The use of fiber bragg grating coated with polyimide for CO_2 gas sensor

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ABSTRACT

This study presents the application of fiber bragg grating (FBG) sensors coated with polyimide for detecting carbon dioxide (CO_2) gas, employing both theoretical and experimental approaches. The basic FBG components were coated with polyimide layers of varying thicknesses. Subsequently, the fabricated FBG sensors were characterized using an optical interrogator system with four channels. Furthermore, the sensor was tested for CO_2 detection at a working temperature of 47 °C. Experimental data showed that the FBG sensor coated with polyimide layers of 10 nm, 15 nm, and 20 nm demonstrated sensitivities of 1.9 ppm, 1.84 ppm, and 1.8 ppm, respectively. In contrast, the uncoated FBG sensor exhibited a higher sensitivity of 3 ppm. Increasing the coating thickness beyond 20 nm leads to a decrease in sensor sensitivity. The findings suggest that an optimal polyimide coating thickness for CO_2 detection using FBG sensors is around 20 nm. Achieving high sensitivity in CO_2 gas sensors is crucial for their effective use across a broad range of applications.

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1. INTRODUCTION

The creation of optical waveguides have fundamentally increased their use in the fields of optical communication and sensing technologies. A variety of both passive and active components have been developed, such as optical couplers, optical switches, dense wavelength division multiplexing (DWDM) devices, ring resonators, Mach-Zehnder interferometers and fiber bragg gratings (FBGs). Other than communication, these optical components can also be used in medical and chemical sensing applications including: photonic sensors, tapered fibers and FBGs. Specifically, the use of FBG technology for medical and chemical sensors has advanced significantly [1]-[3].

The technology of measuring strain, temperature, and pressure within structural elements using optical fibers is referred to as FBG. It works by creating periodic modifications in the refractive index of the core of the fiber that reflects certain wavelengths of light. FBG sensors monitoring temperatures or strains yields precise, instantaneous data about the state and behavior of myriad structural components by monitoring the changes in the reflected wavelengths. This technology is non-invasive and highly sensitive which makes it useful in civil engineering, aerospace and industrial monitoring. It also provides an economical and reliable means of measuring and analyzing complex systems. FBG sensors are critical for maintaining safety and performance in essential infrastructure because they are capable of identifying minute changes, making them valuable for bridges, aircraft, and industrial machines [4]-[6]. Information from FBG sensors allows engineers to foresee issues before they occur, saving time and lowering maintenance expenditures as problems do not escalate. Owing to their versatility and accuracy, FBG sensors are transforming structural health monitoring and maintenance across many sectors [7], [8].

Tracking carbon dioxide (CO_2) gas concentrations illustrates one of the most important uses of FBG sensors. Many works of research have been conducted in this direction with good sensitivity and even better accuracy. For an economic approach, a low-cost method made in the design of the CO_2 gas sensor system was proposed. This design requires changing the light refractive index and grating period inside the FBG. Sensor performance evaluation concerning the optimal sensitivity level was carried out thoroughly. Significantly, the polyethersulfone (PES)-coated FBG sensor proved high sensitivity to CO_2 with a fast response time of 3.27 minutes and 0.78% CO_2 sensing limit. In a separate study [9], enhancements to the FBG-based CO_2 gas sensor were achieved through the incorporation of multi-walled carbon nanotubes (MWCNTs). Research by Shen *et al.* [10] using an ultrasonic chemical precipitation approach, γ-Al_2O_3/CeO_2 powder in the nanoscale range was synthesized. Particles of the material have a size ranging from 20 to 50 nm according to the scanning electron microscope (SEM) data. After the hydroxylation of MWCNTs, the desired amount of dispersant was added and sonicated to form a solution. Support material containing γ-Al_2O_3/CeO_2 was prepared by wet mixing MWCNTs solution with the above moderator materials. Aside from FBG sensors, there are other gas sensing technologies that have been researched thoroughly, each associated with different advantages based on their detection principles. For example, the metal oxide semiconductor (MOS) sensors are popular due to their low cost, small size, and high sensitivity.

While focusing on studying FBG sensors, researchers have also looked into other gas detection technologies which have their advantages based on the detection method used. As an example, the most popular now are MOS due to their low price, small dimensions, and high sensitivity. These types of sensor devices function by measuring the change in electric resistance of a metal oxide due to the adsorption of gas molecules on a heated metal oxide surface. On the other hand, MOS sensors tend to have a lack of selectivity and an undesirably high sensitivity to changes in humidity, temperature, and other environmental parameters leading to inaccurate measurements. To address these issues, it is very common to complement MOS technology with computer-based algorithms which increases the accuracy of the sensor and discrimination between the gases.

