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The optical performance of a U-shaped optical fiber sensor for glucose sensing applications

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ABSTRACT

This project demonstrated the development of a de-cladded U-shaped optical fibre used to measure optical performance and sensitivity in response to varying concentrations of glucose solutions. The optical fibre was fabricated by bending it into a U-shaped pattern with a curvature diameter of 1 cm and 2 cm. Subsequently, the cladding layer in the curved region was de-clad using a flame heating method for durations of 40 and 50 minutes. Optical characterization was conducted by transmitting a 1550 nm laser through the modified fibre that had dropped glucose solutions ranging from 1 mM to 8 mM. Changes in output power, due to refractive index variations in the glucose solutions, were detected using a photodiode. Scanning electron microscope (SEM) results revealed that the highest reduction in cladding thickness occurred at 2 cm curvature diameter with reductions of 4.58% and 5.34% for 40 minutes and 50 minutes heating, respectively. The optical response showed a linear decrease in output power with increasing glucose concentration. The highest sensitivity achieved was 2.5 µW/mM with R^2=0.90 for the 1 cm curvature diameter with 50 minutes of burning. In contrast, the 1 cm curvature at 40 minutes of burning time produced a sensitivity of 1.05 µW/mM (R^2 = 0.99). De-cladded of the cladding layer enhanced sensitivity in curvature region with precisely to detect small changes in output power for different concentrations of glucose solutions. Overall, the integration of the de-cladded cladding layer and U-shaped patterns of optical fibre sensors apparently offers more sensitive sensing detection capabilities.

Keywords: *Brush-flame method, De-cladded optical fiber, Glucose optical sensor, Sensitivity, U-shape optical fiber sensor*

1. INTRODUCTION

The growing research in optical fiber sensors (OFS) offers a significant impact on quality of life, particularly in healthcare applications. Health concerns will drive the demand for non-invasive OFS capable of real-time monitoring of vital biochemical parameters, such as glucose, urea, creatinine levels, pH, and more. Early diagnosis is crucial for effective disease management, where the development of OFS is currently being explored for this purpose. Additionally, the rising number of diabetic patients [1] leads to the necessity of developing a non-invasive device using painless measurement, which is very useful for early monitoring of glucose levels in diabetic patients. Optical fiber sensors provide a non-invasive method [2] and are able to detect small variations [3] in desired physical parameters such as different analyte concentrations. OFS also offers advantages including resistance to leakage and radiation [4], immunity to electromagnetic interference (EMI) [5], cost-effectiveness, light weight, miniaturization, flexibility, and biocompatibility [6]. Moreover, OFS is also suitable for integration into compact systems with multiple sensors and flexible systems. These advantages make OFS unique compared to conventional methods. In addition, the evanescent wave generated in the de-cladded region enables strong interaction between the guided light and the surrounding solution, allowing rapid detection of refractive index changes caused by variations in glucose concentration. However, the integration of U-shaped and de-cladded OFS has certain limitations, particularly in achieving a uniform de-cladded layer. The manual flame heating method often results in inconsistent de-cladding depth and bend diameter, which affects the repeatability and performance of the sensor. On the other hand, numerous variable parameters detected using OFS produced significant research impacts, such as seawater salinity [7], temperature [8], cable forces [9], marine structures [10], and more.

Several cost-effective sensing approaches [11] have been explored by modifying the optical fibre geometry to increase the sensitivity detection. This method allows the interaction of evanescence waves with changes in any physical parameters, changes at the surrounding of optical fibre resulting in higher transmission loss. Examples of physical change are refractive index, strain, temperature and many more. Meanwhile, the examples of sensing approaches that promote sensitive detection include U-bent, D-shape with de-cladded pattern, S-shaped, fibre Bragg grating (FBG) and tapered optical fibres.

This project aims to develop a de-cladded U-shaped optical fibre fabricated using the flame heating method for glucose detection. The normal range of blood glucose concentration in a healthy person is 80 to 120 mg/L (4.4 to 6.4 mM); however, a glucose level exceeding 200 mg/L after a two-hour meal is considered hyperglycemia [1]. In this project, artificial glucose solutions were prepared based on this concentration range to evaluate the sensor's ability to detect changes in output power from the fabricated optical fibre sensor.

