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SENSITIVITY OF GRAPHENE OXIDE COATED TAPERED NO-CORE FIBRE SENSOR FOR URIC ACID DETECTION

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Abstract— This paper analyzes the development, progress, and evaluation of a sensor system, which mainly consists of tapered no-core fibre (TNCF) for detecting uric acid (UA). To augment the capability of TNCF diameter, different powers of CO_2 laser were used for creating the optical-based refractive index sensor. This action will allow for better interaction with the surrounding samples, improving the sensitivity. The sensing region was fixed to improve the sensitivity with a coating of graphene oxide (GO) solution. Experimental findings showed

Sensor	that the TNCF-GO sensor exhibited a higher sensitivity value at 0.00782 ± 0.00049 nm/μM, while NCF-GO sensor sensitivity only at 0.00447 ± 0.00019 nm/μM and NCF sensor sensitivity only at 0.00387 ± 0.00027 nm/μM. The TNCF-GO sensor demonstrated better performance compared to the others. This research improves the development of a susceptible and effective sensor for UA detection, especially in biomedical health diagnostics.

I. Introduction

One way to achieve a healthy life is by having a health checkup. In most cases, invasive and non-invasive procedures have been employed to monitor the health status of individuals. Uric acid (UA) is a chemical produced by purine-containing substances that break down in the body. Purines are present in several foods and drinks, such as beer, mackerel fish, dried beans and peas [1]. Generally, in the human body, the concentration of UA varies between 202M and 434M. However, if the concentration of the UA in the bloodstream increases, it forms urate. The formation of urate crystals is linked to a disease called gout.

In the past several years, various UA sensors with silica optical fibres, plastic optical fibres and polymer optical micro fibres have been fabricated and experimentally tested. Nevertheless, these sensors are pricy and manufactured using intricate processes, slowing market integration [2]. Also, conventional fibre-based systems have some challenges, including poor sensitivity to the measurement of UA due to the confinement of light into the fibre core, which limits the interaction of the evanescent wave with the surrounding reaction medium. To address these issues, this current study intends to use TNCF as a sensor

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to determine the concentration of UA.

In this research, the NCF sensor is the main subject. The NCF, also termed coreless fibre, acts as the structural core and cladding [3]. Several advantages of using NCF for sensing include its high capability of detecting changes in pressure, temperature, and other environmental conditions. NCF sensors are also characterized by their small size, fast response, and immunity to electromagnetic interference [4].

One cannot overemphasize the importance of modifying the pattern of the fibre structure to increase light interaction with the fibre medium for UA optical fibre sensors. One innovative technique known to be compelling enough is the optical fibre tapering technique. Tapered optical fibres offer a significant method of varying the cladding zone's diameter, enabling the core light to strike the fibre cladding.

A more significant proportion of evanescent waves can interact with the surrounding medium, increasing UA sensing sensitivity. This will enhance the detection capability and enable the sensor to detect even minor changes in UA concentrations. Previous researchers have used techniques that include fusion splicing, chemical etching, and flame torch to build tapered optical fibre [5]. However, these techniques are based on low repeatability and waist diameter variation due to flame instability [6]. Tapering optical fibres with a CO2 laser entail placing the fibre in a controlled environment, focusing the laser beam to heat and melt the fibre, forming a tapered shape, and continuously monitoring and modifying the laser settings to get the desired taper geometry [7].

Finally, to improve the effectiveness and sensitivity of the entire TNCF sensor system in specific practical applications, the necessary materials, including graphene oxide (GO), must be deposited on them as a coating. While the NCF comprises a combination of smart layers, the coating elements stand out and bear most of the interaction with the external environment. Although

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several works have been done on the application of NCF sensors in detecting UA concentration, some drawbacks of sensor coatings have been reported in the literature. Most coatings used in the past are inadequate in terms of selectivity and sensitivity; thus, they give a poor performance when it comes to the sensitivity of detecting the UA at low levels. Substances as simple as polymers and simple metal oxides irrespective of the fact that they may be functional still have limitations of lack of binding sites for UA and interferences from other species. It can significantly affect the performance of the entirety of the NCF [8]. The thickness of the coating that can be applied can also be in the micrometre range because specific applications may require a variation of the thickness. It became clear from the comparison that the coating can affect many aspects of the fibre, such as mode coupling and loss properties.

