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High performance of straight and U-shaped probe microfiber sensors for sucrose solution detection applications

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***Abstract*— A low cost, highly sensitive sensor with easy fabrication has been successfully developed to detect variations in the concentration of sucrose solutions using a microfiber probe sensor. The microfiber probe was fabricated using a flame brushing mixture of butane and oxygen with single-mode optical fiber material and pulled on both sides to achieve a size of 16.48 µm. These microfiber probes were characterized into two sensor probe shapes: straight and u-shaped, to measure variations in the sucrose solution concentration. The results for both probe shapes showed a decrease in peak output intensity and a shift in peak wavelength as the sucrose concentration increased from 0.5% to 3%. The straight shape exhibited a sensitivity of 0.241 dBm/% with a slope linearity of 99.5% and a resolution of 0.0415%, while the U-shape had a sensitivity of 2.692 dBm/% with a slope linearity of 90.6% and a resolution of 0.0030%. The measurement spectra results indicated significant differences in u-shape at each concentration. In conclusion, both microfiber sensor probe shapes exhibited excellent performance and are suitable for use as chemical sensors to measure variations in solutions.**

Keywords*— Optical fiber sensor, microfiber, U-shape microfiber, sucrose detection.

I. INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder characterized by high blood sugar levels due to insufficient insulin production by the pancreas. Data from the International Diabetes Federation (IDF) indicates that the global number of diabetes patients reached 463 million in 2019, equivalent to 9.3% of the total population aged 20-79 years. This number is projected to continue rising to 578 million by 2030 and 700 million by 2045. Indonesia is also facing a serious issue with diabetes, ranking 7th among countries with the highest number of diabetes patients in 2019, totaling 10.7 million individuals. Monitoring and measuring blood sugar levels are crucial for controlling diabetes mellitus patients [1].

Glucose is the primary source of energy in cell functions, and its metabolic regulation (gluconeogenesis) is of utmost importance. It serves as a reserve carbohydrate in most cells. Glucose is beneficial for the body, but in excess, it can become a harmful condition. Therefore, controlling glucose levels is an essential aspect of diabetes mellitus prevention [2].

Photonics-based methods are the most sensitive for liquid sensing applications. Recent research in photonics focuses on the development of non-invasive sensors for glucose level measurement. Various photonics methods have been explored, such as using photonic crystal hydrogel-based microneedles [3], gold nanoparticles with MXene composite-based Raman scattering [4], fluorescent [5], and optical coherence tomography (OCT) [6] for non-invasive measurements. The development of photonic-based sensors has led to several types of optical fiber biosensors capable of rapidly detecting biomarkers. This demonstrates significant potential for measurement sensors due to their compact size, ease of implementation, and sensor structure diversity [7].

In this paper, sucrose levels were measured using microfiber by comparing the performance of the straight shape with the u-shape for developing sensors for the prevention of diabetes mellitus.

II. METHOD

Fig. 1 is a setup diagram for making a microfiber sensor. The sensor is made using singlemode optical fiber, which is heated using a flame with a mixture of oxygen - butane and is pulled at both ends constantly. Microfiber is a type of intrinsic sensor where the microfiber. As a probe, will be in direct contact with the material being tested.

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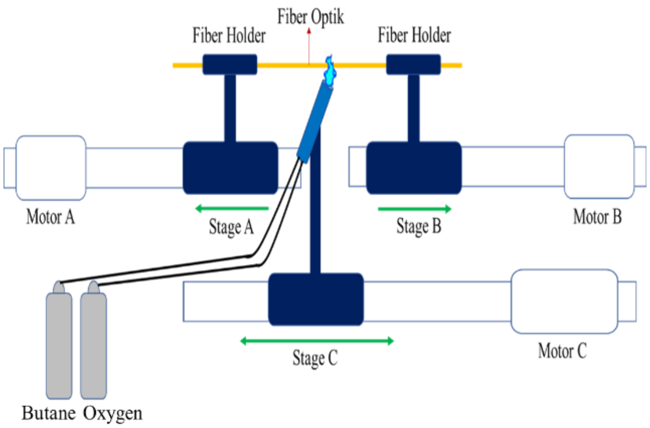

Figure. 1 Setup diagram for making microfiber using the flame brushing method

The finished microfiber is then connected with a patchord to be connected to a spontaneous emission amplitude source (ASE) and an optic spectrum analyzer (OSA) measuring instrument. Fig. 2 is a sucrose solution measurement setup with a straight and u-shaped probe.

