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Development of Fiber Bragg Grating (FBG) as Temperature Sensor Inside Packed-bed Non-thermal Plasma Reactor

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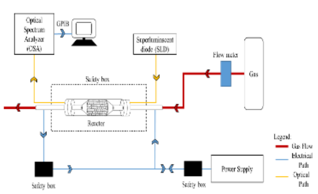
Graphical abstract



Abstract

This paper presents early work on Fiber Bragg grating (FBG) as temperature sensor to monitor temperature variation inside a packed-bed non-thermal plasma reactor. FBG made from germania-doped fiber with center Bragg wavelength of 1552.5 nm was embedded inside non-thermal plasma reactor with sphere shape dielectric bead (barium titanate) and used to probe the temperature variation inside the reactor. The experimental works have proven that FBG is a suitable sensor to monitor temperature variation inside of reactor via LabVIEW program. Besides that, Optical Spectrum Analyzer (OSA) recorded Bragg wavelength shift as voltage of power supply increases, which indicate the non-uniform temperature variation occurring inside the reactor. However, it does not affect the chemical reaction inside the reactor because the temperature condition is in steady state.

Keywords: Fiber bragg grating; temperature sensor; non-thermal plasma

1.0 INTRODUCTION

Fiber optics is one of the devices used in optical technology concerned with the transmission of light through fibers made of transparent materials which is glass, fused silica or plastic to carry information [1]. There are three main structures; namely the core, cladding and buffer coating such as shown in Figure 1. The cladding is made up of material with lower reflective index relative to that of the core. This is because total internal reflection occurs should a higher reflective index material are used in the core relative to the cladding and the outer buffer coating functions as to protect the fiber from being damaged or broken. In addition, fiber optic comprises of three types; which are multi-mode fiber, single-mode fiber and special-purpose fiber [2]. As it name implies, single-mode fiber has only one mode as compared with multi-mode fiber; but it has lower pulse spreading which will reduce dispersion of fiber. An example of single-mode fiber is Fiber Bragg grating (FBG).

FBG is formed when an intense ultraviolet (UV) source such as UV laser was launched into a single-mode fiber optic which creates a vibration of refractive index inside the fiber core called Bragg grating. As illustrated in Figure 2, the part that differentiates FBG from normal fiber optics is Bragg grating, which consists of different in refractive index. Usually, germanium-doped silica fiber is used in manufacture of Bragg grating. The periodical reflective index inside FBG will reflect particular wavelengths of light and transmits all others. These refer to fundamental principle operation of FBG, which is Fresnel reflection. The parameters in concern with FBG include length of FBG (L), grating spacing (Λ) and modulation amplitude (m) [3]. Few fabrication methods of FBG include interference, photomask and point-to-point.

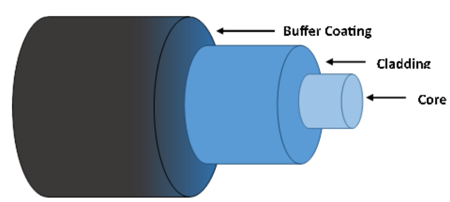


Figure 1 Cross section of a typical fiber-optic cable

Due to these phenomena, FBG has become widely demanded device in communication and sensor network field. Notch filter, multiplexer, and demultiplexer are among FBG applications in communication; and on the other hand, fiber optics are used widely as sensors used to measure temperature, displacement, strain and vibration. Several advantages of this device are small in size, high sensitivity, immune towards electromagnetic radiation and low transmission loss, anti-corrosion and strong multiplexing

[4]. However, FBG also possess critical disadvantages such as poor stability within high-temperature environment; and at temperature 700^{o}C, the grating can be easily completely erased [5].

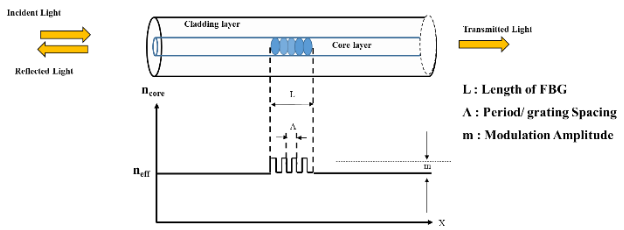


Figure 2 Structure an FBG

In this project, FBG will be utilized as temperature sensor in non-thermal packed-bed plasma reactor to study the effect of varying temperature towards chemical bonding of Volatile organic compounds (VOCs) inside packed-bed non-thermal plasma reactor.

