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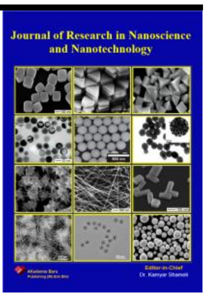

Analysis of Graphene Coating Thickness for Single Mode and D-Shaped Fiber Sensor

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ABSTRACT

This project analyzed the impact of coating thickness on Single-Mode Fiber (SMF) and D-Shaped Fiber Sensors. Graphene was applied as the coating material using the drop casting method. The study aimed to investigate the influence of different coating thicknesses on the transmission spectrum of these sensors and examine the relationship between coating thickness and sensitivity. Coating thicknesses ranged from 0 to 21.523 µm, measured using a 3D laser microscope. The analysis revealed that coating thickness significantly affected the optical characteristics. SMF sensors showed small changes in the transmission spectrum with increasing coating thickness. D-shaped fiber sensors, with their unique cross-sectional shape, demonstrated a redshift in the transmission spectrum. Thinner coatings had peak points around -45.055 dBm, while thicker coatings had peak points around -63.646 dBm. These findings provide insights for optimizing the coating process and customizing fiber optic sensors with graphene coatings. Future research can explore alternative methods, materials, and applications for graphene-coated fiber sensors.

Keywords:
SMF, D-shape fiber, Drop cast method,
Graphene, Transmission Spectrum.

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1. Introduction

Optical fibers were initially developed for data transmission but later found applications in manufacturing sensors. Optical fiber sensors (OFS) have been extensively explored, although they haven't achieved the same commercial success as fiber communications [3]. OFS utilize a sensing element to measure parameters like temperature, pressure, vibrations, and chemical concentrations [3]. They are widely used in remote sensing due to their small size and lack of electrical power requirements [2].

Fiber-optic sensing systems are passive, devoid of electrical circuitry, and impervious to electrical interference, making them ideal for protecting electronic components [1]. Coating a fiber sensor with specific materials can enhance sensitivity by improving the interaction between the evanescent wave and the sample [3]. Graphene is a promising material for coating fiber optic sensors, it is an excellent conductor of electricity and has exceptional sensitivity to changes in the surrounding environment.

Among the various types of fiber optic sensor, this research specifically focuses on two types, which are Single Mode (SMF) and D-shaped fiber sensor. Both types offer distinct advantages and applications based on their specific structural designs [4]. However, both types require optimized coating thickness for efficient signal transmission [2]. The coating thickness plays a crucial role in the efficiency of light transmission through the fiber sensor. Any deviations from the desired coating thickness can lead to signal loss, increased attenuation, or changes in signal characteristics, ultimately affecting the performance of the sensor [5].

Various research groups have analyzed how coating thickness and material choices impact the sensitivity and response time [1]. Thicker coatings offer better protection but result in slower response times [3]. Higher power intensities improve sensitivity and detection range by increasing the signal-to-noise ratio in optical fiber sensors [1]. However, extremely high-power intensities can cause nonlinear effects in the fiber, requiring mitigation.

The transmission spectrum (TS) of OFS refers to the relationship between the power intensity of the transmitted light and its wavelength [3]. As the coating thickness changes, the effective refractive index of the fiber changes, leading to variations in the modal propagation constants [5].

The study aims to determine the optimal coating thickness of graphene for D-shaped and Single Mode fiber sensors, enhancing performance and accuracy in various industrial applications. These findings will provide valuable insights for improving performance and accuracy in industrial settings.

1.1 Fiber Optic Structure

1.1.1 Single mode fiber sensor

SMFs allow only one mode of light propagation and are used in long-distance telecommunications due to their minimal signal degradation [5]. Their structure consists of a solid core surrounded by a cladding layer, achieving low dispersion and attenuation as shown in Figure 1. SMFs find applications in telecommunications, fiber optic sensing systems, and high-speed data communication [3].

The core of the fiber is designed to support only one mode of light propagation. The core has a diameter of 9 μm and a cladding diameter of 125 μm, which enables precise control of light transmission [3].