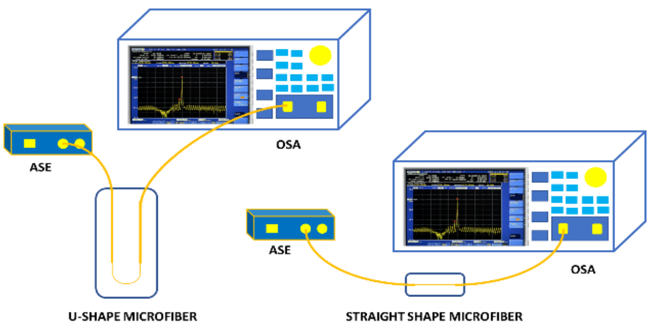

Figure. 2 Experimental diagram for measuring variations in sucrose concentration using a u shape and a straight shape

The sucrose solution used is made from sucrose powder dissolved in distilled water with the addition of 0.5% to a solution concentration of 3%. A Slight improvement is needed to test the response of the microfiber sensor in measuring variations to sucrose concentration. Each concentration of sucrose was tested for its refractive index using an Abbe refractometer to determine the difference between each concentration.

III. RESULT AND DISCUSS

Fig. 3 shows the results of a microfiber diameter of 16.48 µm. This microfiber is used as a sensor probe to measure variations in the concentration of sucrose solution. Fig. 4 shows the refractive index values for variations in sucrose solution concentration using an Abbe reflectometer. A sucrose solution concentration of 0.5% to 3% has a refractive index of 1.324 to 1.329.

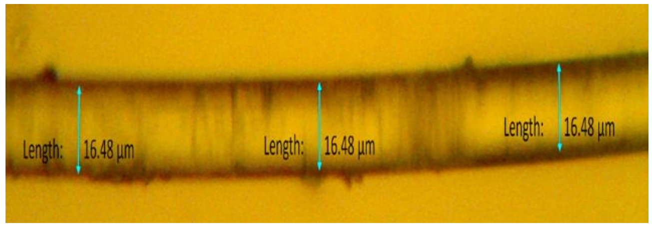

Figure. 3 Results of measuring microfiber diameter using a microscope

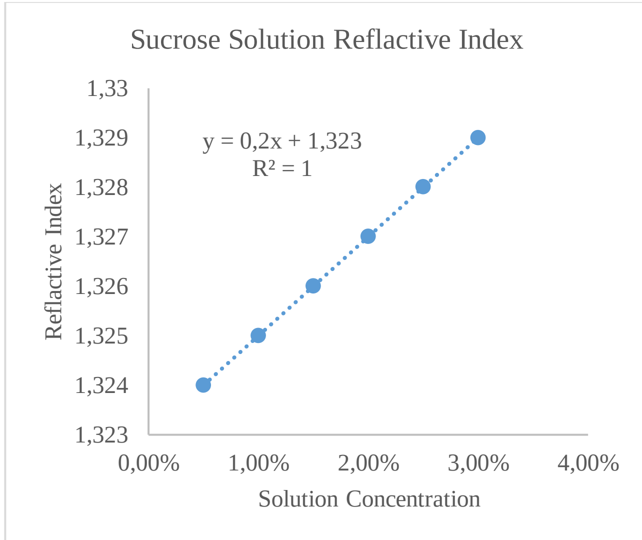

Figure. 4 Refractive index measurement results of variations in sucrose solution concentration

