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## Comparison of Fiber Bragg Grating based on SMF and MMF over Temperature Sensitivity

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**Abstract.** We have successfully fabricated and demonstrated a simple, cost-effective and easy to use of fiber Bragg grating (FBG) based on single mode, and multimode fiber which have been employed for temperature monitoring. The study purposely compared the performance of two types of FBGs; single mode FBG (SM-FBG) and multimode FBG (MM-FBG). The FBGs sensor is fabricated by phase mask technique which being exposed to ArF excimer laser with 20 mm uniform grating length and 99% reflectivity. The proposed FBG is studied for temperature monitoring starting at room temperature until 120 °C, and the configurations with SM-FBG and MM-FBG achieved a sensitivity of 10.9 pm/°C and 13.23 pm/°C, respectively whereas linear response correlation coefficient of 0.98229 and 0.99929. These show the MM-FBG has better sensitivity to be used in sensor applications.

### 1. Introduction

When electronic sensors suffer its limitations, fiber optic sensors had been increasingly study in many applications especially for a couple of decades. Fiber optic has attracted much attention of researchers due to their ability to transmit data in long distance while still offering low losses, low cost, light weight and immune to electromagnetic (EM) wave, which makes it unique compared to other sensors[1-2]. Among various type of fiber optic, fiber Bragg grating (FBG) had gained attention among researchers for sensor development.

FBG is fiber optic that has been modified by changing the refractive index of the core to form a permanent uniform grating period. The main highlight for FBG is their ability to reflect light at certain wavelength and transmit other wavelengths [3]. In a standard telecommunication optical fiber, using a phase mask to fabricate the FBG is one of the most common techniques [4]. Due to external force such as temperature, pressure and strain change will affect in the grating period and in the effective refractive index. Consequently, the Bragg wavelength of the light reflected will be used as reference parameter for a sensor [5].



As it is well known, FBG is used many times as temperature sensor for many applications. Ismail et al., reports direct coupling of SM-FBG with a transistor in solar panel inverter can be used as temperature sensor. The sensor gives highest sensitivity at range 41 °C to 90 °C with the reading of 14 pm/°C [6]. Meanwhile, Lim et al. demonstrated temperature sensors for monitoring an optically powered hydraulic system using MM-FBG which had been fabricated using holographic method. The sensor sensitivity is 6 pm/°C when tested to temperature range of -40 °C to 80 °C [7].

The focus in this paper is to study the performance between SM-FBG and MM-FBG for temperature sensor is proposed and experimentally demonstrated. FBG usually made from SMF had been studied tremendous time not only for temperature sensor but also as other sensors compared to the one made from MMF. SMF is known for their advantages to high potential to transfer data over long distances with low losses [8]. Here, both of the FBGs is tested by placed inside an oven and the temperature is varied. The temperature sensitivity is determined from the relationship between the wavelength shift and temperature change.

## 2. Theory

As it is well known, the basic principle of FBG can be expressed as :

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

Bragg grating wavelength,  $\lambda_B$  is the central of wavelength that reflected by the FBG. It has a relationship with its effective refractive index,  $n_{eff}$  and grating period,  $\Lambda$  [8]. For temperature sensor, the wavelength shift is due to thermal expansion changes the grating spacing and the index of refraction. The changing in grating period space is caused by the thermal expansion of the fiber. Meanwhile, the effective refractive index change because of thermo optic effect. This can show as :

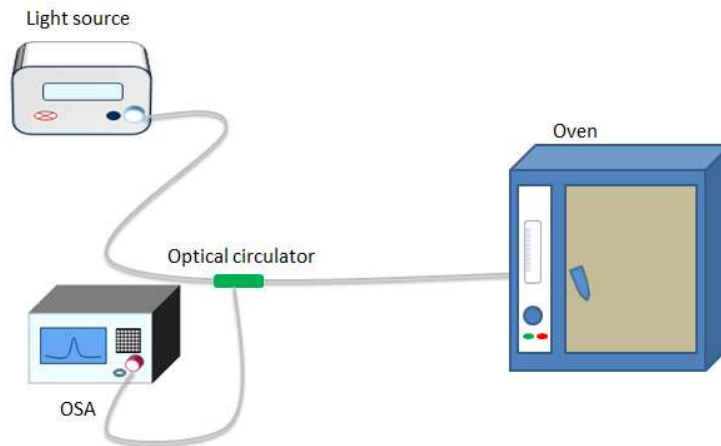
$$\Delta\lambda_B = (\alpha + \xi)\lambda_B\Delta T \quad (2)$$

Where  $\alpha$  is the coefficient of the thermal expansion and  $\xi$  is the thermo optic coefficient of the fiber.

