Graphene-oxide Coated on Fiber Bragg Grating for Temperature Sensor

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***Abstract*— The rapid development and deployment of optical sensors have brought fibre Bragg grating (FBG) as a renowned optical sensor which acquired high sensitivity, fast response to the measurement changes and small in size. However, the implementation of bare FBG sensor could be further enhanced to give significant impact in terms of sensitivity without any alteration on the effective refractive index and the grating period. Therefore, a low cost and high temperature sensitivity of fiber Bragg grating (FBG) sensor coated with graphene oxide (GO) is designed and constructed. The FBG is synthesized with GO by implementing dip coating technique. Then, the bare and coated FBG sensor is tested by applying heat at the grating region of the FBG. The output of the experiment is displayed on the optical spectrum analyzer (OSA) in terms of power (dBm) and wavelength (nm). The performances of the FBG sensors have been evaluated by comparing the temperature sensitivity. The GO-coated FBG recorded better temperature sensitivity of 16.0 pm/°C compared to the bare FBG with sensitivity of 15.0 pm/°C. The results indicate the ability of graphene oxide to improve the Bragg wavelength shift by the combined effect of effective refractive index and grating period that are influenced by the changes of temperature. GO-coated FBG also exhibits better linear fit of 99.1%, which specifies the consistency of the wavelength shift reading as temperature increased and low limit of detection (LOD) compared to the bare FBG as the minimum value of LOD signifies the effectiveness of the sensor.**

Keywords*— *Fiber Bragg Grating (FBG), Temperature Sensor, Graphene Oxide, Dip coating, Temperature Sensitivity

I. Introduction

In the past few years, owing to the various advantages of fiber Bragg grating (FBG) in a wide range of applications, FBG attracted great attention over other conventional fibre optics. The advantages are the immunity to electromagnetic interference, resistant to harsh environments and also small in size. These benefits have led to the rapid development and deployment of FBG especially in the measuring and monitoring devices for structural health monitoring (SHM), medical and industrial application. FBG sensors have been successfully employed to monitor parameters such as strain, temperature, displacement, pressure, electric current and voltage.

Fiber Bragg grating (FBG) is a periodic modulation of the refractive index of the optical fiber core area. When light is launched from the input side, the FBG has the ability to reflect certain wavelengths of the light that fulfill the Bragg condition and transmit the remaining light without any loss [1]. Bragg wavelength has a narrow spectrum output that reflected from the FBG sensor and the Bragg wavelength, λ_B can be written as:

$$\lambda_B = 2\mathrm{n_{eff}}\Lambda \tag{1}$$

where n_{eff} is an effective refractive index of core in the fiber and Λ is the grating period. Several changes either in effective refractive index or grating period will automatically affect the reflected Bragg wavelength as it is responsive to physical changes. Thus, it is a good principle for applying temperature sensor. The wavelength shift $\Delta\lambda_B$ for an applied temperature is given by:

$$\Delta\lambda_B = (\alpha + \xi)\lambda_B\Delta T \tag{2}$$

Recently, there are many industrial applications that utilized FBG as the temperature sensor such as oil/gas down-hole measurement, online temperature monitoring of oil immersed transformer, aerospace application and for early detection in natural disasters [2–5]. However, the bare FBG sensor suffers low temperature sensitivity due to the low thermal expansion coefficient of silica at various and non-uniform temperatures. The alteration of the cladding part due to the temperature will degrade the performance of the FBG sensor. Therefore, few techniques have been investigated to enhance the temperature sensitivity such as embedding the FBG in a metal support and coating the FBG with different type of metal or metal oxide compounds [6]. The work by [7]

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has reported on the fabrication of temperature sensor using a silica microfiber Bragg grating sensor with a zinc oxide (ZnO) nanorods. Somehow, the procedure is quite complicated since the synthesis process of ZnO nanorods involving two methods which are seeding and growth. Other than that, the impact of chromium nitride (CrN) coated FBG for the temperature sensing applications has been highlighted in the paper by Hsiao et al [8]. This paper focuses on measuring very high temperature of up to 650°C. The work by [6] emphasized the use of the graphene oxide (GO) as the coating material. The graphene oxide has property of large specific surface area that making the GO more sensitive towards the temperature variation. The reduction of the GO film is then conducted using hyrazine treatment for 12 hours at 100 °C. Nevertheless, the reduction procedure is quite complicated and difficult to carry out.