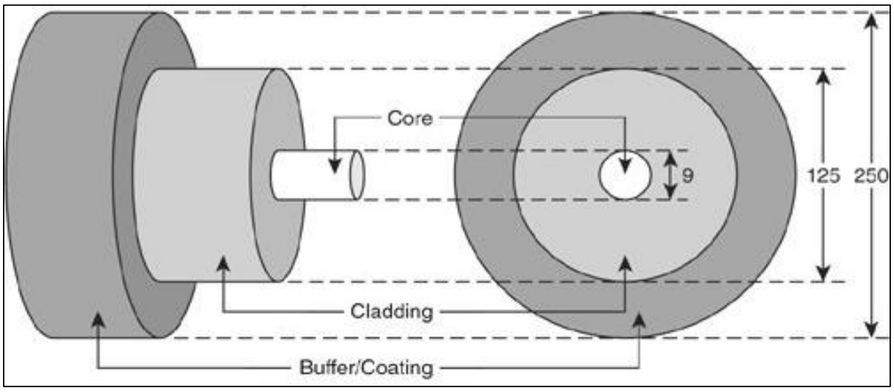

Fig. 1. Structure of single mode fiber sensor [5]

1.1.2 D-Shaped fiber sensor

D-shaped fiber sensors have a flattened shape resembling the letter "D" in cross-section as shown in Figure 2. The flat side of a D-shaped fiber allows for efficient coupling of light into or out of the fiber [2]. The flat side of the fiber can be used to attach sensing elements or coatings, thus facilitating close contact between the sensing material and the external environment and enhancing sensitivity [1].

The exposed portion of the D-shaped fiber can be coated with specific materials or functionalized with sensing layers to selectively interact with target analytes or substances [5]. The rectangular cross-section of D-shaped fibers provides improved mechanical strength and resistance to bending, compared to circular fibers [2]. This can be especially useful in applications where the fibers may be subjected to bending or flexing.

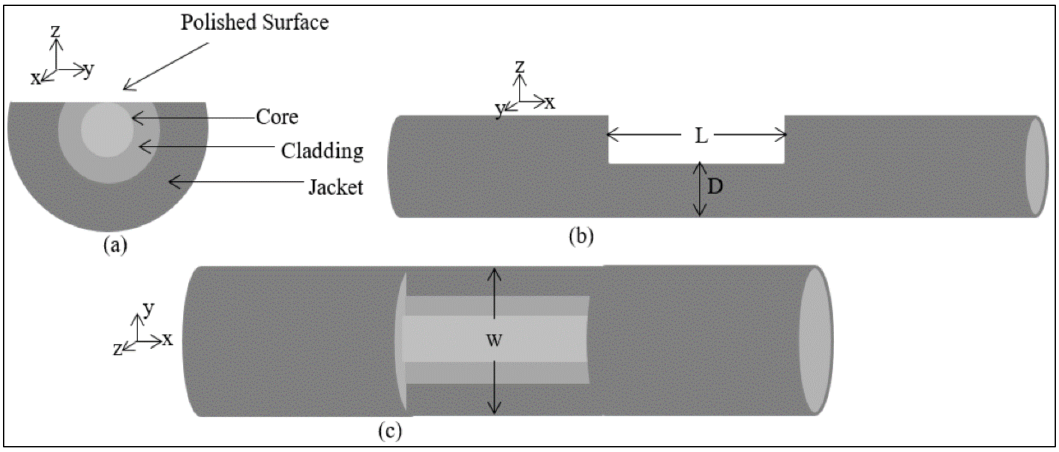

Fig. 2. Structure of D-shaped fiber sensor [2]

2. Materials and Methods

The project analysis incorporates three distinct coating thicknesses, which have been measured in terms of height thickness using a 3-dimensional laser microscope. The coating material employed is graphene. This project involves the utilization of two different fiber types to assess their sensitivity and identify the optimal coating.

The analysis is performed by examining the data from the transmission spectrum. The project methodology encompasses six stages, beginning with a description of the tasks to be accomplished, followed by the consideration of prior work references. The process flow methodology concludes with the analysis of the collected data, as illustrated in Figure 3.

