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SENSITIVITY MEASUREMENT OF FIBRE BRAGG GRATING SENSOR

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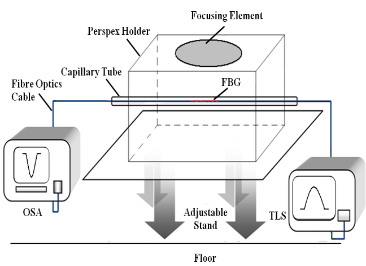
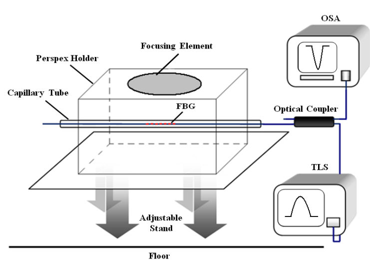
Graphical abstract





Abstract

A practical pass-through type fibre Bragg grating (FBG) temperature sensor system have been designed, developed, simulated, and experimentally investigated. The performance of FBG was evaluated in harsh environments exposed under direct sunlight, rain, and wind. The sensor system designed directly focused with convex and hand lens. The temperature of FBG's sensor head been measured. The broadband laser source was launched into the system using tunable laser source (TLS) and both transmission and reflection spectra of FBG sensor were measured by optical spectrum analyzer (OSA). Results shows that the Bragg wavelength shift, $\Delta\lambda_B$ increased proportionally with the temperature changes. The sensitivity of FBG were recorded at 0.0100 and 0.0132 nm °C^{-1} for the systems where convex and hand lens applied to the FBG's sensor head respectively, while the sensitivity of 0.0118 nm °C^{-1} measured for the system without any focusing element applied.

Keywords: Fibre Bragg grating, Temperature sensor, Bragg wavelength, Sensitivity measurement

Abstrak

Satu sistem pengesan suhu gentian parutan Bragg (FBG) telah direka dan diujikaji. Prestasi FBG dinilai dengan memberi tumpuan kepada unsur-unsur alam persekitaran di pancaran bawah cahaya matahari secara terbuka. Ketua sensor FBG telah direka untuk memberi tumpuan dengan cembung dan kanta tangan. Keputusan menunjukkan bahawa perubahan panjang gelombang Bragg, $\Delta\lambda_B$ meningkat berkadaran dengan suhu. Kepekaan FBG dicatatkan sebagai 0.0100 dan 0.0118 nm °C^{-1} untuk sistem di mana kanta cembung dan kanta tangan digunakan.

Kata kunci: Gentian parutan Bragg, Pengesan suhu, Panjang gelombang Bragg, Pengukuran kepekaan

1.0 INTRODUCTION

Fibre optic sensors (FOSs) emerged as modern device in sensing and communication technologies. The FBG technology in temperature sensing have progress rapidly. Due to its unique advantages, FBG become the best fibre optic temperature sensor device as compared with other temperature sensors [1]. FBG technology was first developed by Hill and his group in 1978 [2] based on the principle of Bragg reflection. It can be used in measuring the temperature and strain accurately in variety of environments [3] includes harsh environment, underground, and disaster places.

Practically, Bragg wavelength changed correspond with the changes in strain and/or temperature of the gratings. As light propagates in fibre core, the parameter characteristics of light wave including amplitude, phase, and polarization will changed with external field changes [4]. As for FBG, the reflected light affect by the small changes of wavelength, strain, and temperature applied onto the gratings. In this paper, the performance of FBG was tested in harsh environment, where the sensor head of FBG exposed into the sunlight was measured directly and with existing of convex and hand lens as the focusing elements. In the presence of the lens, it is measured the reaction of FBG's sensor head where the temperature addressed directly towards it.

2.0 THEORY

Optical waves from broadband laser source are partially reflected from one end grating when it pass through FBG. Certain directions might observed where wavelets created at each plane are in phase. Resonant condition is satisfied if these directions corresponds to a mode of the fibre. However, the optical waves that partially reflected constructively interfere with each other only for a specific wavelength called Bragg wavelength [5]. Hence, for a broadband source, only a narrow spectrum at the Bragg wavelength is reflected and the rest will be transmitted.

The Bragg wavelength, λ_B of an FBG is given by the equation:

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

where λ_B is the Bragg wavelength, n_{eff} is the effective refractive index, and Λ is the grating period of the fibre core. This equation forms the basis equation for any wavelength-modulated FBG sensors.