Electrochemical sensors exhibit a very high sensitivity and specificity for the detection of gases such as carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). These sensors operate by generating an electric signal which corresponds to the gas concentration being measured through redox reaction at the electrodes. These sensors have shown reasonably good performance in detecting low concentration gases, providing good stability but some drift. Over time these electrochemical sensors are subjected to rapid aging and increasing unreliability, requiring more recalibration with time to maintain accuracy. Other gases like CO_2 and methane (CH_4) can be measured non-invasively and accurately by photoacoustic and infrared (IR) sensors. However, despite boasting precision, these optical sensors tend to be bulky and expensive. As noted above, there are many potential alternatives to FBG sensors, but most of them seem to have difficulties when it comes to size, selectivity, durability, or environmental resilience.

This study concentrates on enhancing the sensitivity of polyimide coated gratings by polishing the grating region of FBG sensors. There is a number of gas detecting applications for fiber optic sensors where polyimide coating can provide benefits. Polyimides have high thermal and chemical stability which would greatly increase the reliability of the sensor when subjected to high temperatures or reactive gases. Furthermore, polyimide has the ability to absorb or interact with certain gas molecules such as ammonia or VOCs, causing strain or swelling detectable as a shift in FBG's reflected wavelength.

In addition, the strong adhesion provided by the bond of polyimide to silica fibers assists with the mechanical strength and enduring longevity of the sensor. Altering the constituents of the functional group increases its ability to be sensitive to one particular gas, changing its chemical properties. Furthermore, polyimide's thin-film implementation allows it to be placed on the surface of the FBG without obstructing optics, enabling the FBG to detect changes. These facts support the statement that polyimide is a remarkable material which enhances the performance of FBG gas sensors.

The base FBG will have a coat of polyimide applied with varied thicknesses using radio frequency (RF) sputtering techniques. There are several steps of vacuum deposition in which polyimide is bombarded with high energy ion beams. During sputtering, approximately 13.56 MHz of RF energy is applied to sustain plasma; this causes ions of inert gases, most commonly argon, to ionize over the pentagon polyimide and its atoms or molecules are ionised and deposited on the surface of the FBG. Following this phase, the particles are deposited through the vacuum in a continuous multi-layered manner over the FBG so that thin polyimide can gold filaments be placed atop bronze. This technique allows vapor deposition to be performed along the lines of defined surfaces, enabling polyimide sensing films to be custom designed for purposeful deposits which are very important in the development of gas sensing technologies. The parameters are maintained such that the fiber optics are not damaged which is with low substrate temperatures. With this type of polyimide coating, the sensitivity during gas detection is enhanced with the FBG response, and the defined levels of polyimide swell and reaction pattern shift enabling the desired change in wavelength shift response.

2. METHOD

Fabrication and experimental set up to measure CO_2 gas using FBG sensor. As shown in Figure 1, the elementary workings of the FBG starts with an input signal being introduced to the input port. The signal is usually 1550 nm in wavelength and the input signal is incident on the grating. The grating allows some part of the light to pass through to the output port while the rest is reflected back to the input. It is very clear that the signal which is reflected back toward the input is very important for sensing purposes. First of all, this signal has a particular dependency on the physical and geometric characteristics of the FBG. The signal that is reflected in this manner determines the wavelength of the Bragg reflector's backbone. Many lower factors such as stress, strain, pressure or even the velocity has a direct influence on why this signal is so important. For example, his reasoning can be determined mathematically with the help of (1) [11]:

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

where Λ is grating length, n_{eff} is effective refractive index, and λ_b is Bragg wavelength.