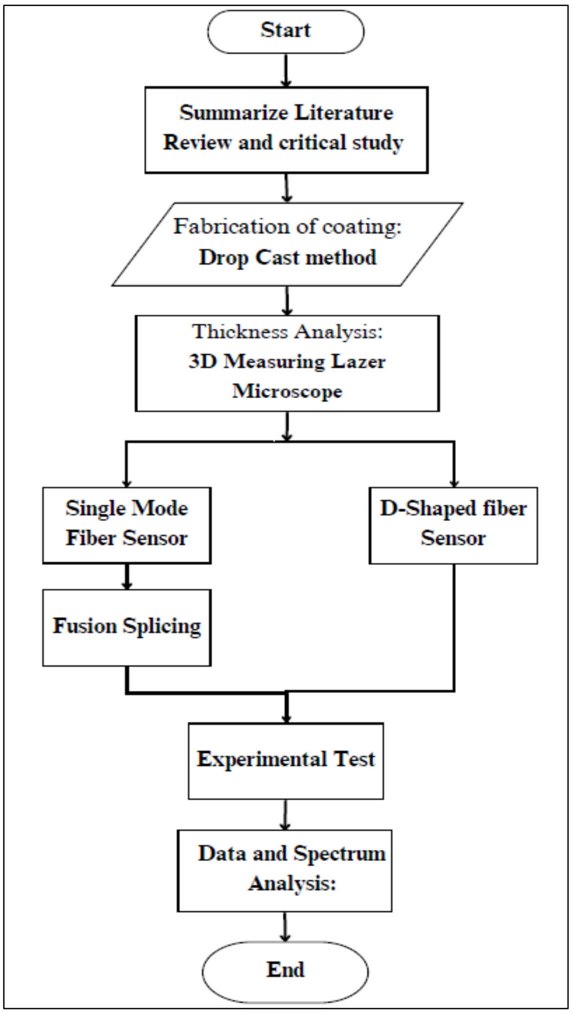

Fig. 3. Methodology flowchart

2.1 Fabrication of Coating

2.1.1 Preparation of graphene solution

The initial step in preparing the graphene solution for fiber sensor coating involves the combination of 50 grams of graphene powder with 100 ml of butyl acetate [7]. In order to achieve complete blending, a magnetic stirrer was employed, set at a temperature of 21°C and a stirring speed of 400 RPM for a duration of two hours [7].

This process facilitates the dispersion and homogenization of the graphene particles within the solution, resulting in a well-mixed and uniform distribution of the graphene [4]. The use of butyl acetate as a solvent enables the graphene powder to dissolve effectively, forming a stable solution suitable for subsequent coating applications [1].

The magnetic stirrer promotes efficient blending by generating a rotating magnetic field, which causes the stirring bar to rotate and induce fluid motion, thereby aiding the dispersion of graphene particles [3]. This step is crucial in obtaining a consistent and optimal graphene solution, enhancing the performance and reliability of the fiber sensor coating [5]. Figure 4 shows the graphene solution that is ready for usage before being dropped onto a fiber.

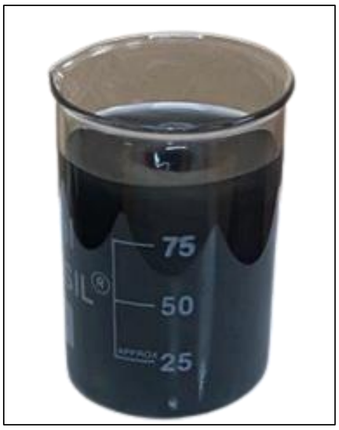

Fig. 4. Graphene solution

2.1.2 Drop-casting method

The drop casting method is commonly used for coating fiber optic sensors [4]. In this method, graphene as a coating material is carefully dropped or dispensed onto the fiber surface [5]. First, the coating material which is graphene is prepared and the fiber surface is ensured to be clean and free from contaminants. Then, place a small amount of the coating material on a suitable surface or container. Using a dropper, dispense droplets of the coating material onto the desired area of the fiber sensor. Aim for appropriate droplet size and ensure even distribution [14].

Allow the coating material to dry or cure. This may involve air drying, heating, or exposure to specific curing conditions like UV light or elevated temperatures [5]. Ensure the drying process doesn't introduce stress or damage to the fiber sensor [8]. Once the coating has dried or cured, visually inspect the coated fiber sensor for any imperfections, bubbles, or unevenness. Perform tests or measurements to verify the coating's performance and thickness aligning with specific requirements [8]. The method of the drop-casting method is shown Figure 5.