Assuming an isothermal condition, the Bragg wavelength change, $\Delta\lambda_B$ upon strain, temperature, and wavelength change [6] can be expressed as:

$$\Delta\lambda_B = 2\left(\Lambda\frac{\delta n_{eff}}{\delta L} + n_{eff}\frac{\delta\Lambda}{\delta L}\right)\Delta L + 2\left(\Lambda\frac{\delta n_{eff}}{\delta T} + n_{eff}\frac{\delta\Lambda}{\delta T}\right)\Delta T + 2\left(\Lambda\frac{\delta n_{eff}}{\delta\lambda} + n_{eff}\frac{\delta\Lambda}{\delta\lambda}\right)\Delta\lambda \qquad (2)$$

where ΔL is the change in strain, ΔT is the change in temperature, and $\Delta\lambda$ is the change in wavelength.

In reality, the variation of refractive index due to the changes in wavelength is negligible [7]. In addition, the periodic spacing of the index modulations in fibre is unaffected by the wavelength change. Thus, by neglecting the wavelength effects, Equation (2) can be rewritten as:

$$\Delta\lambda_B = 2\left(\Lambda\frac{\delta n_{eff}}{\delta L} + n_{eff}\frac{\delta\Lambda}{\delta L}\right)\Delta L + 2\left(\Lambda\frac{\delta n_{eff}}{\delta T} + n_{eff}\frac{\delta\Lambda}{\delta T}\right)\Delta T \qquad (3)$$

The change in physical spacing between successive index modulations will caused a shift in Bragg wavelength. The strain-optic effect will induced a change in refractive index, causing shift in Bragg wavelength [8]. From Equation (3), the changed in center wavelength of the Bragg grating for a given changes in strain is given as:

$$\Delta\lambda_B = \lambda_B(1 - p_e)\varepsilon_z \qquad (4)$$

where $\Delta\lambda_B$ is the Bragg wavelength change, ε_z is the strain applied and $p_e = 0.213$ for germanosilicate optical fibre.

Thermal expansion (or contraction) changed the grating period affect the optical response of FBG [9]. The Bragg wavelength, λ_B and the effective refractive index, n_{eff} of fibre are temperature dependent (thermo-optic effect).

The changed in Bragg wavelength for a given changes in temperature is given as:

$$\Delta\lambda_B = \lambda_B(\varepsilon + \alpha)\Delta T \qquad (5)$$

where $\Delta\lambda_B$ is the Bragg wavelength change, λ_B is the Bragg wavelength, ε is the thermo-optic coefficient, α is the thermal-expansion coefficient, and ΔT is the temperature change (in °C). For germanium-doped silica fibre, the values of p_e, ε, and α are 0.213, 8.60 x 10^{-6} °C^{-1}, and 0.55 x 10^{-6} °C^{-1} respectively [10].

3.0 EXPERIMENTAL SET-UP

An optical FBG sensor was used in this research. The FBG was connected with TLS and OSA through a single-mode optical fibre optic cable. Broadband light from TLS launched into the fibre core and transmitted through the FBG. As the broadband light propagates through it, the light source with the wavelength matched to the Bragg condition will be reflected, while the rest will be transmitted through the fibre. These induced a significant power dip at the Bragg wavelength. Figures 1 and 2 shows the schematic diagram of the experimental set-up for measuring the transmission and reflection spectra of the FBG respectively.

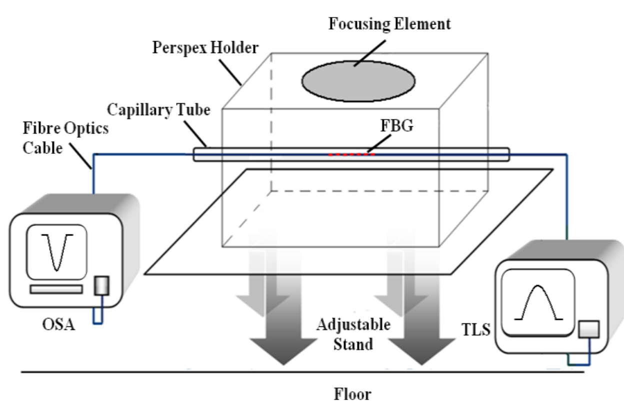


Figure 1 Schematic diagram of experimental set-up for transmission spectrum measurement