Fig. 5 (a) and (b) show the transmission spectrum for measuring variations in sucrose concentration using straight and u-shaped microfiber. Fig. 5(a) measurements using a straight shape with stable spectra result in decreasing for each increase in sucrose solution concentration. The significance of the differences in measurements at each concentration is small. But it shows a stable data trend. In Fig. 5(b), measurements using a u-shape show stable spectral results that decrease with each increase in the concentration of the sucrose solution. The significance of the differences in measurements at each concentration is significant, especially in the solution concentration data of 0% - 1.5%. Even though there is no significant difference at a solution concentration of 2% - 3%, the spectra values still show a decreasing data trend for each increase in solution concentration.

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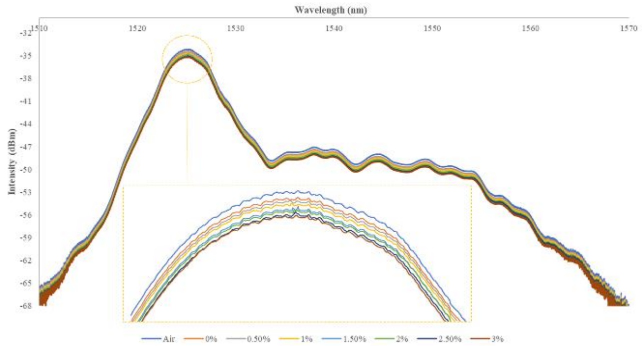
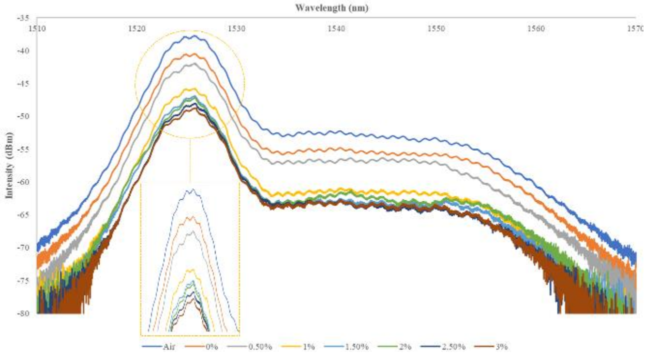


(a)



(b)

Figure. 5 Transmission spectra of microfiber to detect variations in sucrose concentration (a) straight shape and (b) u-shape microfiber

Fig. 6 shows the output power intensity for measuring variations in sucrose concentration with straight and u-shaped probes. As shown in Fig. 6, straight-shape measurements produce a stable output power intensity trend decreasing from -34,433 dBm to -35,140 dBm as the concentration of the sucrose solution increases every 0.5% to 3%. The significance of the difference in peak intensity measurements of concentration variations is at least 0.086 dBm.

Measurements using the U-shape produce a stable output power intensity trend, decreasing from -40,438 dBm to -35.14 dBm as the concentration of the sucrose solution increases. The significance of the difference in peak intensity measurements of concentration variations is at least 0.174 dBm. In both probe forms, straight-shape and u-shape measurements produce a data trend that decreases with each increase in the concentration of the sucrose solution.

The decreasing trend in output intensity is influenced by the reduction in optical fiber diameter due to the microfiber manufacturing process. The smaller diameter makes the microfiber's ability to guide light waves less than optimal, making it possible to interact with sucrose samples that vary in concentration [8].

Another factor that influences this is microbending, which forms a u-shape. Microbending causes attenuation or power loss in optical fibers. As a result, the light intensity becomes smaller due to the greater loss in microbending [7]. This loss also causes a lot of light to interact with the sucrose sample, which makes it very sensitive if the concentration value is varied. So the difference in intensity between solution concentrations is significant compared to the straight shape.