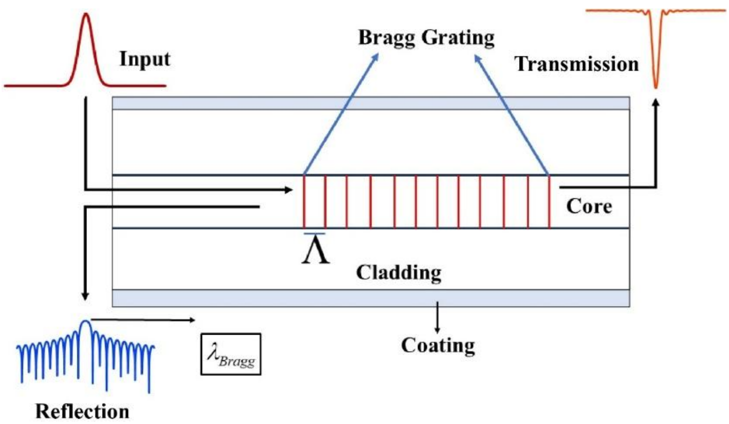

Figure 1. Schematic diagram of FBG

The sensitivity of FBG to detect gas concentration also utilize the exchange of Bragg wavelength ($\Delta\lambda_{bragg}$) in response to the interaction of the sensitive layer on the FBG with certain gases. Several factors affect the formula, including variations in the effective refractive index of the optical fiber and the gas detection sensitivity, which can be represented by (2) [12]:

$$\Delta\lambda_{bragg} = \frac{d\lambda_{bragg}}{d\Delta n_{eff}} \Delta n_{eff} = f_{gass} . C_{gass} \quad (2)$$

where C_{gass} is gas concentration and f_{gass} is physical parameters of FBG.

In this research, silica single mode fiber (SMF) is used to form FBGs using the femtosecond laser inscription technique. Its core refractive index is altered by focused ultrashort laser pulse regions. The Bragg wavelength range of 1449 nm to 1555 nm can be realized, with efficiency at 1550 nm. Such sharp distributed periodic structure engraving enables high precision optical measurement of temperature, voltage, and even structural deformation [13]-[16]. To sum up, the femtosecond laser inscription technique allows the construction of FBG gas sensors with improved sensitivity and dependability. The accurate control of the refractive index within optical fibers guarantees that the sensor will reliably detect and measure changes in the environment. Such precision makes FBG gas sensors appropriate for a variety of applications in the aerospace, agriculture, automotive, and civil engineering industries where measurement and monitoring are critical.

The sensitivity of an FBG sensor to a particular gas is defined by the interaction of the gas with the sensor's sensitive layer that modifies the effective refractive index. This is mostly worked out with some experimental calibration of the interactions between wavelength shifts and gas concentration. Also, how to select the sensitive material which is part of the FBG is equally important because it affects the performance of the sensor. FBGs are fabricated using silica SMF which is done by femtosecond laser inscription as shown in Figure 2. In this method, short bursts of high-energy laser pulses are applied to make certain changes in the refractive index within the fiber's core region [17]-[20]. FBG arises from the interaction of laser pulses with the fiber core, resulting in changes to the refractive index. FBG gas sensor responsiveness and sensitivity can be tuned by changing laser pulse energy and duration. The sensor selectivity to the various gases is controlled primarily by the sensitive material deposited on the FBG layer, thus the choice of materials is highly relevant during the manufacturing process. A gas sensor requires calibration and fabrication to ensure dependable results.

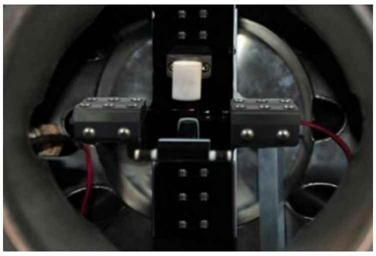

Figure 2. Experimental set up inside of sputtering chamber

In the following description, the FBG is first placed between two vacuum holders before being placed in the coating chamber on top of the polyimide substrate. It is then coated using RF-modified sputtering techniques. Cleaning with alcohol serves the purpose of removing dirt from the FBG, while the sputtering tube is prepared, marking the first step of this particular process. Polyimide is chosen as the coating material for this procedure. Argon gas is injected into the tube, which is then heated to a temperature range of 27 to 600 °C, with power from 0 to 125 watts supplied to both the anode and cathode. Argon was delivered to the sputtering tube together with polyimide, whose atoms are released at a controlled temperature before deposition onto the surface of the SMF FBG, the polyimide coating is built layer by layer until reaching a target thickness. Once the desired thickness is attained, a curing and drying step is carried out in a bid to improve adhesion. Throughout the coating procedure, the polyimide atoms' deposition process is tracked in real-time to regulate the temperature and control the deposition process. The live signal is monitored by FBG signal generation where the signal from the SMF FBG is continuously sent to a power meter, while reflection from the terminal shaft is done in real-time for display observation and seeing the reflected terminal signal. In this work, the coating thicknesses were 5 nm, 10 nm, 15 nm, 20 nm, 25 nm, and 30 nm.