Different curvature diameters and flame exposure durations were tested to identify the optimal combination for enhancing optical sensitivity. The optical performance, specifically the sensitivity of the sensor, was investigated across various glucose concentrations. The integration of the de-cladded region and the U-shaped configuration enhances the interaction of the evanescent field, thereby improving the sensor's sensitivity. Greater penetration of the evanescent wave into the glucose solution is achieved by removing the cladding layer using a manual flame heating method. This approach provides a simplified, cost-effective fabrication technique and demonstrates potential for real-time, label-free, and non-invasive glucose monitoring, offering advantages over conventional detection methods.

2. METHODOLOGY

2.1. Fabrication and Thickness Measurement of De-cladded U-shaped Optical Fiber Sensor

The flame heating method was used to fabricate de-cladded U-shaped optical fiber. Initially, the polymer coating on the single-mode fiber (SMF) was stripped away to expose the foundational optical fiber. Next, the optical fiber was bent into a U-shaped pattern with curvature diameters of 1 cm and 2 cm. Subsequently, the optical fiber was positioned near a blue flame, as depicted in Figure 1(a), for the de-cladding process lasting 40 and 50 minutes. The same process was repeated for the optical fiber with a 2 cm curvature diameter. After completing the burning time, the de-cladded optical fiber was allowed to cool down before thickness measurements were taken.

Before inspecting the optical fiber thickness using SEM, the optical fiber was coated with platinum using a sputtering machine to prevent charging effects and to provide precise imaging. The thickness of the optical fiber before the flame heating process was measured as a comparison for the thickness decrement before and after the burning process. Next, de-cladded U-shaped optical fiber for 40 minutes at 1 cm curvature diameter is measured at three different points as depicted in Figure 1(b). This process was repeated for a 1 cm curvature radius at 50 minutes of burning time and a 2 cm curvature diameter for 40 minutes and 50 minutes of burning time.

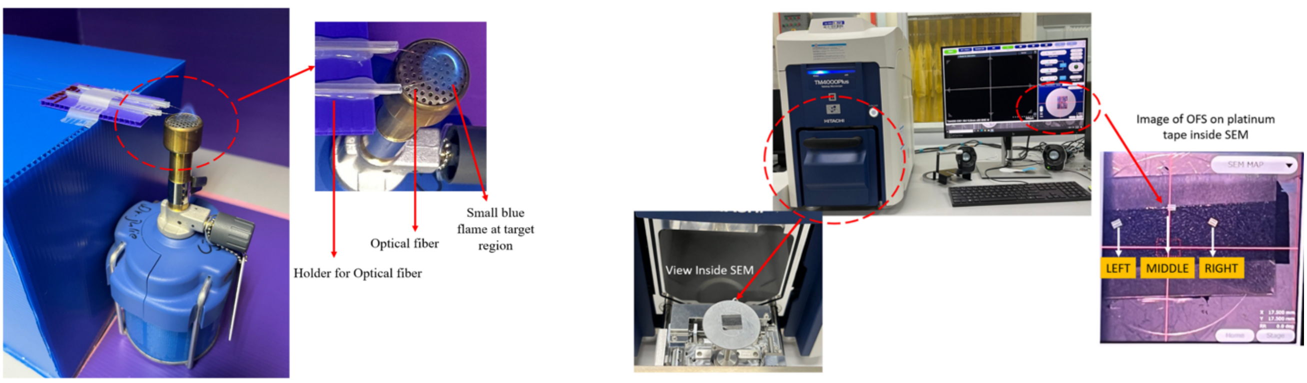
2.2. Preparation of Glucose Solution and Refractive Index Measurement

The concentration of glucose solution was prepared ranging from 1, 2, 4, 6, and 8 mM. Using dilution equation, the concentrated glucose stock solution and volume of glucose solution were set at 100 mM/ℓ and 15 mℓ respectively. After that, the volume of concentrated glucose stock solution is diluted to achieve the desired glucose concentration. For instance, to prepare a concentration of glucose solution for 1 mM with 15 mℓ volume required of 1.8 mℓ concentrated glucose stock solution to be diluted in 13.2 mℓ deionized (DI) water. The process was repeated for each remaining concentration of glucose solution.