II. Methodology

A. Fabrication of Fibre Sensor Structure

Sensor fabrication involves several phases, including stripping, cleaning, aligning, and protecting optical fibre fusion joints and sensor cables. The process begins with stripping single-mode fibre (SMF) and no-core fibre (NCF) ends, which are carefully removed and cleaned using isopropyl alcohol to remove contaminants. This is followed by cutting the fibre using a fibre cleaver to produce clean edges through which jointing in the fusion splicer is facilitated. Fusion splicing is done on a machine with a microscope, whereby fibre ends are arranged sequentially and systematically. The fusion process is repeated to achieve a secure permanent connection due to low loss. The final step involves using a glass slide to prevent fibre degradation and conserve core characteristics. This ensures a high-efficiency and well-bonded fibre connection, ensuring the quality and reliability of the sensor system.

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B. Tapered No-Core Fibre with CO_2 Laser

These modifications were done using the CO_2 laser to effectively taper down the NCF, as shown in Figure 1. This reduction in diameter is expected to improve the sensor's sensitivity as it will increase the surface area towards the field of application. Regarding the tapering process, the input power was set at 28 W, the pulling distance at 5 mm, and the pulling speed at 900 rpm. The power was chosen based on the trial and error, and also from the limitation of the taper machine itself. The smaller diameter raises the system's sensitivity thus making it highly sensitive. However, the attenuation increases as the fibre diameter becomes less than the wavelength of the signal, although extremely thin fibres have larger bend losses which restrict their usage in bending applications. They also may be still week and brittle, as such, they are not as strong and dependable as needed. As for the TNCF that has been designated, it has a waist diameter of 30. 47 µm and manufactured with a 28 W CO_2 laser.

This controlled and precise waist diameter, which is done using the CO_2 laser, is another advantage over techniques such as flame brush tapering, where it is difficult to control the longitudinal shape and size of the tapered optical fibres [9].

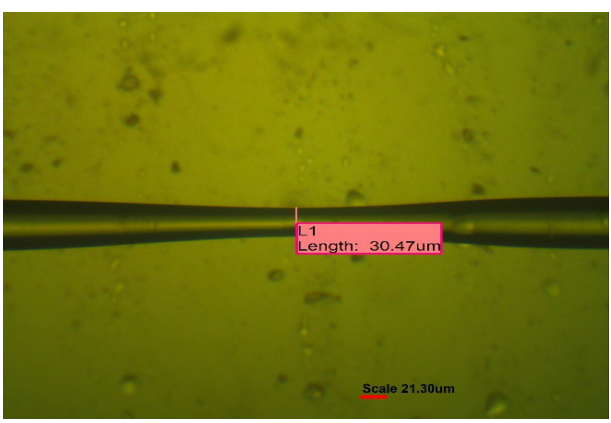

Figure 1: Diameter size of TNCF for 28 W CO_2 laser

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C. Coating of Graphene Oxide on Tapered Fibre Region

A GO dispersion that was commercially bought from the Graphene Supermarket. It contained 6 mg/ml of the substance and with lateral flake size between 0.3 and 7 µm. This pure GO solution was dissolved in deionized water up to 2 mg/ml concentration. The PVA in powder form weighing 0.2 g, was combined with this solution. When the GO/PVA composite was mixed for 12 hours at 30 °C, it attained a homogenous mixture that later can be used as a coating onto the fibre. Then, 6 ml of GO solution is poured onto the NCF or TNCF on a small acrylic slide to create a composite coating on the fibre. The coated sample is left to dry using the drop-cast technique, as depicted in Figure 2. Cleaning of the glass substrate and the fibre optic cable mainly involves using isopropyl alcohol and acetone to remove any debris or impurities on the surface of the substrate. It is advisable to leave the GO solution on the fibre region at room temperature for 72 hours to ensure that it dries thoroughly. The fibre optic cable should be kept away before proceeding with the following process once the film has dried up.