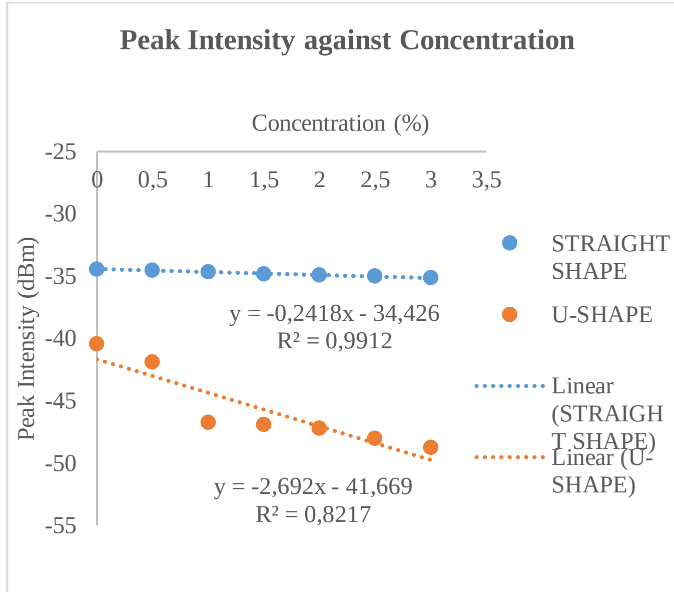


Figure 6. Output peak intensity towards sucrose concentration

Fig. 7 shows the peak wavelength results for measuring concentration variations in both forms of microfiber sensor probes. The results of measuring the shape of the straight sensor probe produced a stable wavelength shift trend, increasing from 1524.96 nm to 1525.14 nm as the concentration of the sucrose solution increased.

On the U-shape sensor probe, the measurement results experienced a shift in wavelength from 1525.77 nm to 1525.93 nm when the sucrose concentration was higher. This wavelength shift is the same as the straight shape, where the wavelength shift is the smallest at 0.02 nm for every 0.5% increase in the concentration of the sucrose solution.

The wavelength shift is caused by the effective refractive index of the core and cladding modes when interacting with the changing external refractive index (sucrose solution). The difference in the refractive index of the optical fiber and the refractive index of the solution concentration causes a shift in wavelength [9]. This is proven by the measurement results of both forms of microfiber sensor probes.

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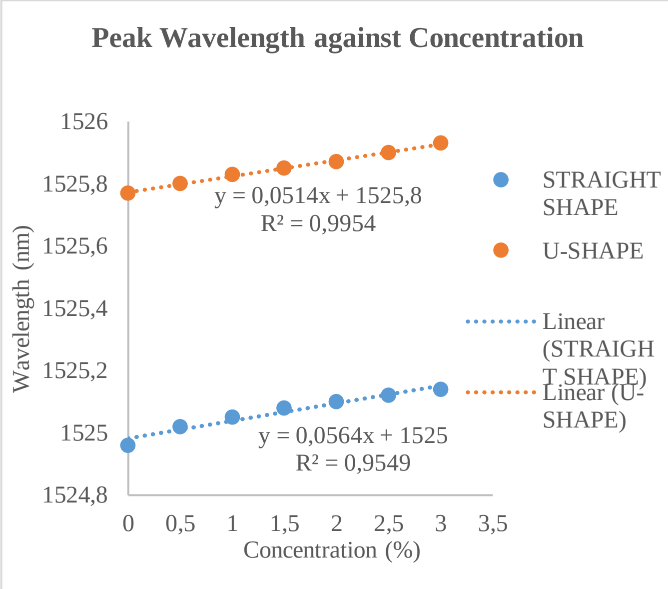
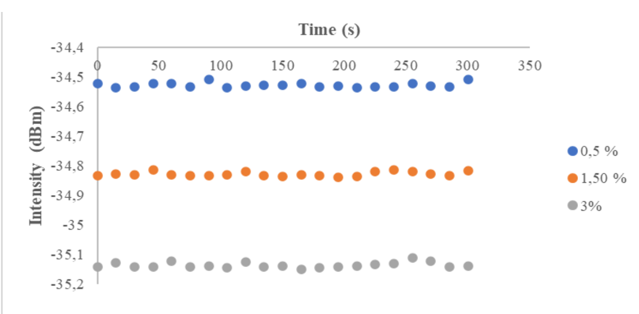
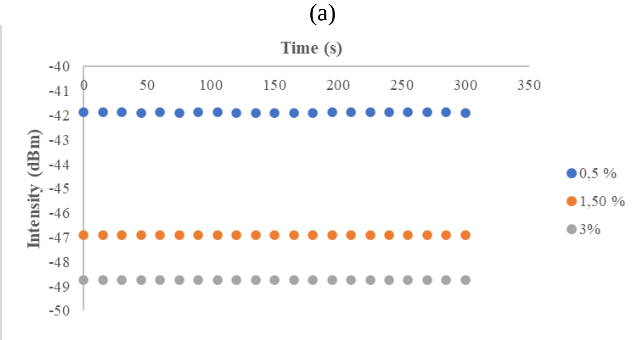