In Figure 3, the setup of the sensor measurement system is presented. A light SMF sends a fiber coupled light source with a wavelength of 1550 nm to a circulator which is connected to the FBG. The FBG is positioned in a chamber 30 cm long and 20 cm in diameter. This chamber is gassed up with two gases CO_2 and CH_4 which is the retained gas. The output signals is sent through the SMF to an optical spectrum analyzer (OSA) to analyze the power spectrum at different wavelengths. The polyimide coated FBG sensor exhibits remarkable sensitivity and stability which allows accurate measurement of gas concentration changes in the chamber. Data obtained from the sensor is processed through an OSA, permitting the researchers to highly accurately assess the power spectrum at a number of different wavelengths. This elaborate design and setup aids significantly to the understanding of the action of CO_2 and methane gases under controlled conditions, thus greatly increasing its usefulness for environmentally enhancing monitoring devices, and for scientific research.

FBG sensors are best coated with polyimide due to its unique properties such as high thermal stability, mechanical flexibility, polyimide's resistance to chemicals, and more. Its use is ideal even in harsh and demanding environments due to its extreme temperature resisting capabilities from -200 °C to beyond 400 °C [21]-[24]. Its flexibility allows optical fibers to bend without permanent damage while still providing excellent durability due to polyimide's strong adhesion to the optical fibers. The lifespan of the sensor is also prolonged due to moisture, chemical, and oxidation resistance. In gas sensing applications, these changes facilitate accurate measurement due to polyimide's ability to absorb CO_2 inducing changes in strain or refractive index. All of these characteristics make polyimide-coated FBG sensors dependable for industrial as well as environmental monitoring.

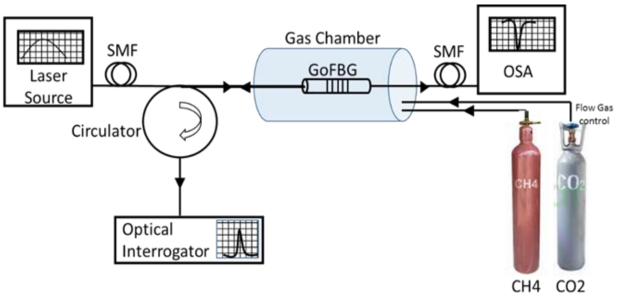

Figure 3. Experimental set up of CO_2 gas sensor system

FBG sensors are polyimide coated using RF sputtering where plasma is generated using a high frequency electromagnetic field in a vacuum chamber and argon gas is used to start the ionization process. The argon atoms that have been ionized are subsequently accelerated onto a polyimide target which causes molecular fragments to be dislodged. The polyimide particles dislodged are propelled through the chamber and deposit on the FBG surface forming thin films. Through these methods, uniform and precise control over the thickness of the coating can be achieved, an important factor needed to maintain the optical properties of the FBG while increasing the FBG's sensitivity to gas interactions. In this research, these measurements were taken with the polyimide coating set a 10 nm, 15 nm, and 20 nm.

Throughout the coating procedure, a portion of the input signal is reflected back to the circulator by the Bragg grating on the FBG. The circulator then assigns this reflected signal to the optical interrogator which acts as a sensing analyzing unit. The optical interrogator provides real-time data concerning the reflections received which is updated according to the monitored wavelengths ensuring uninterrupted tracking of gas concentration and detection of any changes in the environment. Analysis of the data captured enables the gas sensor system to provide accurate and reliable information on the level and concentration of gases in the monitored space.

Optical circulators are employed to control the direction of light propagation through a sequence of optical fibers, ensuring that the light travels consistently in a designated path [25]. Circular optics enable the propagation of the incoming signal and the reflected signal to move in one direction which is important for signal transmission. These devices, by controlling the direction of light flow, assist in the design of optical systems in an easier way by minimizing the volume and dimensions of the system. More often than not, such an approach can result in cost savings while at the same time improving efficiency. In addition, optical circulators increase redundancy and reliability of the system by separating input and output ports, allowing the system to keep functioning when one of the paths fails.

