



# FABRICATION AND CHARACTERIZATION OF CORE OFFSET WAVEGUIDE OPTICAL SENSOR FOR REFRACTIVE INDEX MEASUREMENT

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## ABSTRACT

Refractive index is important parameter in various fields, such as environmental, chemical, industrial, and medical. Measurement of refractive index can be done using optical sensor based buried waveguide core offset. This research aims to fabricate and characterize core offset buried waveguide based on Polymethyl Methacrylate (PMMA). Fabrication of buried waveguide was done by creating a cladding of waveguide made from PMMA which has a refractive index of 1.4908 using computer numerical Control machine (CNC). The material used as waveguide core was unsaturated polyester resin (UPR). Characterization was performed to determine the spectrum of input intensity and output intensity. Characterization were done by dipping the waveguide sample in to a container containing glucose solution with concentration of 12%, 14%, 16%, 18%, 20%, and 24%. Waveguide was connected to Polymer Fiber Optic (POF). One of the of POF as an input is connected to light emitted diode with wavelength of 470 nm and one of the end other POF as an output was connected to Spectrometer Ocean Optic USB4000. The result showed that the total loss at concentration of 12%-24% is -4.62 dB, -5,70 dB, -6,01 dB, -6,49 dB, -6,15 dB, -6,16 dB, respectively. Sensor works well at a solution concentration of 16%-20% with a sensitivity value of 19.62 dB/RIU and correlation factor of 92.76%.

Keyword: refractive index; polymethyl methacrylate; polymer fiber optic; waveguide

## INTRODUCTION

As technology develops, optical fiber plays an important role as a transmission channel guides light as information in communication. In addition, optical fiber also has a wider role. One of them is used as a sensor. sensor is a device that can respond to a stimulus by producing an output that can be seen. Fiber optic sensors have many applications in various branches of science and engineering like measurement many parameters such as temperature, displacement, strain, solution concentration refractive index. Fiber optics sensors have many advantages including stabel performance.

Refractive index is important parameter in various fields, for example the environmental, chemical, industrial, and medical <sup>[1]</sup>. In industrial application, the refractive index can be used to determine the standard of an oil <sup>[2]</sup>. In addition, refractive index can also be used to measure the concentration of sucrose solutions in food industry.

There are various methods that can be used to measure refractive index of a material. Novestiana (2015) used a portable brixmeter to determine the refractive index of sucrose in fruit juices. Faradhillah & Henri used the principle of refraction to measure the refractive

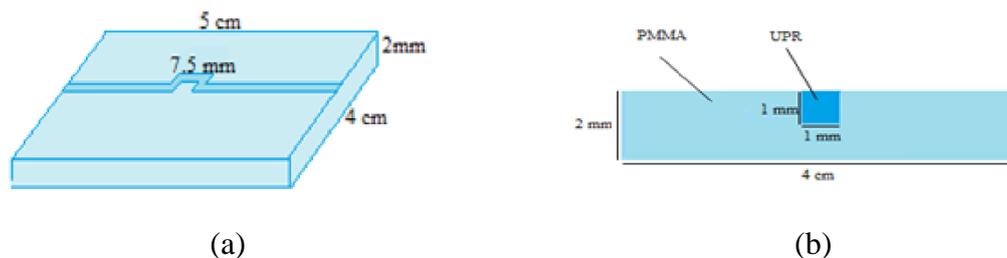
index of several types of glass. Meanwhile, Nugrahaney (2018) used the brewster angle method in determining the refractive index<sup>[3]</sup>.

Planar waveguide based optical sensors have drawn much attention due to their flexible design, real time analysis, low cost and capability for remote sensing in dangerous environment<sup>[4]</sup>. Measurement of refractive index can be done using optical sensor based buried waveguide core. Optical waveguide sensor (OWS) has advantages of robustness and could be integrated with other devices in single substrate<sup>[5]</sup>. The use of waveguide-based optical sensors can increase the sensitivity of the fabricated refractive index sensor. This is due to its stable characteristics and does not experience bending<sup>[6]</sup>.

Previous research on waveguide as a refractive index sensor has been conducted<sup>[7]</sup>. In contrast to the previous studies, this study carried out a modification in the form of a core design with a core offset structure. The core offset was designed to increase the evanescent wave.

The performance of a sensor based on the absorbance of evanescent waves is highly determined by the type of material used. This study uses Polymethylmethacrylate (PMMA) as a cladding material due to its high transparency, ease of fabrication, and low production costs. The material used as the waveguide core was Unsaturated Polyester Resin (UPR) which was Yukalac C 108b. To accelerate the Yukalac C 108b solidification process, mepoxe was used catalyst. The function of mepoxe is to accelerate the solidification process<sup>[6]</sup>. Therefore, this research was conducted to fabricate and characterize core offset buried waveguide based on Polymethyl Methacrylate (PMMA).