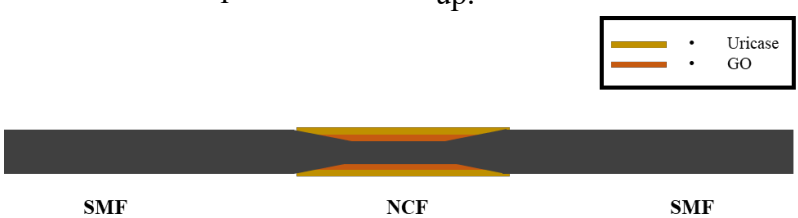

Figure 2: Coating of GO-Uricase on TNCF

D. Measurement Setup

In the experiments, fibres were stripped, connected with a Halogen-Tungsten white light source, and treated with UA solutions as shown in Figure 3. The fibres were then investigated using a CCS 200 small spectrophotometer. Using Thorlabs OSA software Output, the transmission optical spectra were recorded for UA concentrations varying from 100µM to 800µM.

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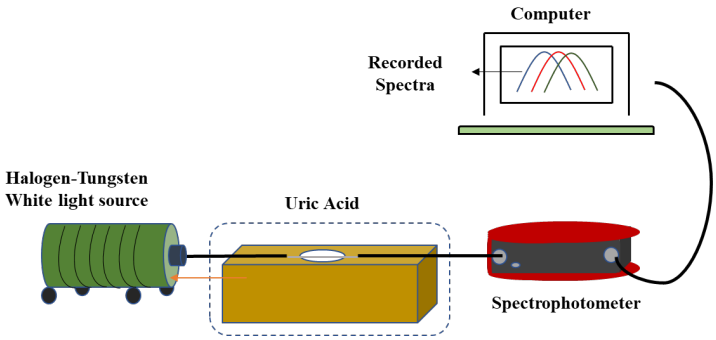

Figure 3: Experimental Setup

III. Main Results

A. Uric Acid Detection by Uncoated No-Core Fibre

The uncoated NCFs were utilized first as the research aims to compare the sensitivity of uncoated NCF, coated NCF and coated TNCF. Figure 4 displays the sensitivity results obtained from uncoated NCF, revealing that the sensitivity measured from the UA detection was 0.00387 ± 0.00027 nm/µM. The graph illustrates the wavelength shift's dependence on the change in the UA concentration, which could vary from 100 µM to 800 µM. The points plotted on the graph refer to the observed changes in the wavelength, enabling a curve fitting to characterize the change.

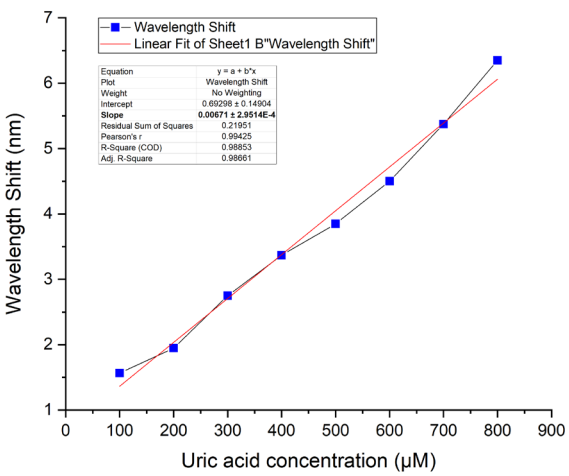

Figure 4: Sensitivity value obtained from uncoated NCF

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B. Uric Acid Detection by Coated No-Core Fibre-GO-Uricase

Then, NCF was coated with GO and uricase solution and placed on the sensing region. Figure 5 displays the fitting graph obtained from the NCF-GO as the sensing region. In this part, a coated NCF-GO sensor was used to detect UA concentration. The sensitivity value measured for TNCF-GO is 0.00447 ± 0.00019 nm/µM.