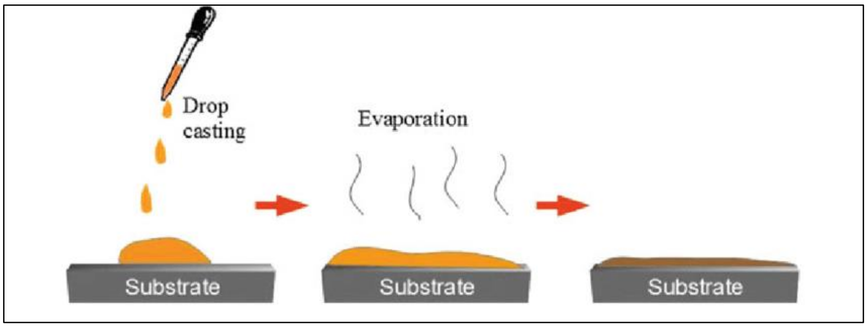

Fig. 5. Drop casting method [3]

2.1.3 Thickness analysis 3D measuring laser microscope

The 3D laser microscope is employed for the analysis of graphene solution thickness. The thickness is determined by evaluating the height of the solution [7]. The procedure for utilizing the microscope to measure the thickness of deposited graphene solutions involves multiple steps.

Firstly, a sample is prepared by applying the solution to a slide. Several drops of the solution are placed on separate slides. Subsequently, the slide is positioned beneath the microscope, and the laser is focused on the sample [8]. The microscope then performs a scan of the sample and generates a height profile of the surface [7]. This profile enables the determination of graphene solution thickness at different locations [6]. Figure 6 illustrates the surface structure for the indicated location of the graphene solution under the 3D laser microscope.

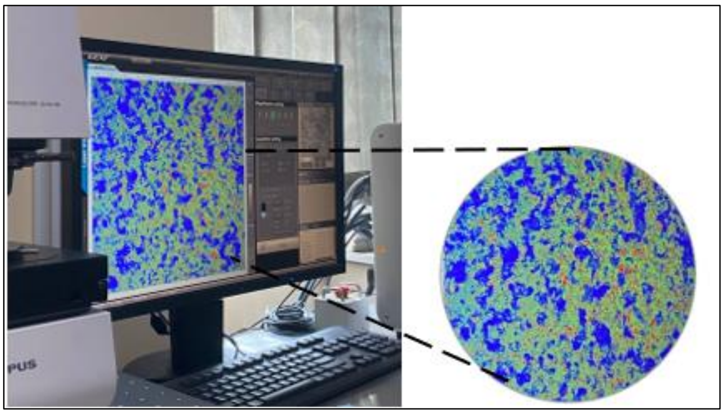

Fig. 6. Graphene solution surface structure

It is important to note that measuring the thickness of graphene solution using a laser microscope can present challenges due to the transparent nature of the material [7]. However, by modifying the wavelength and intensity of the laser, it may be possible to obtain precise measurements [9].

2.2 *Experiment Set-up for Sensing Testing*

A conventional transmission setup was used to examine and monitor the reaction of D-Shaped and Single Mode fiber when coated with graphene of varying thickness. The coating process involved cleaving and splicing a section of the optical fiber at both ends, which was subsequently coated using the drop cast method.

The spectral response of the sensor was obtained by utilizing a standard optical transmission setup. Figure 7 illustrates this setup, which comprises an Amplified Spontaneous Emission (ASE) Source connected to the input of the optical fiber, while the other end is connected to an Optical Spectrum Analyzer (OSA).