■2.0 EXPERIMENTAL

As shown in Figure 3, The FBG temperature sensor setup consists of Superluminscent diode (SLD) as laser diode ranges between 1400nm to 1600nm is launched into FBG with single grating. Light transmitted inside the fiber, hitting the panel grating with different refractive index along it travel path. Due to this, total internal reflection occurs in which some of the lights will be reflected while the rest is transmitted. However, for the purpose of this study, only transmission light will be considered because transmission spectrum is clearer and more accurate as compared to that of reflection spectrum. Optical Spectrum Analyzer (OSA) is utilized as instrument to record the data obtained from FBG. General Purpose Interface Bus (GPIB) will then function to enable easier interconnection between the instrument and the controller (computer and OSA). LabVIEW as real-time program is used to analyse the data obtained and calibration curve can be obtained as an output. The reactor consists of two electrodes made of metal. Since the electrodes are connected the power supply, it creates electric field to break the molecular bonding of the nitrogen gas filled inside the reactor which in turns emit electron [6]. Energy is then transferred to electron in the form of heat, causing the electron to vibrate vigorously and move randomly. The random electron movement between dielectric materials (Barium titanate) creates non-thermal plasma. During this process, heat is produced which causes the Bragg grating to shift its wavelength, λ_B. LabVIEW will then read the Bragg wavelength shift and calibration curve of temperature, T against Bragg wavelength shift, $\Delta\lambda_B$ can be obtained by applying equation of FBG temperature sensing inside LabVIEW program.

The cross-section inside packed-bed non-thermal plasma reactor is as shown in Figure 4. The FBG is embedded carefully inside the packed-bed non-thermal plasma reactor to prevent it from being damaged or broken because of its fragile structure in nature.

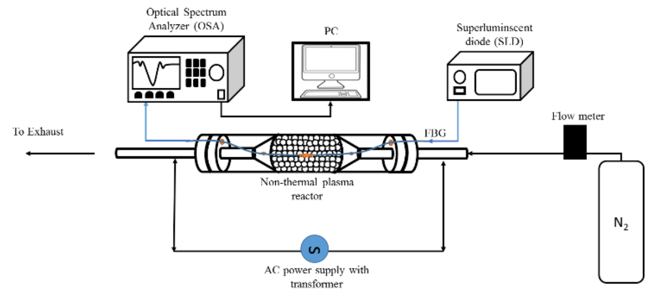


Figure 3 Schematic diagram of embed FBG inside packed-bed non-thermal plasma reactor

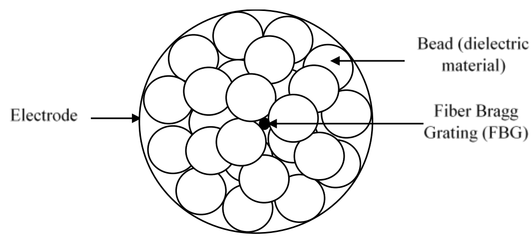


Figure 4 Cross-section inside packed-bed non-thermal plasma reactor

The block diagram for programming inside LabVIEW is as portrayed in Figure 5. The equation of temperature sensing is given as:

$$\Delta\lambda_B = \lambda_B(\xi + \alpha)\,\Delta T \qquad (1)$$

Where, $\Delta\lambda_B$ = Different of Bragg wavelength shift
λ_B = Bragg wavelength shift
ξ = Thermo-optic coefficient
α = Thermal expansion
ΔT = Different of temperature

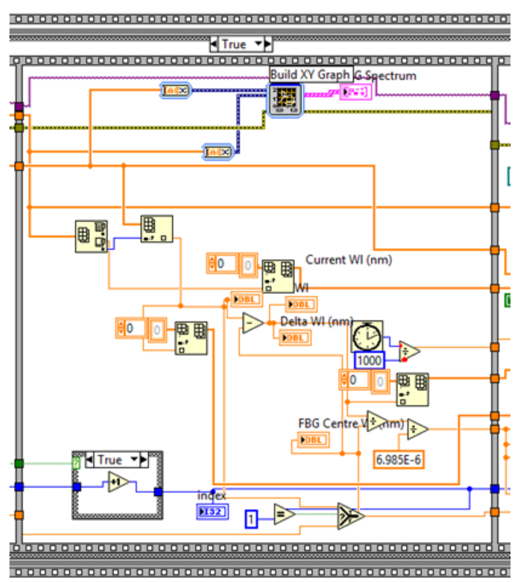


Figure 4 The block diagram for programming inside LabVIEW

3.0 RESULTS AND DISCUSSION

The experimental results as shown in Figure 6, illustrates the graph of power loss of transmitted light, P_{loss} against wavelength, λ for increasing voltage, V. From the spectra, it can be proven that shifting of the wavelength occurs as temperature rises.

