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Fabrication and Characterization of Polyester/Polymethylmethacrylate Buried Waveguide for Operation in Visible Light Range

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Abstract. This study presents the fabrication and characterization of polymethylmethacrylate (PMMA)-based buried waveguide for operation in the visible light range. The fabrication was done by engraving PMMA sheet using a computer numerical control (CNC) machine to be filled with a waveguide core material and then covered with PMMA sheet. The material used for waveguide core were Unsaturated Polyester Resin (UPR) with the brand of Yukalac C108B and Eternal 2441IP. Characterization was done to determine the output power loss by passing light from an LED with wavelength of 660 nm into the waveguide. The output spectrum was observed using a spectrometer. The results showed that power loss for waveguide with Yukalac C108B and Eternal are -7.89 dB and -13.85 dB, respectively.

INTRODUCTION

Optical waveguide (OWG), which relies on total internal reflection for wave confinement, plays an important role in optical communication. The use of OWG could reduce the cost and increase the stability and the robustness of optical circuit since it could integrate many devices on a single substrate. The reliability of the waveguide based devices is potentially high because there are no moving parts. OWG could be designed and modified for various applications in optical communication such as demultiplexer [1,2], optical logic gate [3], and optical modulator [4].

Beside in optical communication, OWG could also be applied for optical sensors. Although optical waveguide-based sensor (OWGS) is not as popular as optical fiber sensor (OFS), OWGS has been developed by several researchers for various applications such as a biosensor [5], ammonia sensor [6] and refractive index sensor [7]. The sensors were developed using 2-D waveguide with complicated fabrication process and high cost materials. In terms of light confinement, 2-D waveguides provide light confinement in transverse direction only. To control the guided modes efficiently, 3-D waveguides can be used to replace 2-D waveguides since these waveguides can provide light confinement within the guide surface addition to light confinement along the depth. In this work, we proposed 3-D waveguide based on polymethylmethacrylate (PMMA) with unsaturated polyester (UPR) as the core material. PMMA and UPR were chosen due to the low cost and they are widely used in daily life [8]. To meet the requirements for sensor application in liquid such as chemical and biochemical sensors, we fabricated waveguide which operates in visible light to minimize absorption and light attenuation [9]. The buried square core waveguide was chosen as waveguide structure since it has a good fiber-to waveguide coupling and little polarization dependency. Simple fabrication was demonstrated by engraving the PMMA sheet and filling it with the core material.

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METHOD

The buried waveguide composed of a lower cladding and an upper cladding made from PMMA acrylic sheet with a size of 4 × 5 cm and 2 mm thick as shown in Fig. 1. The PMMA was engraved with a cross section of 1×1 mm^2 to be filled with the core material. Before the core material was poured, 10 cm of POF was attached at the two ends of the waveguide which function to guide light from source to waveguide and from waveguide to the detector. After the core material was poured into the PMMA, the waveguide was left at room temperature for 24 hours to let the core material solidify.