Next, the technique used to synthesize the GO solution also have been compared by investigating few works [9–11] and it is found that the work by Ridebi et al. [11] have performed an easy and simple dip coating technique. The method has been conducted by dipping the fiber in the 200 µL GO aqueous solution at a constant speed. Then, the fiber will be fully dipped in order to let the solution infuse and coat the fiber. Finally, the withdrawal process of the fiber from the coating solution needs to be done quickly to get a thicker coating on the fiber.

The main focus of this project is to construct a temperature sensor using FBG. The FBG is coated with graphene oxide (GO) to increase the sensitivity of the sensor towards temperature variations. The dip coating technique is used to coat the GO solution onto the grating area of the FBG sensor. The temperature sensing experiment is done by heating the FBG using the hot plate that is controlled by multimeter. The wavelength shift in the output spectrum was observed after analyzing the output from optical spectrum analyzer (OSA). Then, the performance of the FBG sensor will be evaluated by comparing the temperature sensitivity of the bare FBG and GO-coated FBG. The difference in sensitivity of the sensor when various temperatures were applied to it, has proved that the FBG can be used as a sensing device.

II. Experiment

A. Synthesization of Graphene Oxide

Two samples of FBG are used in this experiment which consists of bare FBG and also graphene oxide (GO) coated FBG. The synthesization process started with graphene oxide is weighed to 2.5 mg using analytical balance and the amount needed for deionized water is 10 mL. The amount for both solutions are calculated in order to obtain an aqueous solution with concentration of 250 µg/mL [11]. The graphene oxide powder is poured into a beaker containing 10 mL of deionized water. Then, the mixture is transferred into a 15 mL centrifuge tube before placing it in the ultrasonic homogenizer sonicator. Direct sonication method was used by inserting the probe directly into a sample vessel. The tube needs to be kept on wet ice in order to avoid any degradation of the sample through sonication process. This process was set for 15 minutes with amplitude of 55.

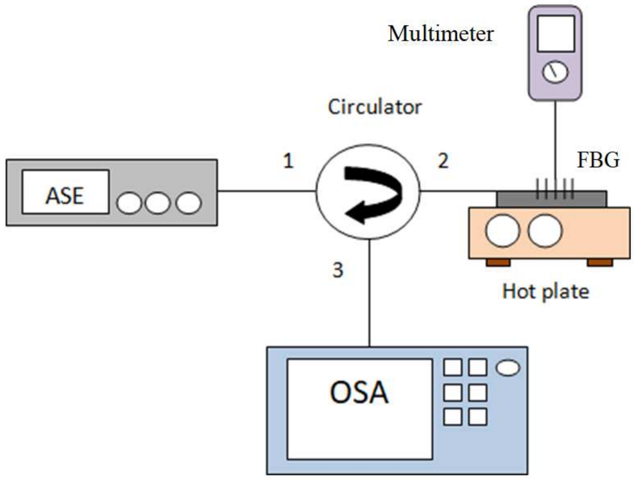


Fig. 1. Experiment setup for the temperature sensing

After that, the process of coating the graphene oxide onto the grating area of FBG was done. The prepared graphene oxide solution with concentration of 250 µg/mL is placed inside the centrifuge tube. Then, the FBG is dipped in the GO aqueous solution followed by the withdrawal process of the fiber from the solution which is done at a constant speed. After the fiber is taken out from the solution, a homogeneous liquid film is formed on the fiber's surface. Afterwards, the FBG is set to dry in room temperature for a few days. The drying process is to ensure that the coating is fully covered to the grating area and eliminate the volatile solvents.