Figure. 7 Output peak wavelength against sucrose concentration

The final measurement is a sensor stability test. This stability test is carried out to find out how stable the designed sensor is when taking measurement data. In the stability test measurements, measuring the output intensity every 15 seconds until the 300th second, the largest standard deviation data was obtained: 0.010 for the straight shape and 0.008 for the u-shape. Apart from knowing the standard deviation of measurement data, the stability test is used to analyze the sensor resolution value and is used as a capability parameter for real-time solution measurements [9].



(a)



(b)

Figure. 8 Sensor stability test (a) straight shape and (b) u-shape

Good sensor performance can be seen from several measurement indicators. Overall sensor performance on the straight-shape and u-shape microfiber sensor probes can be seen in Table 1.

Table 1. Performance of measuring variations in sucrose solution concentration using straight shape and u-shape probes

Sensor Performance	Straight Shape	U-Shape
Range	0.5 % - 3 %	
Linearity	99.5 %	90.6 %
Sensitivity	0.241 dBm/%	2.692 dBm/%
Stability	0.010 dBm	0.008 dBm
Resolution	0.0415%	0.0030%

The measurement linearity for both forms is very good in the measurement range of 0.5% to 3%, with a linearity value of more than 90%. The sensitivity of the u-shape sensor probe is higher than the straight shape: the sensitivity value of the u-shape is 2,692 dBm/%, while the straight shape is 0,241 dBm/%. The diameter of the microfiber is an important factor in increasing sensor sensitivity. The smaller the microfiber that is made, the more penetration the evanescent field can higher so that the sensitivity of the sensor in measuring samples increases [9].

The sensor stability of both sensor probes is very good, with a value of 0.0010 dBm for straight shape and 0.008 dBm for u-shape. This value is due to the difference in diameter between normal optical fibers. Smaller diameters greatly affect the stability of the sensor and make the optical hand structure much more easily broken, requiring special treatment in measurements. Resolution is the smallest unit of measurement that a sensor can measure. The resolution value obtained on the straight shape is 0.0415% and on the u-shape is 0.0030%. The sensor performance is good if the resolution value is smaller. The resolution value can be increased by decreasing the standard deviation value or increasing the sensor sensitivity value [9].

The wavelength shift and the significance of the output intensity measurement are influenced by the diameter of the optical fiber, the radius of the fiber bend, and the effective refractive index [8].

IV. Conclusion

A simple microfiber sensor has been made by modifying the sensor probe with a straight shape and a u-shape. The performance of both probes was tested by measuring variations in sucrose concentration, with very good performance results. Both can be used as chemical sensor candidates, especially for applications in measuring urine glucose levels, because they have linearity above 90%. Microfiber is a chemical sensor candidate that is simple, easy to fabricate, and has good sensitivity for measurement.

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