Next, the refractive index of glucose solutions was measured using MDX-102 digital refractometer. Initially, the calibration process was executed to obtain best accuracy before refractive index is performed. Then, four to five glucose solution was dropped onto cleaned prism surface and refractive index was then measured and tabulated. The simplified of this process was illustrated in Figure 2.

2.3. Optical Characterization of De-cladded Optical Fiber Sensor

The experimental setup to measure the optical power when glucose solution was dropped into the U-shaped region is illustrated in Figure 3. Initially, the wavelength and power of the light source were set at 1550 nm and 7 dBm,



(a) (b)

Figure 1. Flame method for de-cladding process in (a) and the (b) thickness measurement for de-cladded optical fibre at three points labels as left, middle, and right

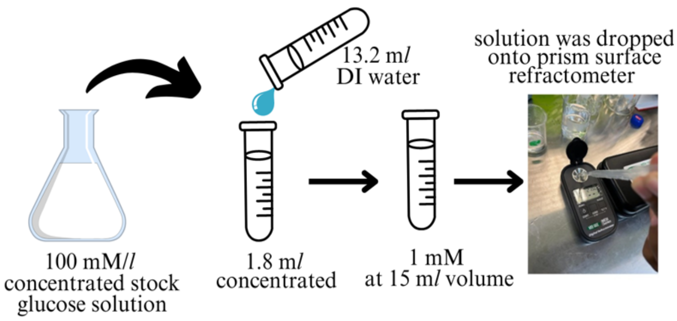


Figure 2. Schematic of glucose solution preparation to obtain 1 mM concentration and the measurement of refractive index using digital refractometer

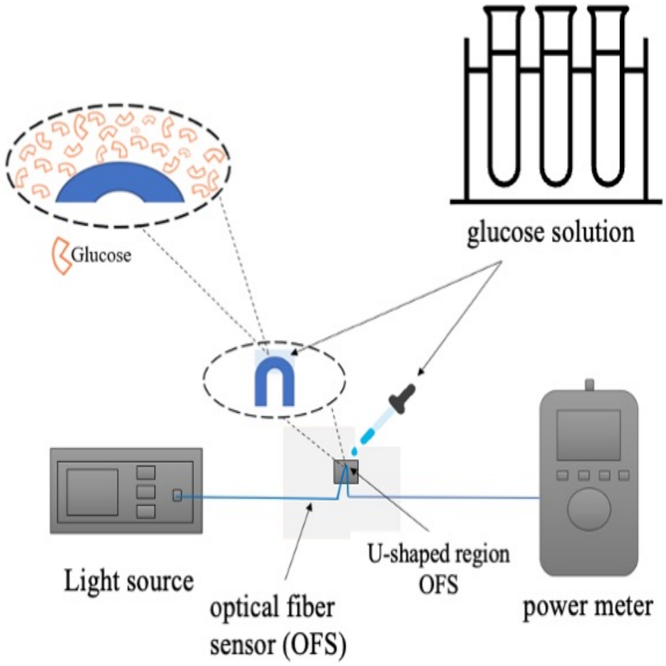


Figure 3. Schematic for optical measurement for varied glucose solutions

respectively. Prior to measuring the glucose solution, the average output power reading without the glucose solution for the U-shaped optical fiber sensor at 1 cm and 2 cm curvature diameters with 40 minutes and 50 minutes of burning time was recorded and tabulated in Table 1. Next, two to three drops of 1 mM glucose solution were dropped at the U-shaped region. Then, the optical power was measured for three readings using an optical power meter. The process was repeated for different glucose solution concentrations.

Table 1. Average output power without glucose solution for U-shaped optical fibre sensor

Burning time (minutes)	**Average output power (µm)**	
	OFS for 1 cm curvature diameter	**OFS for 2 cm curvature diameter**
40	340.6	1.31
50	128.6	1.15

3. RESULTS & DISCUSSION

Figure 4(a) shows an SEM image at a scale of 500 µm of the U-shaped optical fibre before the de-cladding process, with a cladding thickness of 131 µm. The optical fibre thickness in Figure 4(a) was compared with the thickness after the de-cladding process for a 1 cm curvature diameter, as depicted in Figures 4(b) and (c). From Figures 4(b) and (c), at the middle position of the optical fibre, the thickness decreased to 127 µm and 129 µm for 40 minutes and 50 minutes of burning time, respectively. This represents a decrease of approximately 3.05% and 1.53% for 40 minutes and 50 minutes of burning time compared to the thickness of the bare optical fibre. These results indicate that there is no significant trend in thickness reduction with increasing burning time. Additionally, the thickness is not uniform in the burning region due to difficulty in controlling the flame.