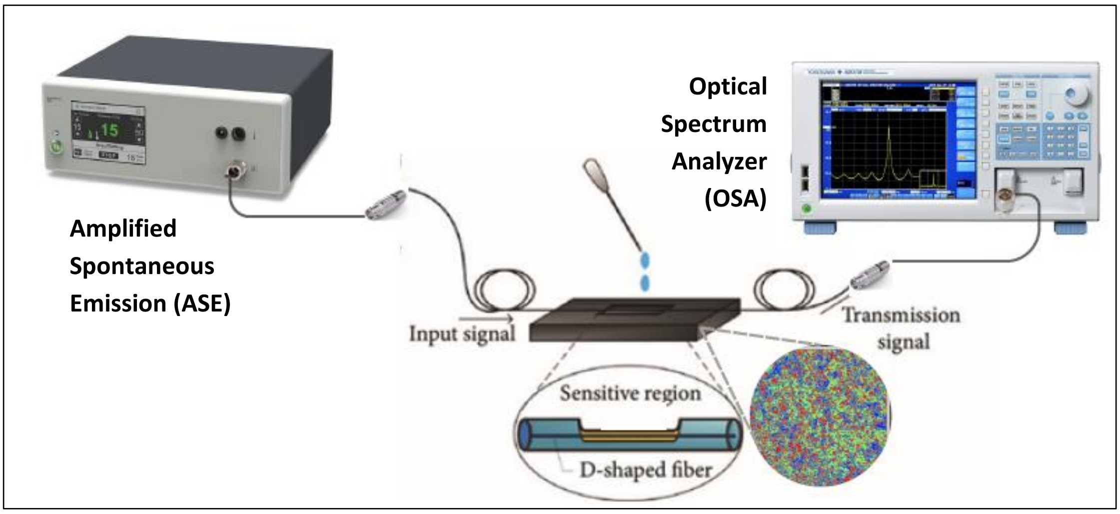

Fig. 7. Schematic diagram of the optical transmission experimental setup

3. Results and Discussion

3.1 Thickness Analysis

The height of the thickness is determined by analyzing the maximum peak in the profile generated by the 3D laser microscope. This peak corresponds to the highest point along the sampling length where the curve reaches its maximum value [8]. The microscope determines the height of the sample feature by comparing the measured phase shift to the reference calibration data.

By identifying and measuring this peak, thickness at that specific point can be deterimned[4]. This information is then recorded in Table 1, which displays the various thickness measurements obtained from three different types of drops. For the calculation yields the height value in units such as micrometers (μm) [11]. The table provides a comparison of the thickness values for each drop type, allowing for further analysis and interpretation of the data.

Table 1. Result of thickness measurement from 3D laser microscope

Number of graphene drops	Average thickness height (μm)
20	9.399
28	17.706
32	21.523

The accuracy of height measurements can be affected by the surface preparation of the sample [12]. During this measurement, if the surface is rough or uneven, it can introduce complexities in accurately determining the true height [6]. So that, calculating the average height are needed to approximate the actual height.

To calculate the average height, sum up the heights of the selected data points, and then divide that sum by the total number of data points selected [7]. The formula to find the average of height as shown in Eq. (1). From this calculation provides an average height value that represents the region of interest as shown in Table 1.

$$Average\ formula: \frac{Sum\ all\ observation\ Height\ (\mu m)}{Total\ number\ of\ data\ point} \quad (1)$$

3.2 Coating Analysis

3.2.1 Analysis of SMF with different coating thickness of graphene

Figure 8 shows the analysis conducted on the transmission spectrum for SMF. Three thicknesses were considered in this experiment: which are 0, 9.399 μm, and 21.523 μm. The OSA has been configured with a specific wavelength range to indicate the beginning and end points of the analyzed spectrum [11]. The start wavelength is set at 1520 nm, while the stop wavelength is set at 1630 nm [11].

By examining the graph, the peak intensity power values at specific wavelengths were recorded for each thickness and summarized in Table 2. The results showed that the SMF sensor without any coating exhibited a peak intensity power of -47.0 dBm at a wavelength of 1550 nm. However, when the thickest coating of 21.523 μm was applied to the fiber, the intensity power decreased to its lowest value of -57.46 dBm

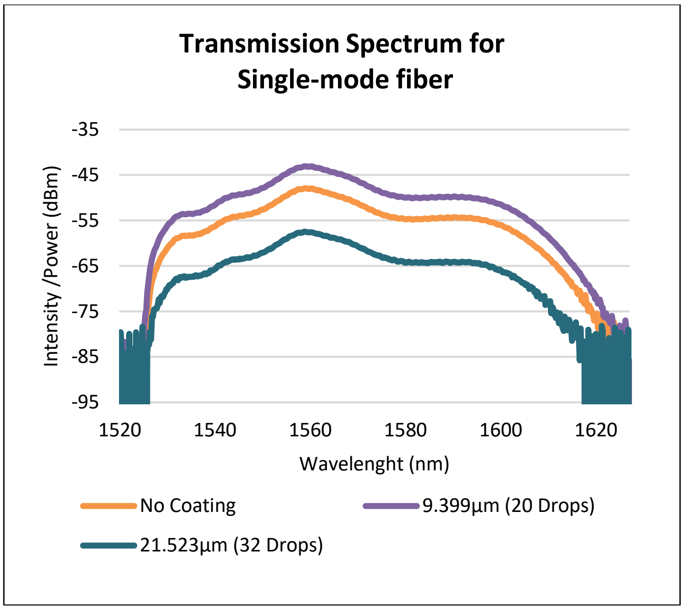

Fig. 8. Transmission spectrum of single mode fiber coated with different graphene coating thickness

Table 2. Transmission spectrum peak point result for single mode fiber sensor

	Peak point Intensity/power (dBm)	Wavelength (nm)
No coating (0 µm)	-47.00 dBm	1550 nm
20 drops (9.399u µm)	-43.05 dBm	1552 nm
32 drops (21.523 µm)	-57.46 dBm	1556 nm

These findings indicate that a coating is necessary for the fiber sensor, but it should be applied in a thin layer to enhance the intensity power compared to the uncoated fiber [13]. Furthermore, when the fiber is coated with a height of 9.399µm, the optic sensor undergoes modifications in its transmission spectrum increasing to -43.05 dBm.