## 3. Methodology

In this study, both types of FBGs are fabricated using phase mask technique. Phase mask technique is a technique that used a phase mask to form an interference pattern laterally by exposing the photosensitized fiber core to ultraviolet light [8]. Both of SMF FBG and MMF FBG used ArF excimer laser with wavelength 193 nm to create a uniform pattern of Bragg grating. Single mode FBG is made from fiber optic with a core diameter of 10  $\mu\text{m}$ , a cladding diameter of 115  $\mu\text{m}$  and multimode FBG is from fiber optic with a core diameter of 62.5  $\mu\text{m}$ , a cladding diameter of 62.5  $\mu\text{m}$ . After the fabrication process, the Bragg wavelength for SMF and MMF are at 1550 nm and 1572 nm, respectively. These differences of Bragg wavelength is due to phase mask that used during the fabrication process.

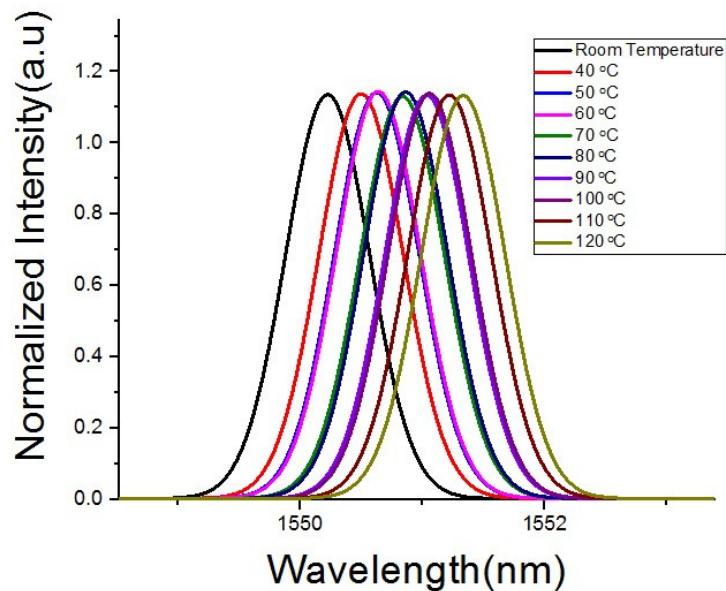
Figure 1 illustrates the experimental setup to monitor the temperature sensing process. An optical circular is used to connect the FBG to light source and spectrometer. The light source used is a super luminescent diode light source (Amonics, ASLD15-025-B-FA) with spectral range of 1400 nm to 1600 nm and optical spectrum analyzer (OSA, Anritsu-MS9710B) with spectral range of 600 nm to 1750 nm. The ASL lamp was for the light source that transmits light inside the optical fiber and the OSA was the light detector to measure the signal intensity passing through the optical fiber. The FBG is then placed inside an oven (J.P Selecta-2000208) that can vary the temperature from room temperature to 120 °C. The temperature is increased at every 10 °C before the data is taken.



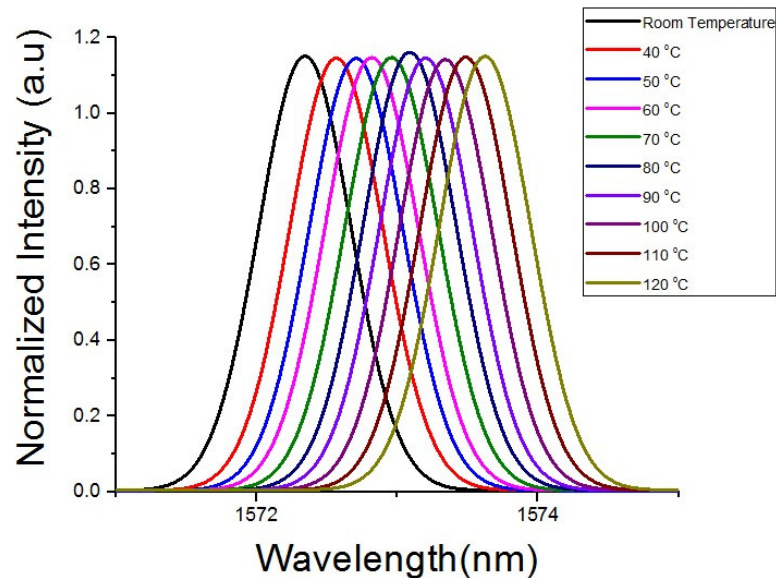
**Figure 1:** Schematic diagram of the experimental set-up.