Offset core waveguide consist of a cladding from slice of PMMA size 4×5 mm with a thickness of 2 mm carved using a CNC machine with depth of 1 mm as shown in Figure 1.



**Figure 1.** (a) Design of cladding (b) Cross section of the waveguide

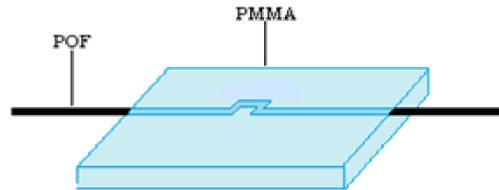
## METHOD

### Fabrication of Waveguide

Sample of waveguide consisted of PMMA as the cladding and UPR material with core offset waveguide consist of Yukalac C 108b as the core of the waveguide. PMMA has advantages of controlled refractive index values and low transmission<sup>[2]</sup>. Before the material was used as core's material for waveguide, the refractive index value was tested first using an abbe refractometer<sup>[6]</sup>.

One of the waveguide fabrications was done by cutting 15 cm long POF and then peeling the 1 cm long POF tip. POF is placed on both ends of the chiseled acrylic shown in Figure 2. POF functions as a connector between light source of waveguide and Spectrometer Ocean Optics USB4000. After POF is connected to the waveguide, then the center of acrylic is filled with core's material of waveguide as shown in Figure 3. Core's material for waveguide

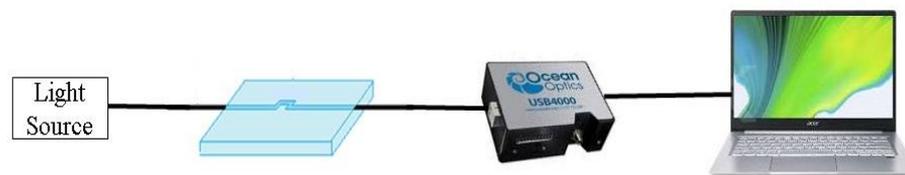
is yucalac C 108b with a mepoxe catalyst. Mepoxe function to speed up the solidification process. Then waveguide was dried for 24 hours. Design of the waveguide with POF is shown in Figure 2. Prior to waveguide characterization, the sample of waveguide was viewed using a CCD microscope with a magnification of 25 times.



**Figure 2.** Design of Waveguide with POF

### Characterization of Waveguide

Characterization of waveguide was done to get the sensitivity of sensor . At this stage, one the end of POF as input of waveguide connected to light source of LED with a wavelength of 470 nm. Meanwhile, the other of the POF as a waveguide output was connected to a Spectrometer Ocean Optics USB 4000. The circuit of the waveguide testing tool is shown in Figure 3.



**Figure 3.** Schematic of the set of tools during the characterization process

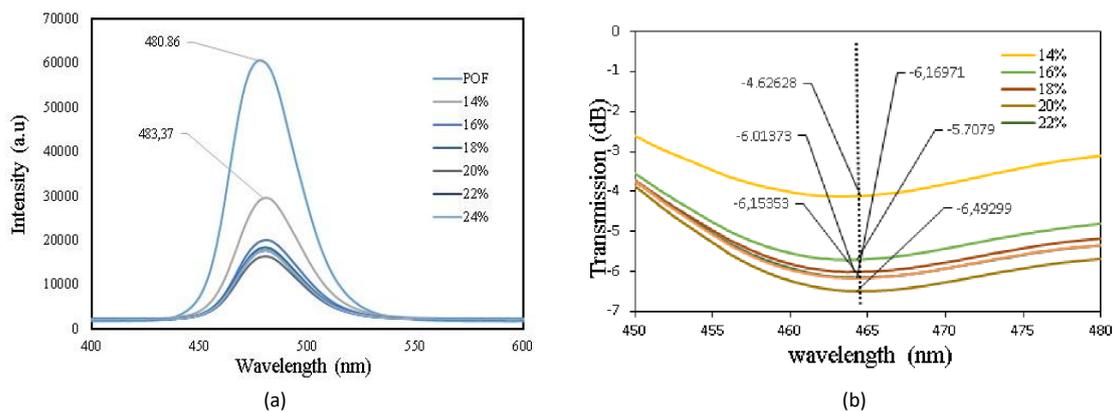
Characterization was carried out by immersing waveguide sample into glucose solution with various concentrations of 14%-24%. The sensor was immersed into the glucose solution with a concentration of 14%, 16%, 18%, 20%, and 24%. Measurement of each concentration were done for 3 minutes. Then, before taking measurements in the other concentrations, the sensor was cleaned using distilled water and dried.