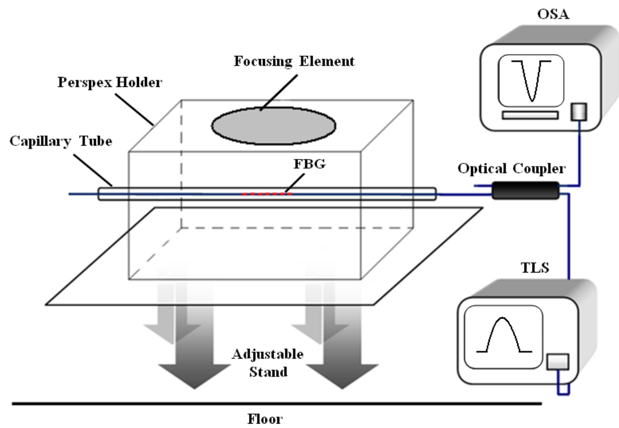


Figure 2 Schematic diagram of experimental set-up for reflection spectrum measurement

4.0 RESULTS AND DISCUSSION

The experimental set-up for measuring the sensitivity of FBG in temperature responds were prepared in an open area. Broadband laser were launched into the fibre core and both transmission and reflection spectra of FBG were measured through the OSA. Figures 3 and 4 shows the transmission and reflection spectra of the FBG at room temperature.

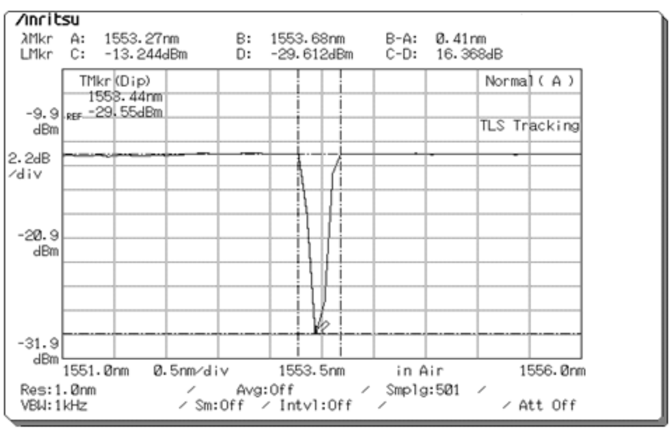


Figure 3 Transmission spectrum of FBG at room temperature

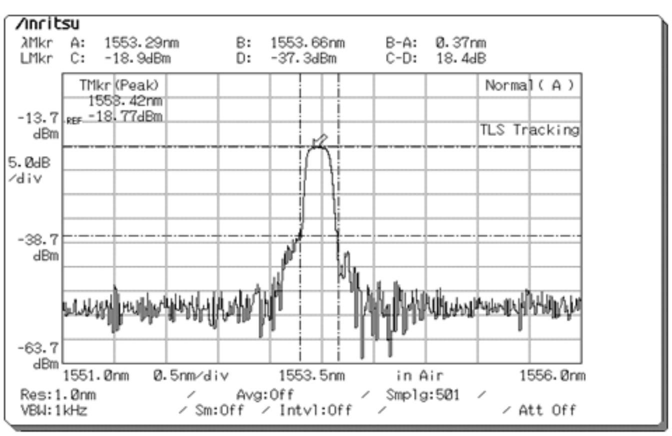


Figure 4 Reflection spectrum of FBG at room temperature

The changes of Bragg wavelength with external temperature were observed for both transmission and reflection spectra. This is due to the perturbations of the gratings resulting a shift in the Bragg wavelength for both transmitted and reflected spectra. As the outdoor temperature change to environmental conditions, thermal expansion in the grating occurred. Due to the thermal expansion, the effective refractive index, n_{eff} of the FBG changed. This caused the variation in FBG wavelengths. The variation in $\Delta\lambda_B$ monitored based on transmission or reflection spectra from the OSA.

Mathematical modeling of FBG profile is important enough as the comparison with experimental measurements. The simulation of FBG profiles with temperature change was done using MatLab 2015a software. Figure 5 shows the simulation profile of FBG sensor system calculated based on 1550 nm germanium-doped fibre FBG. Based on the simulated graph plotted, the shift in Bragg wavelength increased with the increases of temperature from 24 to 42 °C. The graph shown that the highest increment of Bragg wavelength shift was measured to be 2.6848 nm at 41.923 °C.