Additionally, optical interrogators serve as crucial analyzers of the reflected signals in this design. They are essential components in optical sensor systems, responsible for collecting and interpreting data obtained from the sensors [26]. Gas concentration monitoring is just one of the many environmental parameters that an optical sensor system can detect and an optical interrogator can help in its measurement. They provide real-time data that is essential for environmental monitoring which is pivotal for ecological preservation. The achievement of optical sensor systems is optimized with the addition of interferometers due to increased precision and efficiency. This invention is vital for numerous fields and fosters the further modification of optical sensors. Lets us describe in detail the entire research methodology conducted to achieve this aim which is based on is the application of micron optics optical interrogators with four active channels.

In the case of detecting CO, FBG sensors are often due to their necessity, coated or combined with sensitive materials which measure shifts in the Bragg wavelength. This study capitalizes on a polyimide coating which is known to absorb CO_2 selectively. The interaction of CO_2 with this material causes changes in motion, for example swelling or changes in a refractive index. This results in a measurable shift in the effective refractive index of the FBG which is strain sensitive, therefore, changing the refracted light's wavelength. Moreover, FBGs can be added into microfluidic systems or gas-permeable membranes that allow preferential diffusion of CO_2 which increases sensitivity to detection. The concentration of CO_2 is calculated from the shifted wavelength of the reflected signal. Along with numerous benefits, FBG based CO_2 sensors are able to provide remote sensing, high sensitivity, real-time data streaming, and immunity to electromagnetic signals. This has resulted to an increased application of the sensors in environmental monitoring, industrial safety, and medic medical fields. Through modifying the coating materials and improving the sensor design, reliable and efficient CO_2 detection can be achieved using FBG sensor-based technologies, making them ideal candidates for gas sensors.

3. RESULTS AND DISCUSSION

3.1. Experimental results of polyimide coated fiber bragg grating for CO_2 gas sensor

The FBG sensor has shown to have a high level of precision and reliability when detecting the changes in CO_2 levels. Because of its exceptional stability and repeatability over time, it is well suited for long-term monitoring applications. Also, its reliability was further improved because the sensor showed low drift and low interference from other gases. These results demonstrate the accuracy and reliability of the improved FBG sensor in monitoring the CO_2 levels. Not only did the FBG sensor meet performance expectations, but also the sensor's potential applicability for other environmental monitoring projects is remarkable. Environmentalists and researchers who are in need of accurate and reliable data for CO_2 measurement found the enhanced FBG Sensor to be extremely helpful. The reason why the sensor is favorable for long-term monitoring projects is because of its precision, stability, and low interference from other gases. Beyond CO_2 detection, the remarkable performance of the sensor highlights its wider versatility and no scope applicability. The advanced FBG sensor will have great significance given its accuracy and dependability, in the development of environmental research and monitoring efforts.

The results achieved from measuring CO_2 gas using the developed FBG sensors is shown in Figure 4. Figure 4(a) is transmittivity of an uncoated FBG, Figure 4(b) shows the FBG coated with 10 nm polyimide, Figure 4(c) shows FBG coated with 15 nm polyimide, and Figure 4(d) shows the FBG coated with 20 nm polyimide The uncoated FBG was capable of measuring CO_2 concentrations of 3 ppm or more, achieving peak sensitivity at 1.8 ppm during rigorous measurements. When coated with 10 nm of polyimide, the sensor's sensitivity increased to 1.9 ppm. Sensitivities of 1.83 ppm and 1.8 ppm were achieved with 15 and 20 nm coatings respectively. It is clearly observable from these results that lower sensitivity values (in ppm) are related with higher sensitivity values of the sensor.