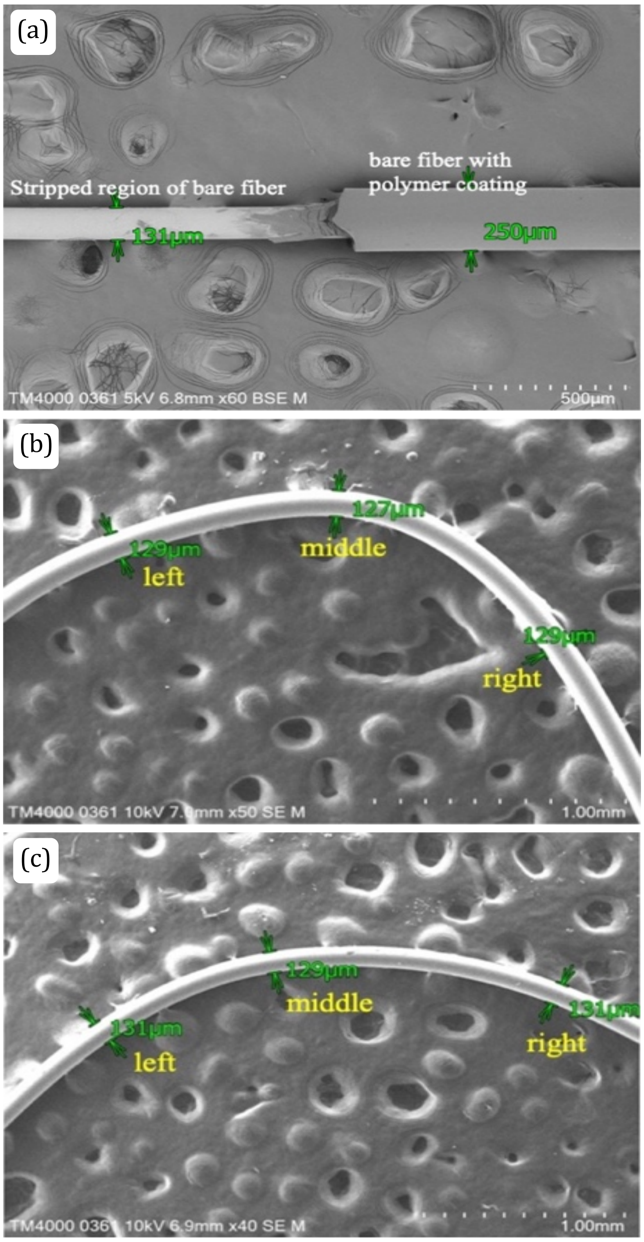


Figure 4. SEM images of thickness optical fibre (a) before de-cladded process and after de-cladded process meanwhile, (b) 40 minutes and (c) 50 minutes burning time for 1 cm curvature diameter

The uniform thickness reduction observed at three positions of the cladding layer for the 2 cm curvature diameter at 40 and 50 minutes of burning time is illustrated in Figure 5. The thickness decreased to 125 µm and 124 µm for 40 and 50 minutes of burning time respectively. This represents a total reduction of approximately 4.58% to 5.34% from the original thickness of the bare optical fibre. These results indicate that longer burning times lead to a decrease in the thickness of the cladding layer of the optical fibre.

Figure 6 shows a linear graph illustrating the correlation between the concentration of glucose solutions and the refractive index value with good agreement and a sensitivity of 0.000185 RIU/mM. Meanwhile, the linearly dependent coefficient, the R^2 value, shows the solution accuracy of 0.998. Essentially, increasing the concentration of solutions increases the refractive index, which performs linear correlation as similarly reported in [12–13].