3.2.2 Analysis of D-shape fiber with different coating thickness of graphene

In the subsequent experiment, the focus shifted to D-shaped fiber, and the graph of the transmission spectrum for D-shaped fiber with different coating thicknesses was examined as depicted in Figure 9. Like the previous SMF experiment, three thicknesses were employed to observe the effects.

The D-shaped experiment requires a specific wavelength range for the OSA. The starting wavelength is set at 1520nm, and the stopping wavelength is set at 1630nm [11]. The selection of this wavelength range considers both the capabilities and limitations of the measurement equipment utilized.

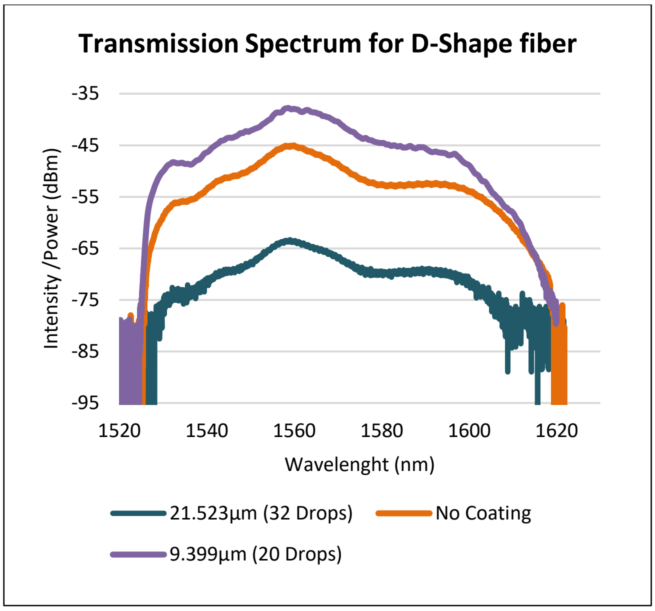

Fig. 9. Transmission spectrum of D-shaped fiber coated with different graphene coating thickness

The peak intensity power values at specific wavelengths summarized in Table 3. It was observed that, the D-shaped sensor without any coating shows a higher peak intensity power of -45.055 dBm compared to the single-mode fiber experiment. Conversely, when the thickest coating of 21.523 µm was applied to the D-shaped fiber, the intensity power decreased to its lowest value of -63.646 dBm.

Table 3. Transmission spectrum peak point result for D-Shaped fiber sensor

	Peak point Intensity/power (dBm)	Wavelength (nm)
No coating (0 µm)	-45.055 dBm	1551 nm
20 drops (9.399 µm)	-37.94 dBm	1553 nm
32 drops (21.523 µm)	-63.646 dBm	1547 nm

When a thin layer of coating was applied to the D-shaped fiber, an increase in intensity power was observed. Specifically, the intensity power reached -37.94 dBm at a wavelength of 1553 nm. This improvement in intensity power compared to the scenario without any coating highlights the positive effect of the coating on the D-shaped fiber [13]. This indicates that the coating plays a crucial role in enhancing the intensity power of the D-shaped fiber sensor [10].

3.2.3 Analysis between SMF and D-shape fiber

In comparing the analysis between Single Mode fiber (SMF) and D-shaped fiber sensors, the peak values of intensity/power response to changes in coating thickness when utilizing graphene were examined. This comparison is illustrated in Figure 10.