B. Experiment Setup

The arrangement of the temperature sensor experiment is carried out as in Fig. 1. This setup consists of ASE as the broadband light source, the OSA is to display the output spectrum, while circulator acts as a tunnel for the output spectrum to be observed at port 3. Hot plate is used to supply the various temperatures to be detected by the sensor. Multimeter and thermocouple are used as a measurement device. The ASE is connected to port 1 of the circulator while the OSA is connected to the port 3 of the circulator with resolution of 0.2 nm, span of 50.0 nm and sampling point of 10 001. The port 2 of the circulator is linked to the end of the FBG while the other end of the FBG is placed on a hot plate. A thermocouple rod is attached to a multimeter and it is fixed closed to the grating area to measure the actual temperature sensed by the fiber during the experiment.

The GO-coated FBG is tested against the bare FBG to evaluate the performance of the GO coating on the FBG. The fibers are tested under normal room conditions for a temperature range of 30°C to 100°C. The temperature was increased gradually at 5°C at a time and the temperature was maintained for about 5 minutes before the data was taken to avoid any instability. The data on reflected spectrum measured by the SOA is analyzed and recorded at every desired temperature level. Optical spectrum analyser (OSA) will display the response of FBG in terms of power (dBm) and wavelength (nm). The wavelength shift can be observed as the temperature is increased. In addition, the temperature sensitivity, linearity and the resolution of the two fiber samples can be analyze and compared.

III. Results and Discussion

A. *Characterization of FBG and Graphene Oxide*

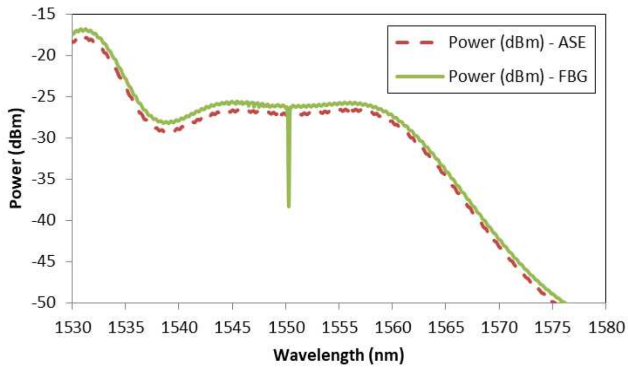
The FBG characterization must be conducted in order to observe the spectrum of the FBG before applying any coating or temperature variations. The FBG is first spliced with the pig tail at both ends to make sure direct connection between the light source, FBG sensing element and the spectrum analyzer. For this experiment, the broadband amplified spontaneous emission (ASE), was used as the broadband light source. A circulator is used to direct the light to port 3 to observe the reflected spectrum from the FBG. The YOKOGAWA AQ6370D optical spectrum analyzer (OSA) was used to measure and display the output spectrum of the experiment with a resolution of 0.02 nm and sampling point of 20000. Fig. 2 shows the results of the FBG characterization for (a) transmitted spectrum and (b) reflected spectrum of the FBG's wavelength, λ_B which occurred at 1550.30 nm.

Afterwards, the presence and the geometry of the GO coating are examined using the scanning electron microscope (SEM). Fig. 3 (a) shows the bare fiber surface [12], while Fig. 3 (b) demonstrates the lateral image of graphene oxide coated on the FBG under 10000X magnification. The presence of the GO flakes can be observed in (b) and can be compared to a very smooth surface of bare FBG in (a). This layer of microstructure is resulted from the synthesization of GO using dip coating technique. The microstructure of the GO will be slightly different if the fibre is dipped in the GO solution with different periods of time [13].