The optical power performance of de-cladded U-shaped optical fiber sensor for varied glucose solutions concentration was depicted in Figure 7 and Figure 8. Figure 7 and Figure 8 shows the output power decreased when concentration increased which comparable trend of reported graph in [14]. The U-shaped pattern and de-cladded region increase the evanescence wave absorption and refraction loss [15]. On the other hand, increment effective refractive index (RI) at surrounding of de-cladded region produced higher of refraction loss [15]. An increment of loss at de-cladded and U-shaped region resultant reduction of guided light inside core fiber. Hence, this was cause the decrement of transmitted power when concentration of glucose solution increase as illustrated in Figure 7 and Figure 8. At 1 cm and 2 cm curvature diameters for 40 minutes burning time gives the sensitivity of 1.05 µW/mM and 0.014 µW/mM respectively as shown in Figure 7. However, for 50 minutes burning time at 2 cm curvature diameters gives the smallest sensitivity of 0.0035 µW/mM compared to 1 cm curvature radius with the sensitivity value of 2.5 µW/mM. For the 2 cm curvature diameter, the smallest sensitivity value is due to reduced absorption of the evanescent wave, resulting in higher transmitted power within the optical fiber. In contrast, the depth of the evanescent wave is relatively small compared to the 1 cm curvature radius. A good response and higher sensitivity in the OFS are achieved when the sensitivity value is high. Among these OFS configurations, the 1 cm curvature diameter with 50 minutes of burning time demonstrates good sensitivity at 2.5 µW/mM. Overall, the results reveal that a longer burning time and smaller curvature diameter offer better optical performance and the highest sensitivity value. This developed optical fiber sensor was able to sense small changes in effective refractive index change and shows the combination of U-shaped with de-clad cladding layers offers more sensitive detection.