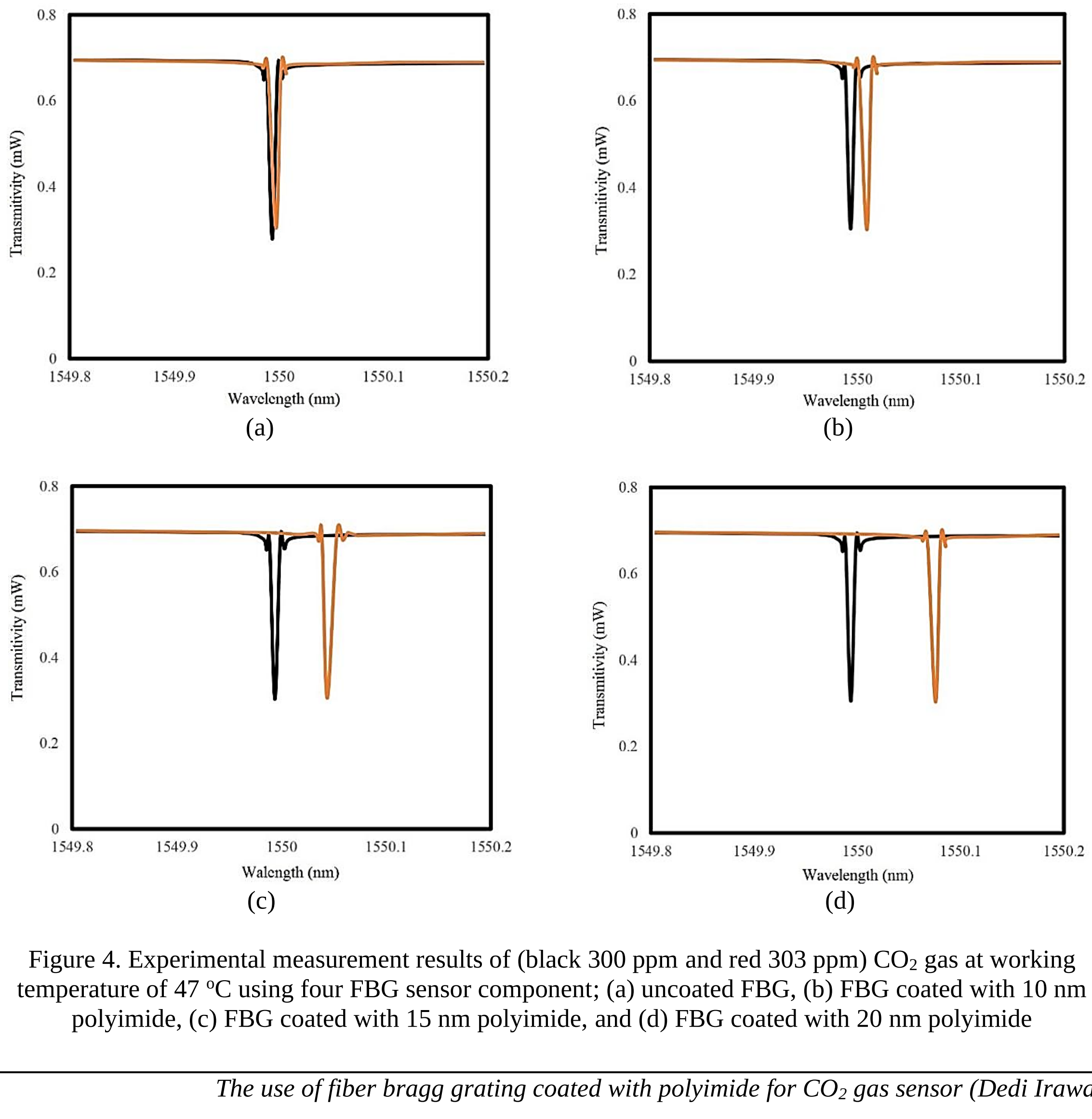

Figure 4. Experimental measurement results of (black 300 ppm and red 303 ppm) CO_2 gas at working temperature of 47 ^{o}C using four FBG sensor component; (a) uncoated FBG, (b) FBG coated with 10 nm polyimide, (c) FBG coated with 15 nm polyimide, and (d) FBG coated with 20 nm polyimide

Increasing the thickness of the coating material on the FBG substrate does not always lead to enhanced sensitivity. As illustrated in Figure 5, a sensitivity of 1.8 ppm is realized when a 20 nm polyimide coating is applied to the FBG, but further increasing the coating thickness to 30 nm reduces the sensor's sensitivity. Regardless, these results mark an improvement from earlier studies where the FBG was simply coated with polyimide material [27]. Like other gas detectors, FBG sensors show great sensitivity towards CO_2 gas. FBG sensors however go a step further, as their gas detection becomes less hazardous, more power efficient, and optically based. This operational stand makes the use of FBG sensors more stable and technologically advanced. This result is still comparable with other research which has been done such as shown in Table 1.