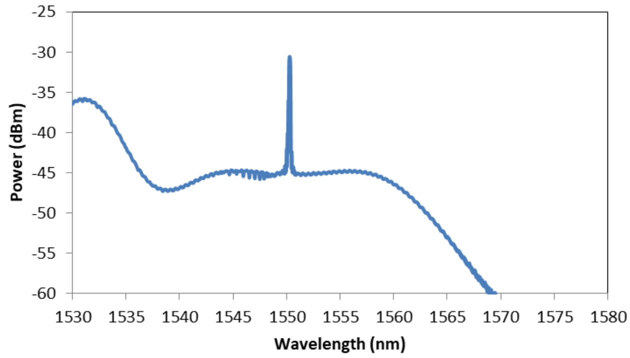
B. *Temperature Sensing Performance*

Both FBGs experiences shifted in wavelength as the temperature increased from 30°C to 100°C. This is due to the temperature dependence of refractive index and the thermal expansion corresponding to the equation (2). Fig. 4 shows the wavelength is shifted to the longer wavelength due to the temperature applied on the GO-coated FBG sensor. The total wavelength shifted recorded is 1.5362 nm which is slightly higher than the bare FBG due to the presence of the graphene oxide on the grating area of the FBG.

The output peak wavelength of both bare FBG and GO-coated FBG are plotted as in Fig. 5 which shows the spectral response of FBGs towards the temperature rises. A good linear correlation between the temperature and wavelength shift can be observed in the graph below. The results for both fibers are compared by observing the amount of the wavelength shift at different temperatures. The GO-coated FBG display a higher temperature sensitivity and linearity of 16.0 pm/°C and 99.1%, respectively in comparison to the bare FBG with temperature sensitivity of 15.0 ppm/°C and linearity of 97.4%. The performances of the bare and GO-coated FBG in the temperature sensing experiment are compared in terms of sensitivity, intensity and resolution as summarized in the Table 1.

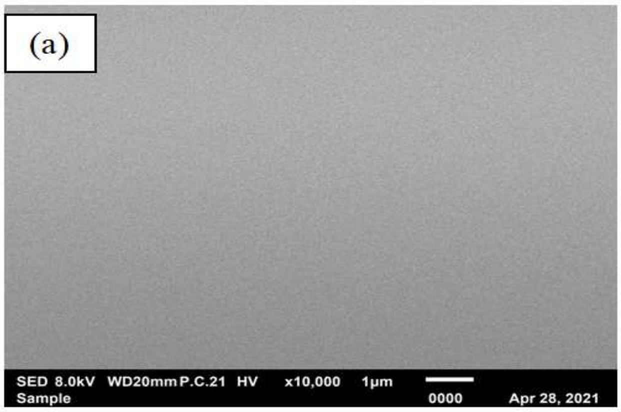


(a)



(b)

Fig. 2. FBG characterization of (a) transmitted spectrum (b) reflected spectrum of the FBG's wavelength, λ_B.



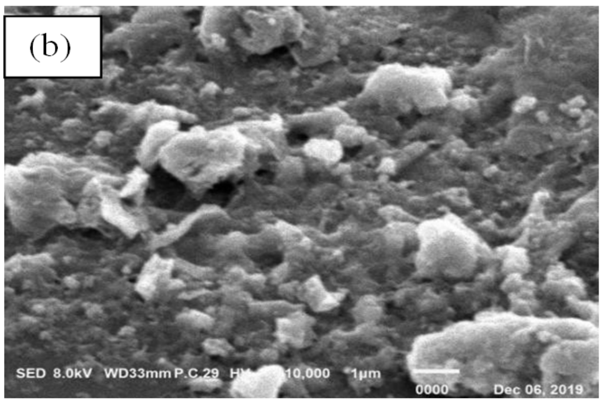


Fig. 3. SEM images of (a) bare fibre, (b) GO-coated fibre

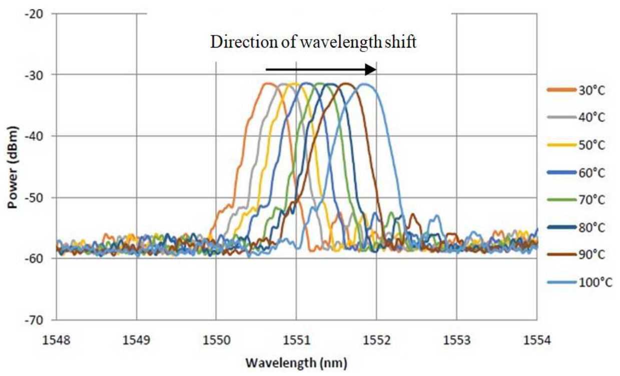


Fig. 4. Reflected spectrum of GO-coated FBG at different temperature.