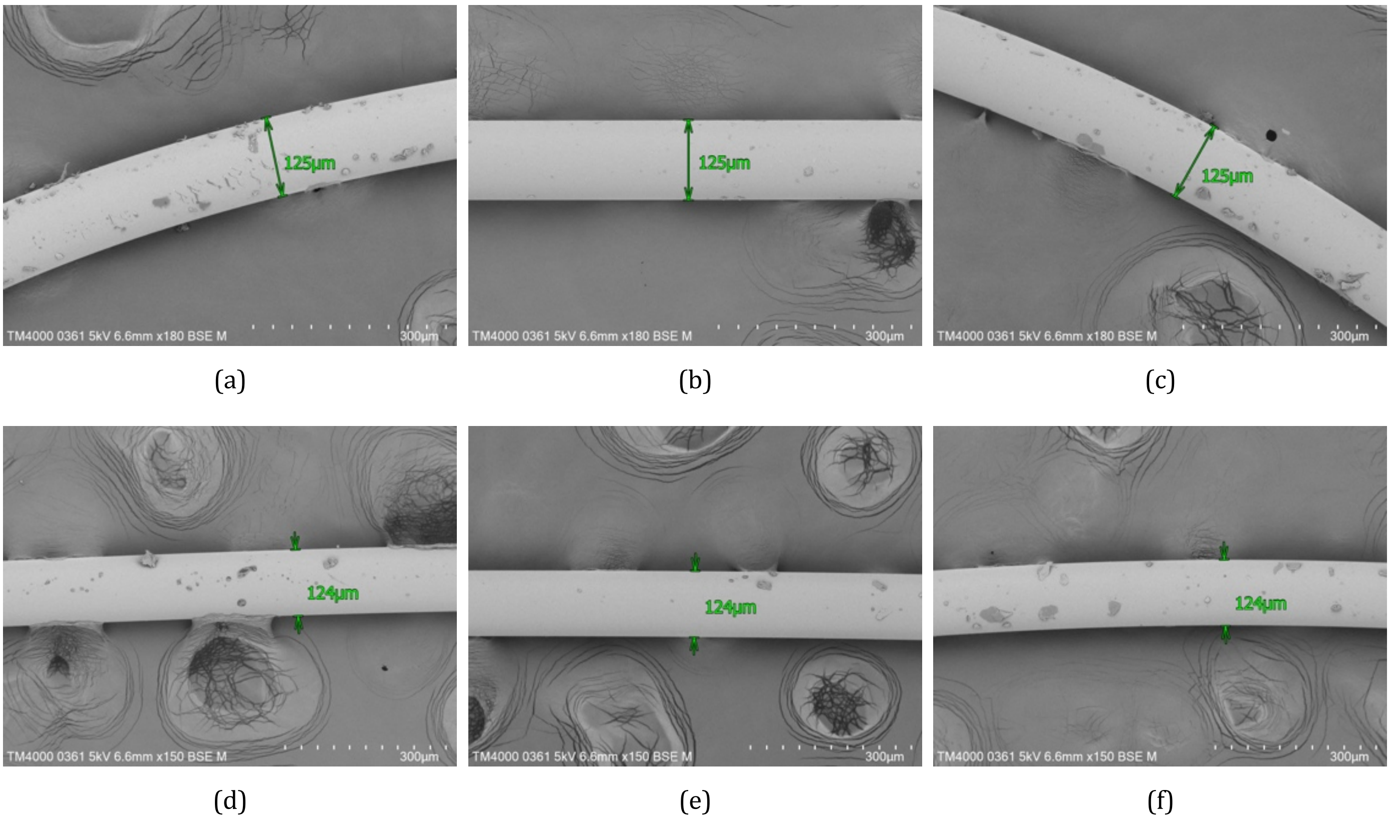


Figure 5. Images of the thickness of the optical fiber after the de-cladding process for a 2 cm curvature diameter at different positions with labels as (a) left, (b) middle, and (c) right for 40 minutes of burning time. Meanwhile, for 50 minutes of burning time, the different position thickness measurements were labeled as (d) left, (e) middle, and (f) right

4. CONCLUSION

An optical fibre sensor with a de-cladded U-shape pattern was successfully fabricated using the flame heating method with the smallest reduction thickness of 5.34%. the de-cladded and U-shaped pattern were a suitable combination that led to the increment power at the surrounding of cladding, which made the sensing region more sensitive towards changes of effective refractive index. Optical performance produced a linear relationship between output power and the increment of concentration of glucose solution. At 50 minutes, burning time at 2 cm curvature diameter gives the smallest sensitivity of 0.0035 μw/mm compared to other parameters. Overall, the most responsive and highly sensitive OFS is obtained at 50 minutes of burning time with a curvature diameter of 1 cm with the sensitivity value of 2.5 μw/mm.