### RESULTS AND DISCUSSION

The surface image of the fabricated waveguide using a CCD microscope is shown in Figure 4. Based on Figure 4, it can be seen that the surface of the waveguide cladding is homogeneous and the core surface looks flat with the surface of the cladding. It was observed that there was light scattered in the core due to surface roughness. Surface roughness on the waveguide causes the light traveling inside of the waveguide core not fully reflected back into the waveguide core, but there is some light refracted outward[8]. Transmission of waveguide sample was obtained by comparing output intensity and input of intensity. As shown in Figure 5. Based on figure 5, it was shown that the wavelength of the spectrum dip was shifted. The shift was occurred due to the change of the environment refractive index, in this case, the refractive index of the glucose solution. The shift was caused by a change in the propagation angle when light travels through a medium with a different refractive index<sup>[10]</sup>.

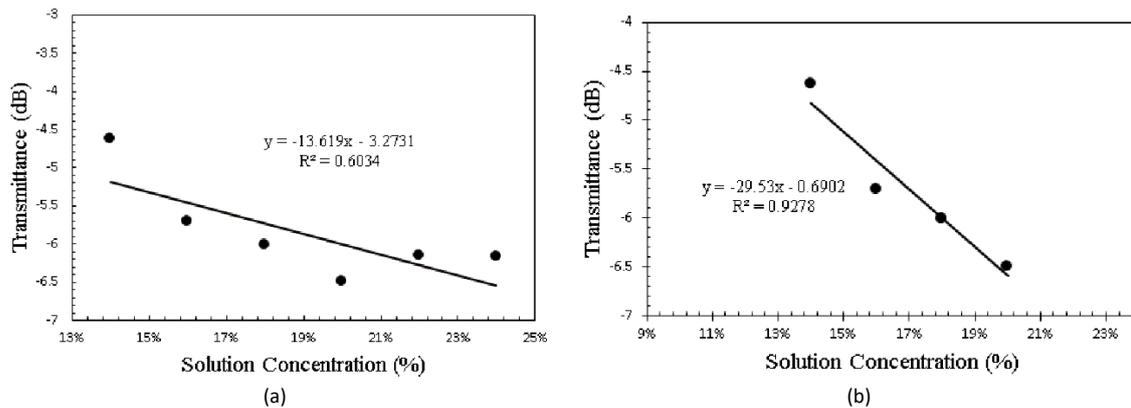


**Figure 4.** The surface structure of the waveguide (a) without light (b) with light



**Figure 5.** (a) Output spectrum of waveguide sample (b) Transmission of waveguide sample at wavelength of 470 nm.

Regarding the output transmission, the fabricated waveguide has different transmission values for each concentration of the test solution. This is due to the scattering of light between the POF and the core material on the waveguide. The scattering of light results in light being refracted outside the core, and some being transmitted into the core. The magnitude of the output transmission are in the range of -6.49299 dB to -4.62628 dB at a wavelength of 470 nm. The sensor sensitivity and linearity can be obtained by plotting a graph of changes in light intensity with respect to glucose concentrations. It is shown that the sensor sensitivity has good linearity at a glucose concentration of 14%-20% with a correlation factor of 92.78% and a sensitivity value of 29.53 dB/RIU. Overshoot occurs at concentrations of 22% and 24%. The overall correlation coefficient value is 60.34% with a sensitivity of 13.619 dB/RIU. The sensitivity value of core offset waveguide sample shows a positive response gradient, which means that higher glucose concentration, light intensity transmitted in waveguide will also increase. The increase of the light intensity was influenced by the change in refractive index of the cladding that occur when interacting with glucose, so that chelates structure was formed. The chelates structure has a lower density than claddings that have not interacted with glucose so that refractive index of the sheath is lower<sup>[9]</sup>. Despite the narrow working range, the sensor has advantages such as a simple fabrication process, compact size, low cost and light weight. The sensor could be applied for glucose concentration measurement in biomedical application.



**Figure 6.** (a) Graph of sensitivity of solution concentration 14%-24% (b) Graph of sensitivity of solution concentration 14%-20%

## CONCLUSIONS

Waveguide optical sensor have good sensitivities and linearity at glucose concentration of 14%-20% with a correlation factor of 92.78%. The sensitivity value of core offset waveguide sample shows a positive response gradient, which means that higher glucose concentration, light intensity transmitted in waveguide will also increase. The sensor could be applied for glucose concentration measurement in biomedical application.

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