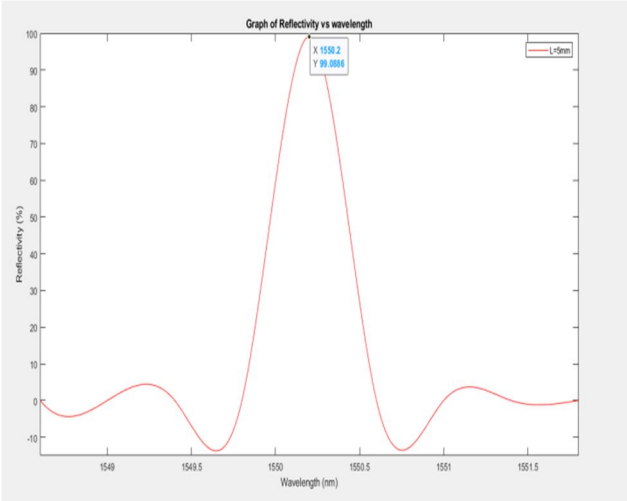

Figure 14 : The reflection spectrum of Fiber Bragg Grating with grating length, L = 5mm at refractive index change of Δn = 0.0003 with peak reflectivity, R = 99.08%

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IV. CONCLUSIONS

In a conclusion, this research is fully achieved all of the proposed objectives. This research proposed simulation of Fiber Bragg Grating characteristics and behaviors as strain and temperature sensor. This simulation can be used to investigate the performance, determine the characteristics and behavior and also to analyze the effectiveness of strain and temperature sensor. Present work for this simulation designed model for Fiber Bragg Grating characteristics and behaviors as strain and temperature sensor which is by using MATLAB were successfully analyzed. MATLAB software has been used for this research simulation to develop coding and simulate the strain and temperature sensor of Fiber Bragg Grating sensing system. Fiber Bragg Grating performance, characteristic and behavior can be analyzed by using this simulation. The strain, temperature and spectral reflectivity for both different refractive index change and grating length are some of the features. These characteristics and behaviors were analyzed in this simulation by the changes in refractive index and grating length.From the simulation, the strain is generated when the length of the fiber changes from its original length. The increment of strain does affected the increment of Bragg wavelength shift in the simulation. As well goes to temperature which get a linear simulation in this research. The Bragg wavelength shift is actually affected the temperature where when the Bragg wavelength shift increase, the temperature is also increase. In addition, with the increasing in refractive index change, the spectral reflectivity of Fiber Bragg Grating are increase. A 100% of reflection may achieved with the higher refractive index change. The spectral reflectivity is also increased with the increment of grating length in the simulation of Fiber Bragg Grating. It became 100% and above for 6.0 mm grating length and also when the value for longer grating length is maintained.

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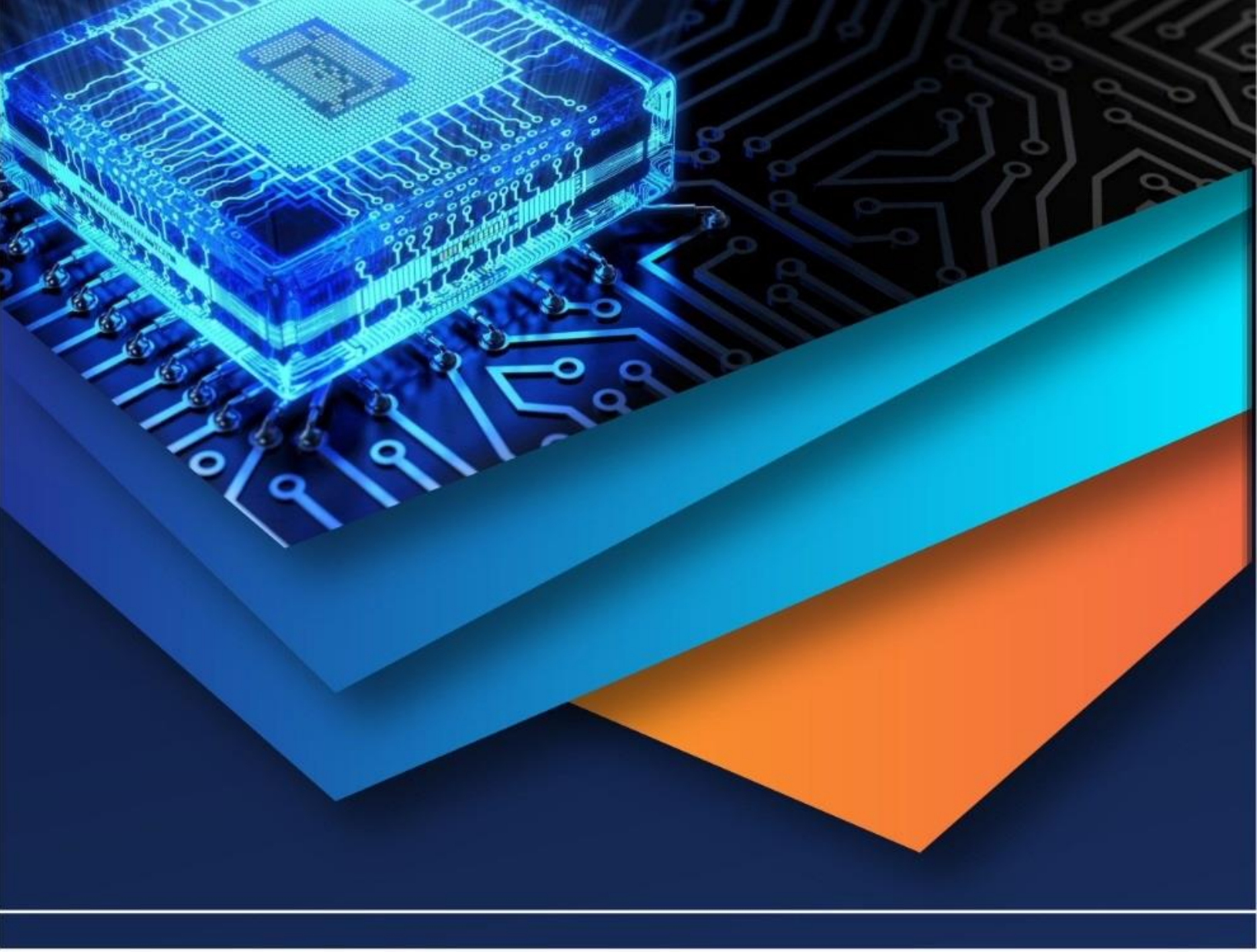

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