Characteristics of High-Temperature Sensor Based on Transmission Spectrum from Fiber Bragg Grating(FBG)

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Abstract-This Paper reports design and experimental analysis of a fiber Bragg grating (FBG) for High-Temperature Sensor. This study uses Bragg wavelength shift effect (λ_B) as a consequence of the effect of temperature changes on the FBG. Data acquisition of Bragg wavelength shift (λ_B) uses Optical spectrum of analyzer (OSA) with a light source from the Internal Wavelength Calibrator. The Temperature performance of fiber Bragg grating (FBG) sensors were studied in temperature range of 30-120^{o}C. Characteristics of FBG was derived analytically and verified by experiments. The Hysteresis, repeatability and linearity was measured in this experiment. The wavelength shift was linear with temperature increase. The result of experiment of sensor to achieve linearity of 99.33%, sensitivity of 10.73 ± 0.21 pm/^{o}C, and good repeatability.

Keywords: Fiber Bragg Grating (FBG), Bragg wavelength(λ_B), Internal Wavelength Calibrator, Optical Spectrum Analyzer(OSA)

1. INTRODUCTION

Optical fiber technology in its utilization as waveguides has grown rapidly, especially in the field of telecommunications. Aside from these applications, the development of optical fiber technology has also been developed in the application as sensors [1]. Has been a lot of research related to the application. One application of optical fiber as the sensor is a temperature sensor. However, it is limited only to the measurement at low temperatures [2]. For that, we need a more precise application for the use of optical fiber as the sensor at high temperatures. Sensor with high temperature specifications is required for several purposes such as health monitoring and process materials, transformation of electrical and mining exploration applications [3]

Fiber Bragg Grating (FBG) is an optical sensor that works based on the resonant effect of a grating refractive index, which is determined by the wavelength resonance lattice spacing. FBG can be used as a temperature sensor and a strain sensor. From these principles, then when the lattice spacing change due to changes in the temperature of the peak wavelength, resonance will also change. Changes in the resonant peak are measured to determine the temperature. Fiber Bragg Grating (FBG) sensors have many advantages, they are free from the influence of electromagnetic interference, high stability, and easy to apply [4] [5]

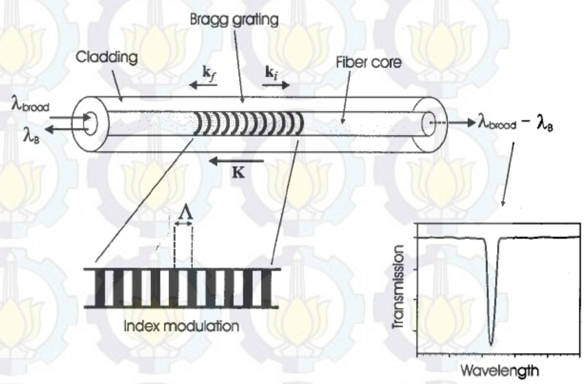

Figure 1. Principle of fiber Bragg grating

In principle, the Bragg grating, light as a particle that has momentum and energy because in principle on Bragg grating light as the collision there was an interaction between photons. In the process of collision, the law of conservation of energy and momentum must be fulfilled. The law of conservation of energy requires that the frequency of the incident radiation and reflected radiation has to be in same value ($\hbar\omega_f = \hbar\omega_i$)[6].

The law of conservation of momentum requires that the incident wave vector (Wave Vector is coming) ki, added to Wave vector lattice K, together with scattered Wave vector [7], it can simply be defined as follows:

$$\hbar \boldsymbol{k}_i + \hbar \boldsymbol{K} = \hbar \boldsymbol{k}_f \quad (1)$$

$$\boldsymbol{k}_i + \boldsymbol{K} = \boldsymbol{k}_f$$

$$\frac{2\pi n_{eff}}{\lambda_B} + \frac{2\pi}{\Lambda} = -\frac{2\pi n_{eff}}{\lambda_B} \quad (2)$$

$$\lambda_B = 2n_{eff}\Lambda \quad (3)$$

Where λ_B is Bragg grating wavelength which is the wavelength of the input that will be reflected back by Bragg grating, and Neff is the effective refractive index and Λ is the distance between the lattice planes [6][8].