#### 4. Result

Figure 2 and Figure 3 represent the output reflective spectrum of the SM-FBG and MM-FBG, respectively. The FBG sensor is exposed start from room temperature and increased with step-up of 10 °C. From both of the graphs, the Bragg wavelength for SM-FBG and MM-FBG shifted to the higher wavelength as the temperature of the oven is increased. Even though both of FBGs shifted to the same direction, but there are some slight differences pattern of changes.

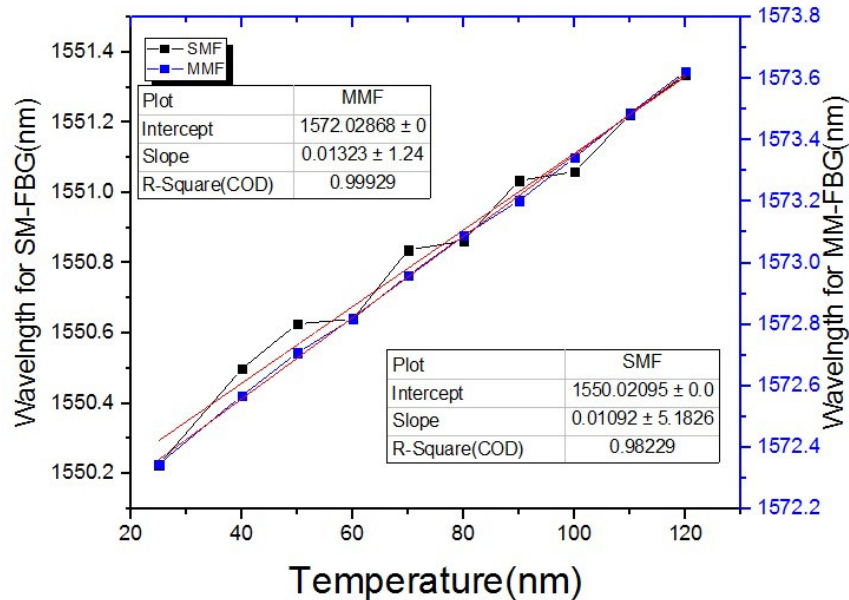


**Figure 2:** Reflection spectrum of single-mode FBG



**Figure 3:** Reflection spectrum of multi-mode FBG

Based on Figure 4, from room temperature, 25 °C to 40 °C the Bragg wavelength shift for SM-FBG is much higher compared to MM-FBG which are 18.2 pm/°C and 14.9 pm/°C, respectively. As the temperature of the oven is increased with an interval 10 °C, starting from 40 °C to 120 °C, the MM-FBG show a consistent Bragg wavelength shift. The rate of wavelength shifted is 13.23 pm/°C. Meanwhile, for SM-FBG, the wavelength shift is more consistent for every 20 °C. But overall, the rate of wavelength shifted is 10.92 pm/°C. The temperature sensitivity affected the grating period in MM-FBG is higher compared to SM-FBG due to larger core diameter and high thermal expansion core (TEC) of doped glass. The core of SM-FBG is 10  $\mu\text{m}$  and the cladding 115  $\mu\text{m}$ . Meanwhile, the core of MM-FBG is 62.5  $\mu\text{m}$  the cladding for MM-FBG is around 62.5  $\mu\text{m}$ .



**Figure 4:** Comparison of Bragg wavelength peak for single mode and multimode FBG

## 5. Conclusion

In summary, comparison of work performance between SM-FBG and MM-FBG was presented. As the temperature increases with an interval of 10 °C, the Bragg wavelength shifted to the higher wavelength. The result shows the sensitivity for SM-FBG and MM-FBG are 10.92 pm/ °C and 13.23 pm/ °C, respectively. Therefore, both types of FBG can be used as temperature sensor but MM-FBG gave higher sensitivity.

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