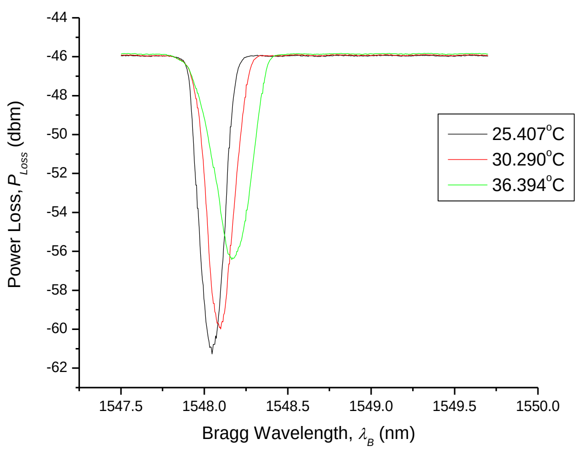


Figure 6 Power loss, P_{loss} against wavelength, λ with increasing voltage, V

The graph of change in temperature, ΔT against time, t is as shown in Figure 7 and Table 1 presents the detailed data extracted from the graph, with peaks numbered from 1 to 5. As can be seen from the table, temperature inside the reactor increases with increasing voltage. This is as explained earlier, where the formation of plasma is dependence on the emission of the electron from the breaking of the nitrogen gas molecular bonding. As more voltage is supplied, more energy is being transferred to the electron causing it to vibrate and move more vigorously. This excess energy in form of heat increases the reactor temperature. As plasma is formed when electrons collide, the excess energy causes the electron to collide with each other at a more frequent rate, producing more plasma which is indicated by visually brighter plasma. It is also observed that when the voltage is increased, it takes a few seconds for the temperature inside the reactor to stabilize, but once the power supply is turned off and non-thermal plasma disappeared, temperature immediately fall to room level. From this result also, it can be deduced that non-thermal plasma was successfully developed because the produced plasma temperature is below 100ºC.

With reference to Figure 7, the changing pattern of the reactor internal temperature with changing time was observed. This experiment was conducted with the aim to observe the response time of the temperature inside the reactor with changing voltage supply. The results obtained illustrates that the temperature changes rapidly when voltage supply is varied. This is indicated by the sudden rise and falls in the graph, forming peaks. Data obtained illustrated that the temperature can change up to rate of approximately 1.36ºC per second, which is considered rapid. This phenomenon is exactly the same as observed earlier where the temperature drops immediately to room temperature when power supply is turned off due to the fact that the barium titanate ($BaTiO_3$) beads do not absorb heat, or the amount of heat absorbed is negligible. As voltage is now no longer supplied, no electric field is present to break the molecular bonding of the gas; thus no emission and collision of electron occurs. This also correlates as to why the temperature fluctuates rapidly upon changing the supply voltage.

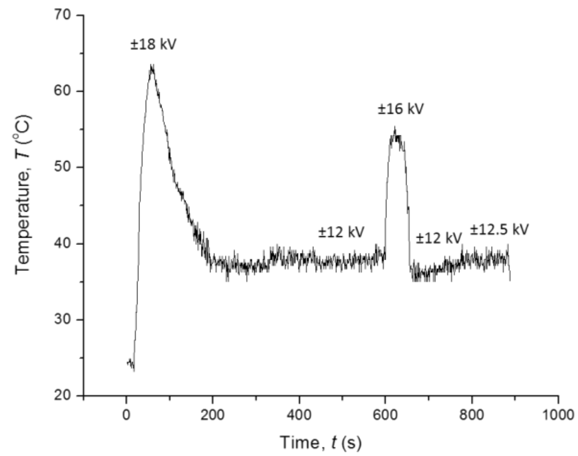


Figure 7 Graph of change in temperature, ΔT against time, t

Table 1 Detailed data of temperature, T against time, t curve

Voltage, V (±0.1kV)	*Time, t (s)*	*Temperature, T (ºC)*
18.0	59	63.157
12.0	484	37.114
16.0	621	55.426
12.0	699	36.707
12.5	844	38.335

The graph of temperature against Bragg wavelength is as illustrated in Figure 8. The slope of the curve represents the sensitivity of the FBG, and from the data obtained, the sensitivity is 10.81 pm/ºC. This sensitivity is considered suitable to probe the temperature difference inside the packed-bed non-thermal plasma reactor as the rate of temperature fluctuation is rapid. If the sensitivity is not high enough, the rapid rise or fall of the reactor internal temperature cannot be detected and recorded.

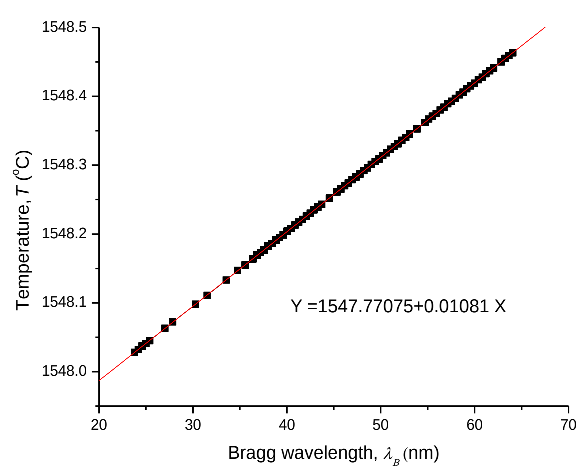


Figure 8 Temperature, T against Bragg Wavelength, λ_B

■4.0 CONCLUSION

In this research, FBG of single grating managed to be utilized for sensing the temperature variation inside a packed-bead non-thermal plasma reactor. The FBG sensitivity obtained from this preliminary work is 10.81 pm/°C, which is considered suitable for sensing the rapid fluctuation of temperature inside the reactor. Findings also show temperature variation occurs inside the plasma reactor, indicated by the shifting of Bragg wavelength from the spectra. Besides, the temperature inside the reactor is obtained at lower than 100°C, proving that non-thermal plasma is obtained. At this moment, works are already underway to further investigate whether the temperature variation inside packed-bead non-thermal plasma reactor is localized or not.

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