There are two parameters that affect the Bragg wavelength shift due to temperature change, that are the change in grating period due to thermal expansion of the fiber and the refractive index. Thus, wavelength shift for temperature change ΔT can be written as follows:

$$\frac{d\lambda_B}{dT} = 2\frac{dn_{eff}\Lambda}{dT} \quad (4)$$

$$\frac{d\lambda_B}{dT} = 2\Lambda\frac{\delta n_{eff}}{\delta T} + 2n_{eff}\frac{\delta\Lambda}{\delta T} \quad (5)$$

$$\Delta\lambda_B = \lambda_B\left(\frac{1}{n_{eff}}\frac{\delta n_{eff}}{\delta T} + \frac{1}{\Lambda}\frac{\delta\Lambda}{\delta T}\right)\Delta T \quad (6)$$

$$\Delta\lambda_B = \lambda_B(\alpha_n + \alpha_\Lambda)\Delta T \quad (7)$$

Where α_Λ is *thermal expansion coefficient* of fiber and α_n is *thermo-optic coefficient*[9]

$$\frac{1}{n_{eff}}\frac{\delta n_{eff}}{\delta T} = \alpha_n \quad (8)$$

$$\frac{1}{\Lambda}\frac{\delta\Lambda}{\delta T} = \alpha_\Lambda \quad (9)$$

This article describes in detail Characteristics of Fiber Bragg Grating (FBG) measurement methodology, the results of experiments and the analysis of the basic characteristics of FBG-based temperature sensor.

2. EXPERIMENTAL DETAILS

In this study, using Fiber Bragg Grating (FBG) with a length of 10 mm with the Centre Wave length (CW) 1550 +/- 0.5 NM. FBG is used with Single Mode type Fiber (SMF28-C polyamide fiber) that was recoated with Polyimide.

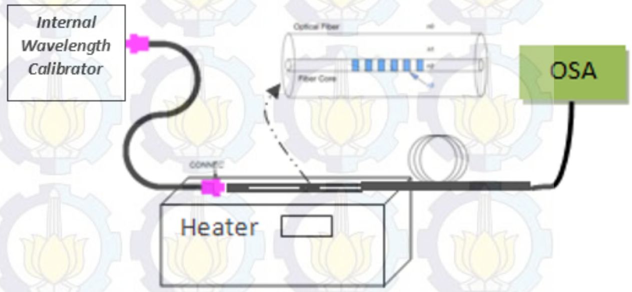

Figure 2 Schematic experimental setup

This study was designed to put the FBG on a heater. This is done to know the effect of temperature on the performance of FBG. This is also done to determine the measurement range and endurance of FBG fiber to the influence of temperature.

The tests are to determine the effect of temperature on the FBG. FBG section with a length of 10 mm is clamped with metal materials to ensure that only the Bragg section being in contact with the heater. Light source that used is the Internal Wavelength Calibrator as input and will be displayed on the optical spectrum analyzer (OSA Agillent type 86142B) in the form of Bragg wavelength shift. The data acquisition Bragg wavelength shift through observation of the transmission spectrum FBG. Temperature calibration was processed by using thermocouple Type K. Analysis of the characteristics of FBG due to the influence of temperature consists of linearity, Hysteresis and Repeatability of FBG.

3. RESULT AND DISCUSSION

In this study, FBG used has a wavelength center Bragg (λB) at 1550 NM. FBG is used has a length of 10 mm and a grating made of polyimide so that they can be bent without suffering structural damage.

Bragg wavelength shift (λB) was tested by measuring the temperature of 30oC-120oC range. Heating process using a hot plate specially designed for this study. Bragg wavelength values are at the highest attenuation in the transmission spectrum of the FBG.

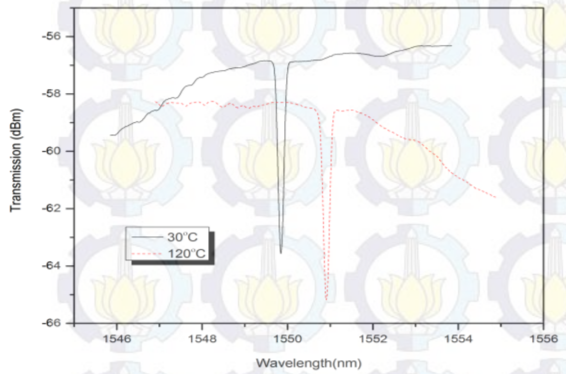

Figure 3. Spectral response of the proposed FBG temperature sensor

Graph transmission spectra can be monitored in OSA shown in Fig. 3. Figure 3 shows that when the FBG undergo a process of heating it will cause a shift in wavelength Bragg. Bragg wavelength shift of FBG caused by two parameters that characterize the effect of temperature on the optical fiber, they are the thermal expansion coefficient (α_Λ) and thermo-optical coefficient (α_n). The thermal expansion coefficient characterizes the physical expansion or contraction the volume of material, while the thermo-optic coefficient characterizes the refractive index changes in response to temperature changes.