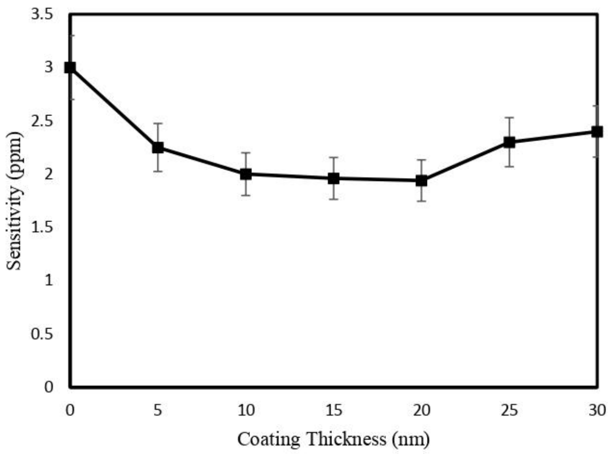

Figure 5. Sensor sensitivity profile as function of coating thickness

Table 1. Comparison between propose study with previous results

No	Research	Gas type	Sensor material	Sensitivity (ppm)
1	[10]	CO_2	Polymer nanocomposite	3
2	[28]	CO_2	Carbon nanostructure	2.2
3	[27]	CO_2	Graphene coated FBG	3.7
4	This proposes study	CO_2	FBG coated with polyimide	1.8

FBG sensors coated with polyimide maintain their dimensions. Apart from the coating improving the sensor's sensitivity, it also increases the sensor's durability, enabling it to withstand a variety of applications. The small size of the sensor combined with its strength facilitates its deployment in difficult or far-off regions, allowing researchers to collect data from places that were difficult to reach before. This is important for analyzing the effects of global warming on different ecosystems and regions. In addition, the low power consumption and ease of integration with other monitoring systems make the sensor economical for financially strained organizations. In summary, the sophisticated FBG sensor has the capability to change the way environmental data is monitored and analyzed which will improve decision making and conservation efforts. The sensor's accurate and precise measuring capabilities regarding CO_2 concentrations enables detection of areas that require immediate attention. Moreover, applying machine learning algorithms to analyze the sensor's parameters and optimize the FBG's geometric configurations could further enhance the detection sensitivity of the FBG sensors. The functionality of FBG sensors is improved through the application of machine learning by enhancing their sensitivity, selectivity, and data interpretation capabilities. Regardless of background noise and external changes, machine learning can precisely detect and categorize spectrum changes caused by gases due to their robust technologies. Using neural networks and support vector machines, the sensor system can distinguish between vast patterns contained in reflected wavelength data, allowing differentiation between various gases. Additionally, machine learning can aid in unfitting changes from temperature and humidity calibrations, improving real-time monitoring procedures and enhancing the reliability and effectiveness of FBG sensors in various gas sensing applications.

3.2. Optical properties of fiber bragg grating coated with polyimide

The detection of CO_2 using polyimide-coated FBG sensors have a remarkable sensitivity. This is due to the protective characteristics of the polyimide layer which enables the sensor to be monitored continuously over varying conditions since it is protected against corrosion. This allows freedom for researchers to study emission levels of CO_2 and its effects on ecosystems and wildlife. In terms of conservation, important information gathered through the use of these sensors can support policies to be made for sustaining the future. These polyimide-coated FBG sensors enable accurate measuring of emission levels of CO_2 in real time aiding researchers complement their studies on climate change's impact on ecosystems, proving the technology's potential for enabling scientists to gain further insights into CO_2 impacts biodiversity and ecosystem health. The application of these sensors into environmental monitoring systems paves the way for more strategic plans to reduce the adverse effects of the emission of CO_2.

In addition, polyimide coated FBG sensors can serve one of the most crucial purposes aiding in the early recognition of environmental wildfires, and industrial activities which might discharge harmful, wasteful gases into the atmosphere. Monitoring CO_2 levels in a nation in a preemptive manner helps in not allowing ecosystems and wildlife to suffer from irreversible destruction which makes civilization more favorable towards life. Also, the information accumulated from such sensors helps in policymaking and taking required actions towards negative carbon emission policies and tackling climate change initiatives. We can create a much healthier and resilient planet for the coming generations by technological innovation. Comprehensive monitoring offers better understanding regarding the impacts brought about by human endeavors made towards the environment, which can be further used in decision-making for measures and policies crafted to minimize damage. With real-time data, investment in proactive systems makes dealing with upcoming environmental challenges easy, turning possible crises into postponed ones. The planet is in dire need of imagination that can be coarse useful, by understanding the socio-environmental dynamics that can enable world requirement attention where need be.