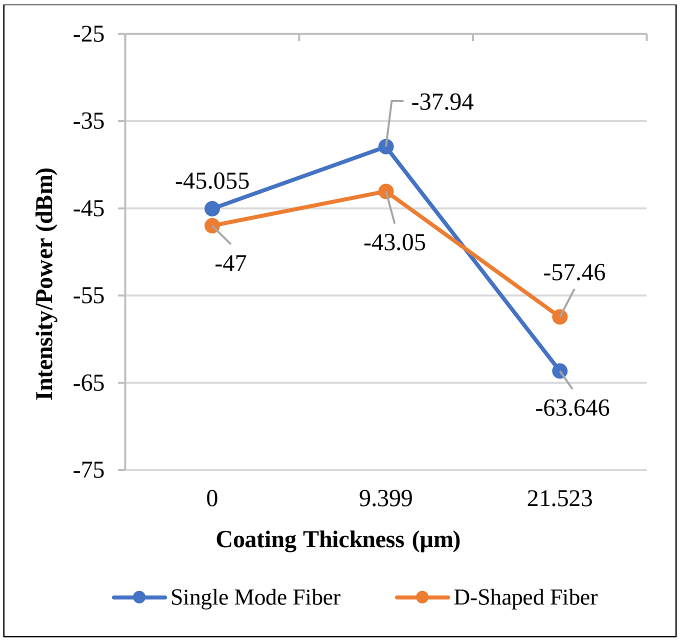

Fig. 10. The peak values of intensity/power (dBm) response of D-shape and single mode fiber to the thickness of graphene coating

The D-shaped fiber sensor exhibits higher sensitivity than SMF due to its unique structure [10]. Without any coating, the D-shaped fiber has an intensity power of -45.055 dBm, higher than SMF's -47.0 dBm. Applying a thin coating of graphene solution to the D-shaped fiber significantly increases intensity power to -37.94 dBm. SMF shows a smaller increment, from -47 dBm to -43.05 dBm, with the same coating.

These changes result from the modified effective refractive index due to the thicker graphene coating layer [8]. Higher coating thicknesses correlate with lower power levels (-dBm), indicating greater sensitivity in fiber sensors. Higher sensitivity enables the detection of smaller changes in the measured parameter [13]. However, thicker coatings may lead to slower response times, although they offer better sensor protection [13].

The increase in intensity (in dBm) of the transmission spectrum in this research is not directly linked to total internal reflection or evanescent wave phenomena. Intensity represents the power of transmitted light at different wavelengths, and a higher intensity indicates increased power [10]. This rise can stem from factors unrelated to total internal reflection and evanescent waves [11].

The changes in the transmission spectrum, including intensity increases at specific wavelengths, can be caused by variations in the refractive index of the sensor coating material, alterations in the absorption or scattering properties of the coating, or changes in the concentration or presence of analytes in the sensed environment [10]. These factors influence the interaction of light with the coating and impact the transmitted light, contributing to modifications in the transmission spectrum [13].

The analysis reveals the D-shaped fiber sensor's superior sensitivity to SMF when using graphene coating with varying thicknesses. The intensity power values and effects of thicker coatings emphasize the trade-off between sensitivity and response time in fiber sensors [8].

4. Conclusions

In conclusion, a fiber sensor's sensitivity to changes in the surrounding medium's refractive index and its transmission spectrum are both affected by changing the coating thickness. The transmission spectrum shows the relationship between wavelength and power intensity [1].

The primary objective of the research was to explore the correlation between coating thickness and the sensitivity of D-shaped and Single-mode fiber sensors. Both D-shaped fiber sensors and single-mode fiber sensors rely on total internal reflection and evanescent wave phenomena for their operation [5], the specific impact on the transmission spectrum and sensitivity differs due to variations in the design and geometry of the sensors [10].

By examining the trade-offs and limitations associated with different coating thicknesses on the D-shaped and Single-mode fiber sensor, it becomes evident that thinner coatings enhance sensitivity but may cause shifts in the transmission spectrum, whereas thicker coatings reduce sensitivity while affecting the transmission spectrum differently. This can be attributed to alterations in total internal reflection and interactions with the evanescent wave, both of which are influenced by the properties of the surrounding medium and the graphene coating [15].

Determining the optimal coating thickness relies on the specific requirements of the application and the desired balance between sensitivity and spectral characteristics [9]. Lastly, the analysis of the results has demonstrated that, when utilizing graphene, D-shaped fiber sensors exhibit higher sensitivity compared to SMF when subjected to variations in coating thickness. The power intensity values and the impacts of thicker coatings emphasize the trade-off between sensitivity and response time in fiber sensors [15].