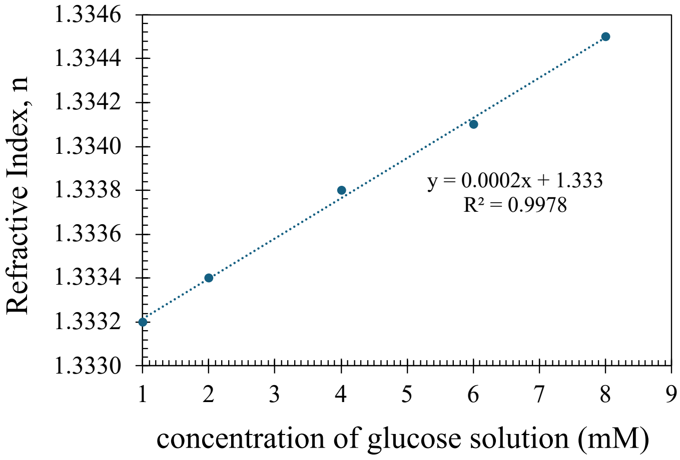
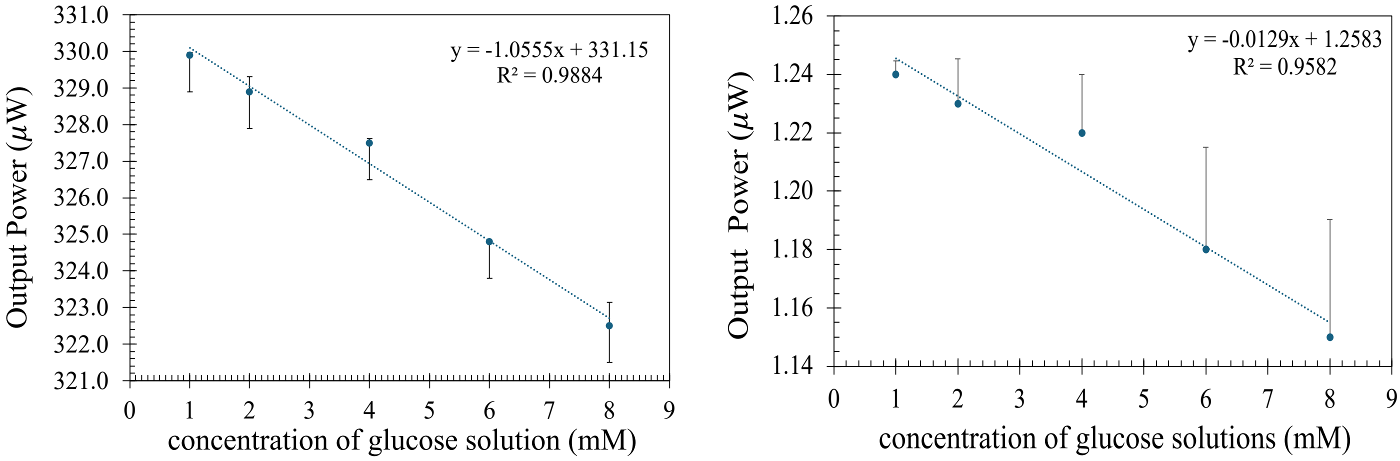
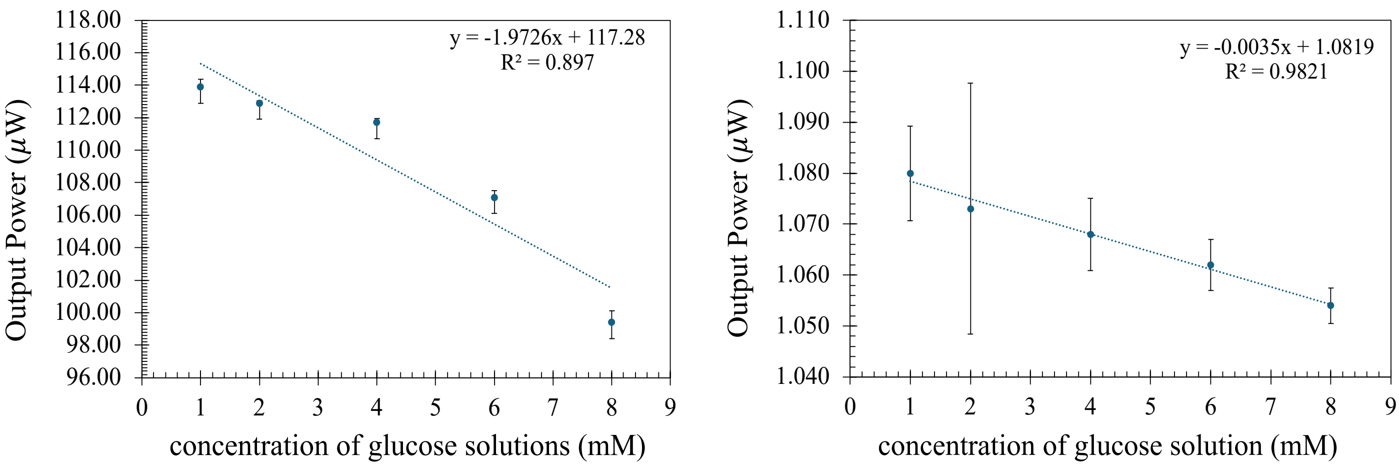


Figure 6. Relationship of glucose solution and refractive index



(a) (b)

Figure 7. Output power vs. concentration of glucose solution for 40 minutes burning time at curvature diameter of (a) 1 cm and (b) 2 cm



(a) (b)

Figure 8. Output power vs. concentration of glucose solution for 50 minutes burning time at curvature diameter of (a) 1 cm and (b) 2 cm

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REFERENCES

[1] J. L. Cano Perez *et al.*, "Fiber Optic Sensors: A Review for Glucose Measurement," *Biosensors*, vol. 11, no. 3, p. 61, Feb. 2021, doi: 10.3390/bios11030061.