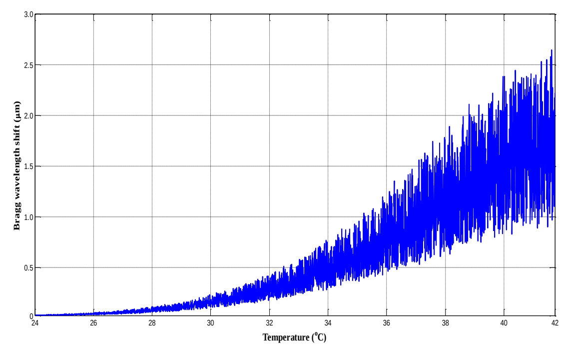


Figure 5 Simulation profile of FBG sensor system

The application in reflection method offers advantages over the transmission method. Only the light matched with the Bragg condition of the grating is measured over relatively small background intensity in reflection spectrum. Figure 6 shows the comparison of Bragg wavelength shift, $\Delta\lambda_B$ against outdoor temperature for the reflection spectra and theoretical analysis. Results show the linearity of the FBG sensing system. There is a good correlation between temperature changes and Bragg wavelength shift obtained from the experiments done. A linear response observed between the temperature change and Bragg wavelength shift throughout the measured region.

The sensitivity of FBG then measured with the present of focusing elements (convex and hand lens). Figure 7 shows the graph of Bragg wavelength shift against temperature for the FBG sensor head focused with convex lens, hand lens, and without focusing element. The slope of graph determined the sensitivity of FBG sensor. The sensitivity of FBG focused with convex lens, hand lens, and without focusing element measured as 0.0100, 0.0132, and 0.0118 nm °C^{-1} respectively. It can be seen that there is a good agreement between the experimental results, the theoretical calculation, and the typical temperature sensitivity [11].

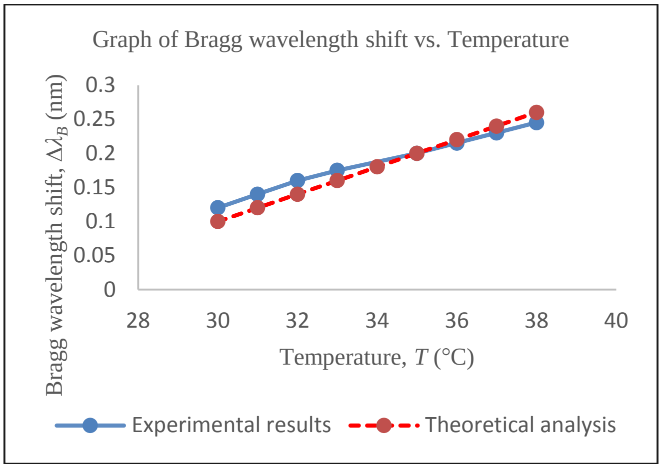


Figure 6 Comparison of experimental results and theoretical analysis

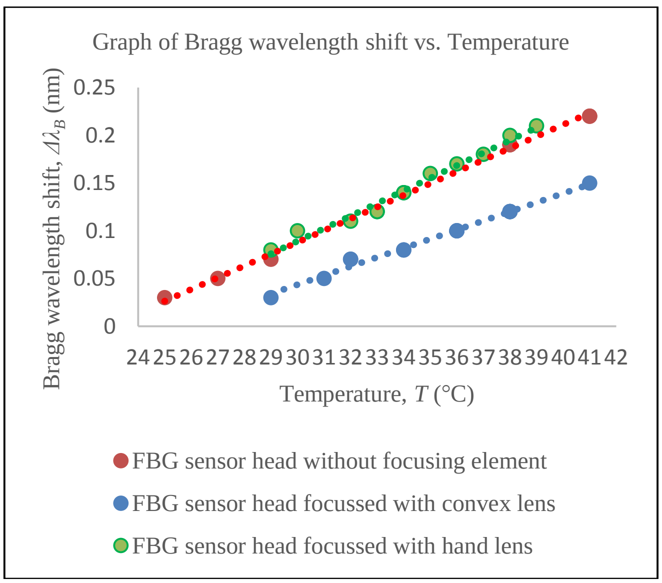


Figure 7 Sensitivity measurements of FBG in different focusing elements

5.0 CONCLUSION

The sensitivity of FBG for the temperature sensor system has been designed, developed, and its performance has been tested. An excellent linear response observed between the temperature changes and the Bragg wavelength shift, $\Delta\lambda_B$ throughout the outdoor temperature from 24 to 42 °C. With the capability of the linear response, the FBG sensor can be used for outdoor temperature sensing.

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