References

1. Moosa, Ahmed, and Mayyadah Abed. "Graphene preparation and graphite exfoliation." *Turkish journal of Chemistry* 45, no. 3 (2021): 493-519. https://doi.org/10.3906/kim-2101-19
2. Tien, Chuen-Lin, Hong-Yi Lin, and Shu-Hui Su. "High sensitivity refractive index sensor by D-shaped fibers and titanium dioxide nanofilm." *Advances in Condensed Matter Physics* 2018 (2018): 1-6. https://doi.org/10.1155/2018/2303740
3. Pathak, A. K., R. K. Gangwar, P. Priyadarshini, and V. K. Singh. "A robust optical fiber sensor for the detection of petrol adulteration." *Optik* 149 (2017): 43-48. https://doi.org/10.1016/j.ijleo.2017.09.036
4. Chauhan, Maya, and Vinod Kumar Singh. "A fiber optic refractive index sensor using a high index layer of TiO2." In *AIP Conference Proceedings*, vol. 2220, no. 1. AIP Publishing, 2020. https://doi.org/10.1063/5.0001690
5. Li, Changxu, Wenlong Yang, Min Wang, Xiaoyang Yu, Jianying Fan, Yanling Xiong, Yuqiang Yang, and Linjun Li. "A review of coating materials used to improve the performance of optical fiber sensors." *Sensors* 20, no. 15 (2020): 4215. https://doi.org/10.3390/s20154215
6. "3D Measuring Laser Microscope | MJIIT Microscopy Laboratory." https://mjiit.utm.my/microscopy-lab/3d-measuring-laser-microscope/ (accessed May 12, 2023).
7. "LEXT OLS4000 Industrial Laser Confocal Microscopes - Olympus 3D Laser Measuring Solution." https://www.olympus-ims.com/en/metrology/ols4000/ (accessed May 12, 2023).
8. Ying, Yu, Jia-Kai Wang, Ke Xu, and Guang-Yuan Si. "High sensitivity D-shaped optical fiber strain sensor based on surface plasmon resonance." *Optics Communications* 460 (2020): 125147. https://doi.org/10.1016/j.optcom.2019.125147
9. Musa, Nurfatin, Muhammad Safwan Abd Aziz, Hazri Bakhtiar, Ganesan Krishnan, Mohd Hafiz Dzafran Othman, Mukhlis A. Rahman, and Ahmad Fauzi Ismail. "Performance of Single Mode Tapered Optical Fiber Sensor Based on Localized Surface Plasmon Resonance (LSPR) for Various Coating Time." In *Journal*

of Physics: Conference Series, vol. 1484, no. 1, p. 012021. IOP Publishing, 2020. https://doi.org/10.1088/1742-6596/1484/1/012021

10. Amiri, Iraj S., Siti Anis Khairani Alwi, Sofiah Atirah Raya, Nur Aina'A. Mardhiah Zainuddin, Nurul Syazwani Rohizat, MS Mani Rajan, and Rozalina Zakaria. "Graphene oxide effect on improvement of silver surface plasmon resonance D-shaped optical fiber sensor." *Journal of Optical Communications* 44, no. 1 (2023): 53-60. https://doi.org/10.1515/joc-2019-0094
11. "Optical fiber sensors - Optical fiber sensors." http://www.optique-ingenieur.org/en/courses/OPI_ang_M06_C04/co/OPI_ang_M06_C04_web.html (accessed Mar. 24, 2023).
12. Jusin, Jashiela Wani, Madzlan Aziz, Goh Pei Sean, and Juhana Jaafar. "Preparation and characterization of graphene-based magnetic hybrid nanocomposite." *Malaysian Journal of Analytical Sciences* 20, no. 1 (2016): 149-156. https://doi.org/10.17576/mjas-2016-2001-16
13. Johra, Fatima Tuz, Jee-Wook Lee, and Woo-Gwang Jung. "Facile and safe graphene preparation on solution based platform." *Journal of Industrial and Engineering Chemistry* 20, no. 5 (2014): 2883-2887. https://doi.org/10.1016/j.jiec.2013.11.022
14. "Intoduction to Drop Casting - Glassy Carbon Electrode." https://academic-accelerator.com/Manuscript-Generator/Drop-Casting/Glassy-Carbon-Electrode (accessed Jun. 15, 2023)
15. Jusin, Jashiela Wani, Madzlan Aziz, Goh Pei Sean, and Juhana Jaafar. "Preparation and characterization of graphene-based magnetic hybrid nanocomposite." *Malaysian Journal of Analytical Sciences* 20, no. 1 (2016): 149-156. https://doi.org/10.17576/mjas-2016-2001-16