[2] P. Gong *et al.*, "Optical fiber sensors for glucose concentration measurement: A review," *Optics & Laser Technology*, vol. 139, p. 106981, Jul. 2021, doi: 10.1016/j.optlastec.2021.106981.

[3] S. N. Khonina, N. L. Kazanskiy, and M. A. Butt, "Optical Fibre-Based Sensors—An Assessment of Current Innovations," *Biosensors*, vol. 13, no. 9, p. 835, Aug. 2023, doi: 10.3390/bios13090835.

[4] Y.-L. Chou *et al.*, "A U-Shaped Optical Fiber Temperature Sensor Coated with Electrospinning Polyvinyl Alcohol Nanofibers: Simulation and Experiment," *Polymers*, vol. 14, no. 10, p. 2110, May 2022, doi: 10.3390/polym14102110.

[5] H. Liang, J. Wang, L. Zhang, J. Liu, and S. Wang, "Review of Optical Fiber Sensors for Temperature, Salinity, and Pressure Sensing and Measurement in Seawater," *Sensors*, vol. 22, no. 14, p. 5363, Jul. 2022, doi: 10.3390/s22145363.

[6] S. Praveena, G. Melwin, P. R. Babu, and K. Senthilnathan, "MoS_2 sensitized tapered fiber optic evanescent wave sensor for refractive index based glucose sensing application," *Current Applied Physics*, vol. 77, pp. 46–56, Sep. 2025, doi: 10.1016/j.cap.2025.05.015.

[7] G. Li, Y. Wang, A. Shi, Y. Liu, and F. Li, "Review of Seawater Fiber Optic Salinity Sensors Based on the Refractive Index Detection Principle," *Sensors*, vol. 23, no. 4, p. 2187, Feb. 2023, doi: 10.3390/s23042187.

[8] Y. Zhang *et al.*, "U-shaped MZI optical fiber temperature sensor based on PDMS sensitization," *Optical Fiber Technology*, vol. 93, p. 104252, Sep. 2025, doi: 10.1016/j.yofte.2025.104252.

[9] Y. Yao, M. Yan, and Y. Bao, "Measurement of cable forces for automated monitoring of engineering structures using fiber optic sensors: A review," *Automation in Construction*, vol. 126, p. 103687, Jun. 2021, doi: 10.1016/j.autcon.2021.103687.

[10] S. Chen *et al.*, "Marine Structural Health Monitoring with Optical Fiber Sensors: A Review," *Sensors*, vol. 23, no. 4, p. 1877, Feb. 2023, doi: 10.3390/s23041877.

[11] C. Leitão *et al.*, "Cost-Effective Fiber Optic Solutions for Biosensing," *Biosensors*, vol. 12, no. 8, p. 575, Jul. 2022, doi: 10.3390/bios12080575.

[12] Y.-L. Fang, C.-T. Wang, and C.-C. Chiang, "A Small U-Shaped Bending-Induced Interference Optical Fiber Sensor for the Measurement of Glucose Solutions," *Sensors*, vol. 16, no. 9, p. 1460, Sep. 2016, doi: 10.3390/s16091460.

[13] P. N. S. S. Ja'afar, N. M. Razali, S. Ambran, and F. Ahmad, "Sodium Chloride Concentration Measurement via Optical Fiber Tip Sensor," *IOP Conference Series: Materials Science and Engineering*, vol. 1051, no. 1, p. 012030, Feb. 2021, doi: 10.1088/1757-899X/1051/1/012030.

[14] H. Haroon, M. N. Mohd Nazri, S. K. Idris, H. Abdul Razak, A. S. Mohd Zain, and F. Salehuddin, "Comparative study of solution concentration variations for polymer optical fibers sensor," *Malaysian Journal of Fundamental and Applied Sciences*, vol. 16, no. 2, pp. 140–144, Apr. 2020, doi: 10.11113/mjfas.v16n2.1451.

[15] N. Punjabi, J. Satija, and S. Mukherji, "Evanescent Wave Absorption Based Fiber-Optic Sensor - Cascading of Bend and Tapered Geometry for Enhanced Sensitivity," 2015, pp. 25–45. doi: 10.1007/978-3-319-10948-0_2.