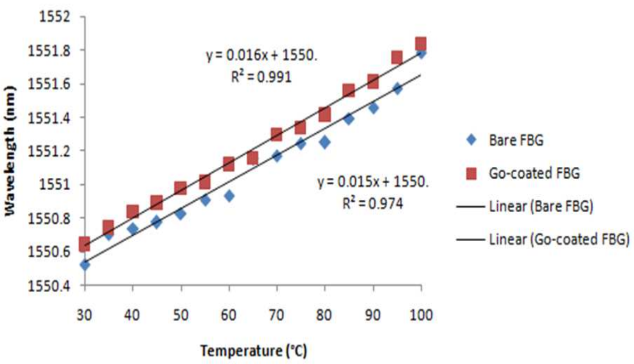


Fig. 5. Graph of temperature versus wavelength

TABLE I. PERFORMANCE OF FBG TEMPERATURE SENSOR

Parameter	Bare FBG	GO-Coated FBG
Sensitivity (pm/°C)	15.0	16.0
Linearity (%)	97.40	99.1
Linear Range (°C)	30 - 100	30 - 100
Standard Deviation (pm)	360	370
Limit of detection (°C)	24	23.1

The temperature sensitivity of the GO-coated FBG is 16.0 pm/°C while bare FBG is 15.0 pm/°C which indicate that almost 7% of the improvement from the bare FBG. This enhancement of temperature sensitivity is the result from the properties of the GO itself, which has a large surface area and high thermal conductivity, making the FBG sensor more sensitive towards the temperature variation. The linearity of the graph also shows that the output of FBG-coated sensor is superior as it specifies the consistency of the wavelength shift reading as temperature is increased.

Besides that, the performance of the sensor also can be evaluated by comparing the limit of detections (LOD) of both sensors. The LOD can be obtained by dividing the standard deviation and sensitivity of the fibers,

$$LOD = \frac{standard\ deviation}{sensitivity} \tag{3}$$

The GO-coated FBG exhibit a lower LOD of 23.1 while the bare FBG recorded LOD of 24. This comparison indicates that the GO-coated FBG sensor has better efficiency than the bare FBG since the minimum value of LOD signify the effectiveness of the sensor.

Apart from that, the total wavelength shifted for both sensors also acts as an indicator of a good sensor. The Bragg wavelength shifts recorded for the bare and the GO-coated FBG ranging from the room temperature up to 100°C are 1.487 nm and 1.5362 nm, respectively. This specifies that both bare and GO-coated FBG able to function as temperature sensor as wavelengths of both FBG are shifted against increased temperature. However, the GO-coated has higher wavelength shift than the bare FBG, therefore, indicate better sensor performance for GO-coated FBG. In addition, the linear fitted trend shows $R^2 = 0.991$, which exhibit the consistency of the wavelength shift reading as temperature increased.

IV. CONCLUSION

As a conclusion, an experiment of fiber bragg grating (FBG) temperature sensor based on graphene oxide (GO) was successfully conducted. The GO solution has been coated on the FBG surface by using dip coating technique. As the GO has large surface area, it helps to enhance the shift in Bragg wavelength by the variation in the thermal expansion coefficient and the refractive index as the temperature changed. The results show that the GO-coated FBG has a temperature sensitivity of 16.0 pm/°C in the range of 30°C to 100°C which proving its benefits in high sensitivity by simple fabrication. Besides that, the GO-coated FBG also has lower LOD compared to the bare FBG and indicate better linear fit of 99.1% as it specifies the consistency of the wavelength shift reading as temperature increased.

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