Tasting characteristics of the FBG sensor with a linearity test. Tests to determine the response of FBG Bragg wavelength shift due to the influence of temperature. The experiment set up is shown in Fig. 2, hot plate temperature was set in the range of 30≤T≤120oC. The transmission spectrum of the FBG was observed in OSA. The data acquisition Bragg wavelength shift at every 5 ° C rise. Linearity test results were shown in Fig. 4.

Based on the obtained curve in Fig. 4 is a linear equation λB = 0.01T + 1549.6. The sensitivity of the FBG obtained by differentiating equation is linear with

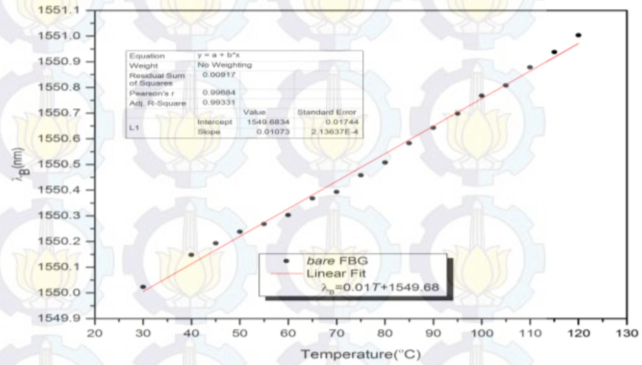

Figure 4. Temperature response of FBG at temperature 30-120°C

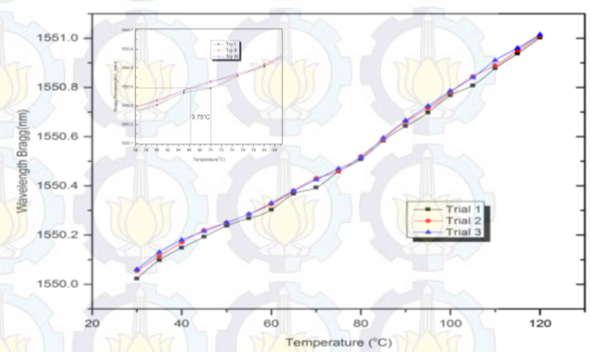

Figure 5. Repeatability response of FBG

temperature line. Then obtained a sensitivity of FBG at10.73 ± 0.21 pm / OC, the linearity of 99.33%. Linearity test results showed that FBG has high accuracy.

Repeatability of FBG was tested by measuring the effect of the repetition of the temperature rise of the wavelength shift Bragg. Temperature measurement is repeated three times. The measurement range for test repeatability is at a temperature of 30-120 °C. Repeatability measurement results can be seen in Fig. 5.

The maximum repeatability error is 3.75arc that was represented on the inner graph. These results are reinforced by analysis of standard deviation calculations to determine the deviation of data from average data obtained. The results of the analysis showed that there are 3 data with a standard deviation 0.2 at a temperature of 30° C, 70° C and 105°C. However repeatability test results showed that FBG has good repeatability. Good Repeatability represents a sensor with high precision.

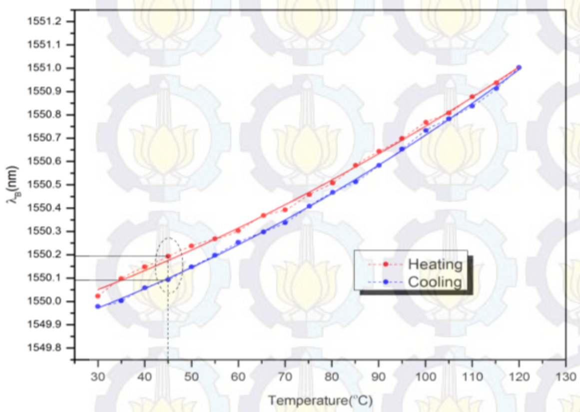

Figure 4. Measured Bragg wavelength during both heating and cooling

Analysis of the response characteristics of the FBG is Bragg wavelength due to the temperature increase and decrease the temperature. The test results are shown in Fig. 6.

The graph in Fig. 6 showed the largest hysteresis value at temperature of 45oC with hysteresis error reaches 0.1 mm. However, the graph indicates high stability of FBG at the time of the increase and decrease in temperature. Good response to the temperature shift of FBG indicated by the absence of the effect of temperature anomalies. These results indicate that the FBG has reliable performance on the temperature change.

4. CONCLUSION

Fiber Bragg Grating (FBG) is able to detect changes in temperature through the shift Bragg Wavelength (λB). By using a simple measurement system has been able to observe that monitored by the transmission spectrum in Optical Spectrum Analyzer (OSA). FBG had a sensitivity of 10.73 pm/°C with linearity, accuracy, stability and good repeatability. FBG of Polyimide material has a high potential for sensor applications at elevated temperatures.

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