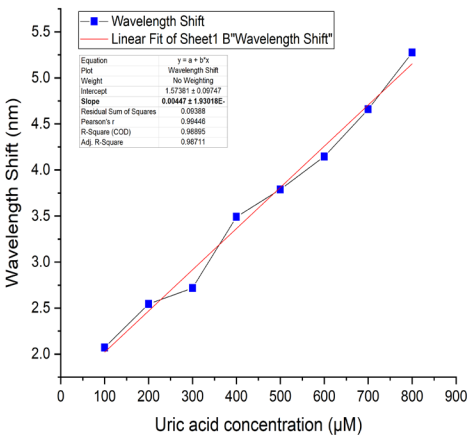

Figure 5: Sensitivity value obtained from coated NCF-GO

C. Uric Acid Detection by Coated Tapered No-Core Fibre-GO-Uricase

On the other hand, Figure 6 displays the fitting graph generated from the results obtained by using TNCF's 30.47 µM diameter as the sensing region. In this part, a coated TNCF-GO sensor was used to detect UA concentration. The coating was done by applying 6 ml of GO solution to the sensing region. The sensitivity value for the 30.47 µM diameter size is obtained as 0.00782 ± 0.00049 nm/µM. These findings show that the TNCF-GO has a higher sensitivity than the NCF-GO and uncoated NCF.

Findings proved that the NCF's diameter influences the sensor system's sensitivity. A smaller diameter of NCF provides a more significant interaction area between the evanescent field and the sample, leading to increased sensitivity

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in detecting changes in the refractive index. Also, findings showed that the GO coating also improved the sensitivity value of the sensor as the GO's functional groups, which include hydroxyl and epoxide groups, allow it to disperse in water [10]. These functional groups are very biocompatible and provide an additional surface area on the surface of optical fibres to attach biomolecules [11].

The results highlight the importance of the diameter size of the NCF sensing region and the functional GO coating in enhancing the sensor system's performance.

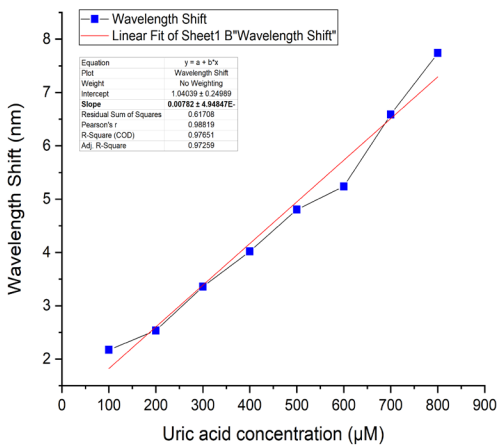

Figure 6: Sensitivity value obtained from coated TNCF-GO

IV. Conclusion

An optical TNCF GO-based biosensor for UA concentration detection has been developed—the tapered fibres with a waist diameter of 30.47 µm produced by CO2 laser. Regarding the outflow of evanescent waves and outflow handling capacity, 30.47 µm diameter TNCF is superior for fabricating all the sensor probes. To increase sensitivity, the tapered section of the fibre probes was coated with GO by drop-wise addition of 6 ml of GO solution. The experimental results showed that the TNCF-GO sensor exhibited a higher sensitivity value at 0.00782 ±0.00049 nm/µM, while NCF-GO sensor sensitivity only at 0.00447

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±0.00019 nm/μM and NCF sensor sensitivity only at 0.00387 ±0.00027 nm/μM. The TNCF-GO sensor demonstrated better performance compared to the others. Finally, this particular TNCF sensor's diameter is perfect for accurately detecting changes in refractive index through this particular sensor. For detailed UA measurement and detection, the coating and the diameter size for this particular TNCF sensor are found to be perfectly appropriate.

Establishing a TNCF for a UA sensor will advance science and medicine since probable changes in the solution's refractive index may be measured. The proposed method of using a coated GO on the TNCF sensors for sensing UA, can be applied on a larger scale in real life situation especially in the medical and healthcare industries. Since this technology can be employed in the construction of miniaturized, sensitive, and selective diagnostic instruments for detecting UA in body fluids which include blood or urine, it can be useful in. Timely and efficient determination of UA is important in the diagnosis of diseases such as gout and kidney stones and other metabolism complications. Due to its fast and accurate response, these sensors can help in early diagnosis and treatment, improve patient care, and possibly eliminate hospitalization expenses for stable chronic diseases by conducting tests at home and continuously monitor patients' conditions.

V. Acknowledgement

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