Figure 6 displays the profiles of the signals reflected back from the four terminals of the sensor interrogator. In this case, the experiment was conducted with four FBGs having fundamental wavelengths close to 1549.98 nm. The black line indicates the reflected signal from an uncoated FBG whose peak wavelength is roughly 1549.98 nm. Coating the FBG with polyimide, as discussed, does improve the sharpness of the spectral waveform. Out of all the coatings, the FBG with 20 nm polyimide surface layer has sharper spectrum than those with 15 nm and 10 nm polyimide layers. A sharper spectrum tends to improve the rate of response of the sensor to physical variations, thereby improving sensitivity for describing physical parameters. Furthermore, the FBG spectra display stable symmetrical shapes.

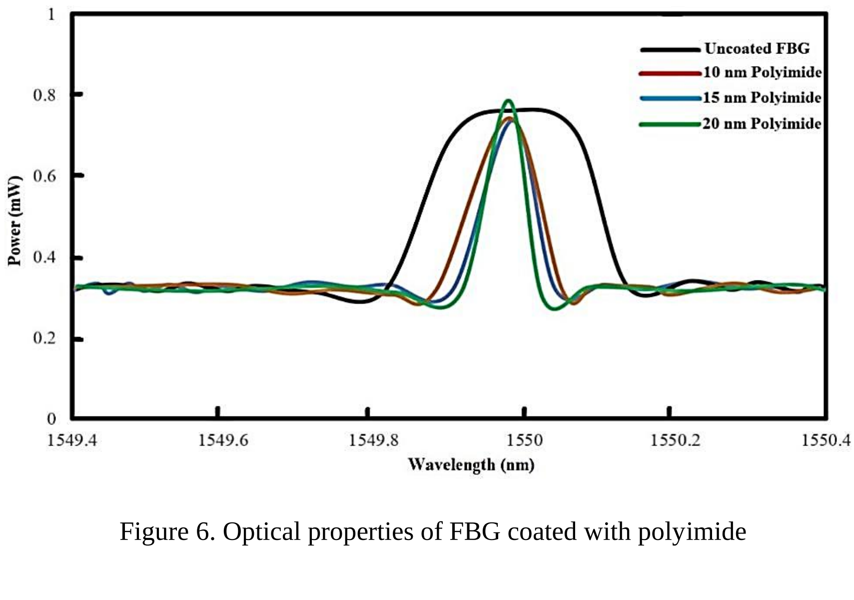

Figure 6. Optical properties of FBG coated with polyimide

Thanks to the efficacy and quick reaction of optical spectrum FBG sensors, real-time tracking of environmental conditions is now possible. These sensors are capable of unprecedented accuracy in providing certainty on changes of temperature, pressure, and chemical composition, hence proper actions can be executed based on decisions made within a very short period of time. Such advancement of environmental protection and sustainability efforts through the use of optical spectrum FBG sensors are made possible due to reliable and accurate readings from the sensors. Newer earth friendly initiatives aimed towards combating climate change largely depend on such technology which is made available through innovation to monitor and maintain a greener planet for the future. Employing these equipment results in ease and efficiency in monitoring optical spectrum FBG sensors tracking changes in the environment. These technologies will enable us to act before any potential harm to ecosystems arise, allowing us to minimize risks in advance. Placed in strategic locations around the world and integrated as a system, these technologies will greatly help in achieving environmental sustainability for future generations.

4. CONCLUSION

Successfully fabricated FBGs with varying reflectance coefficients and thicknesses of polyimide coating are complete. From the optical characterization results, it can be inferred that adding polyimide to the surface of the FBG improves the sensor's sensitivity for CO_2 detection. From the experiments conducted, it was noted that the sensitivities of the polyimide-coated FBG sensors with coating thickness of 10 nm, 15 nm, and 20 nm were 1.9 ppm, 1.84 ppm, and 1.8 ppm respectively. The sensitivity of the uncoated FBG was measured at 3 ppm which is lower than expected. It was also determined that increasing the coating thickness further beyond 20 nm reduces the sensitivity of the sensor. Hence, a polyimide coating thickness of 20 nm may be ideal for enhanced FBG sensitivity in CO_2 detection. These polyimide-coated FBG sensors with high sensitivity require further work but have astonishing potential for widespread use in industrial, agricultural, aerospace, and automotive applications.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

This research is not related with animals and peoples.

DATA AVAILABILITY

The data that support the findings of this study are openly available in [repository name] at doi: 10.3389/fenrg.2021.634321 [10], 10.26554/sti.2024.9.3.710-717 [27], and 10.1063/5.0104007 [28].

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