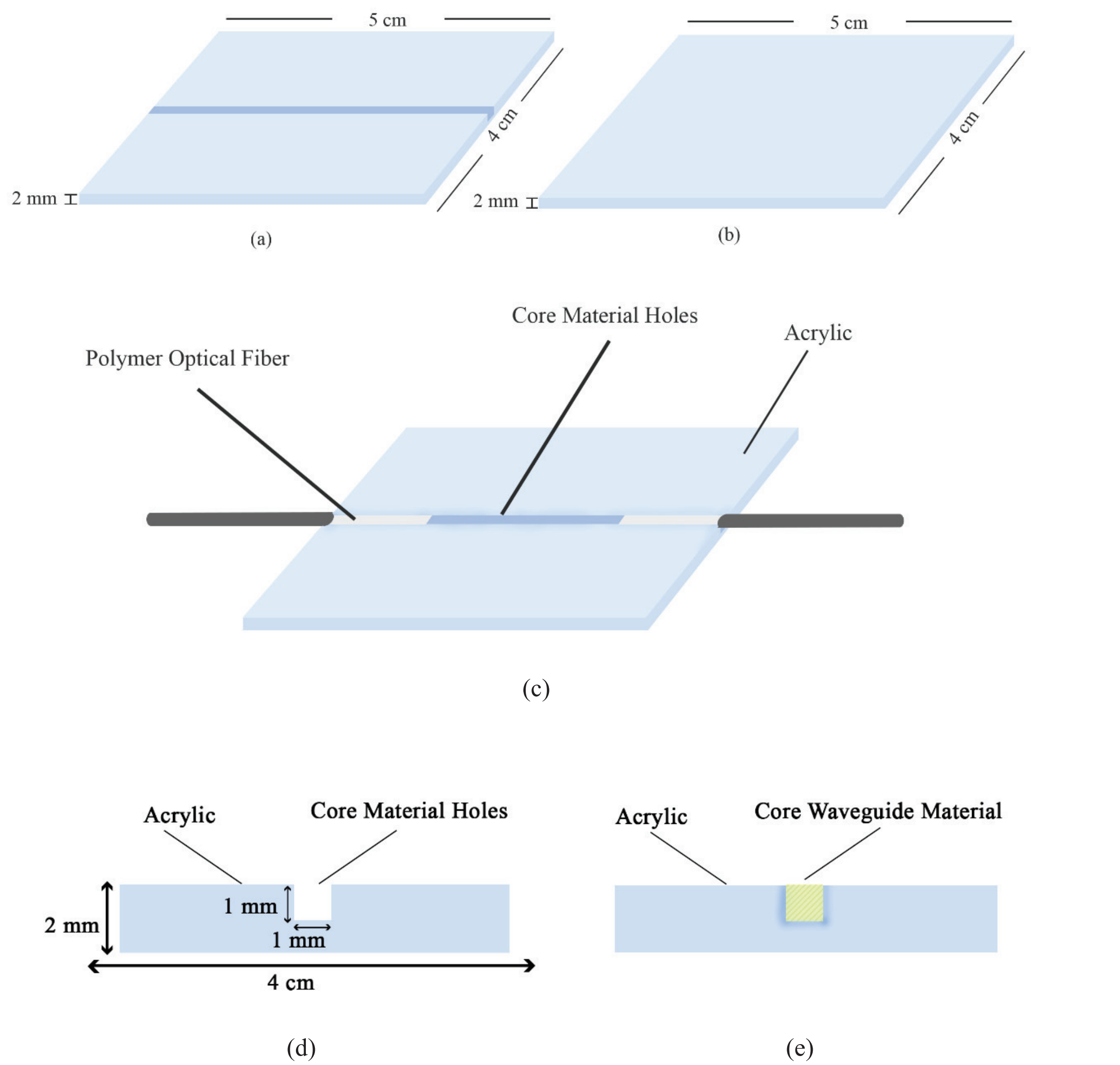


FIGURE 1. Engraved PMMA to be filled with core material (a), PMMA sheet to be used as upper cladding (b), PMMA with POF at the ends of the waveguide (c), cross section of engraved PMMA (d) and cross-section of PMMA filled with core material (e).

The material used as the waveguide core was Unsaturated Polyester Resin (UPR). For comparison purpose, we use two types UPR which were Yukalac C 108b and Eternal 2441IP. To accelerate the Yukalac C 108b solidification process, mepoxe was used as catalyst [10]. Meanwhile, the catalyst for UPR Eternal 2441PI is mepoxe and cobalt.

The function of mepoxe is to accelerate the solidification process, while the function of cobalt is to help mepoxe to release free radicals [11]. Before the material was used, the refractive index value of the material were first measured. Table 1 shows the refractive index value of UPR material which were used as a waveguide core material.

TABLE 1. The refractive index value of the waveguide core materials.

Name Of Resin	Liquid Refractive Index Value	Solid Refractive Index Value
Eternal 2441PI	1.542	1.566
Yukalac C 108 b	1.541	1.529

Based on Tab. 1, it can be seen that the difference in the refractive index values of the two materials is not significant, but the refractive index value of the two materials is higher than the PMMA acrylic refractive index, which is 1.484. These results indicate that both materials can be used as a core waveguide material because based on Snellius's law, light could be guided in a waveguide if the refractive index of the waveguide core is higher than the refractive index of the cladding.

After the core material solidified, the core surface was scraped using a cutter and sandpaper type P60 to obtain a smooth surface. The final step of the fabrication process was attaching the upper cladding using acrylic glue. The waveguide with core material of Yukalac C 108b (sample A) and 2441IP Eternal (sample B) are shown in Fig. 2.

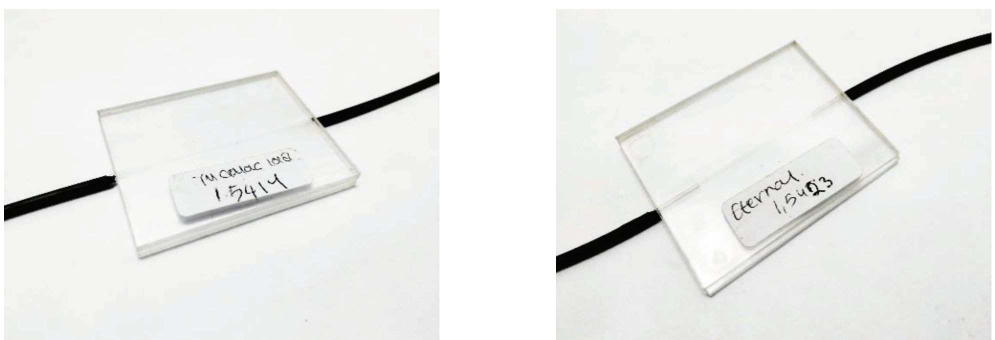


FIGURE 2. (a) Sample A and (b) Sample B.

RESULTS

Output power measurement was done by connecting the POF at an input port with a red LED with wavelength of 660 nm. Meanwhile, POF at the other end was connected by a spectrometer (Ocean Optics USB4000). The characterization set up is shown in Fig. 3.

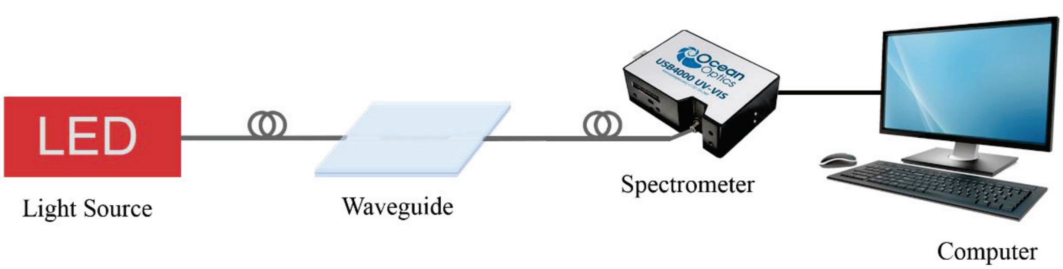


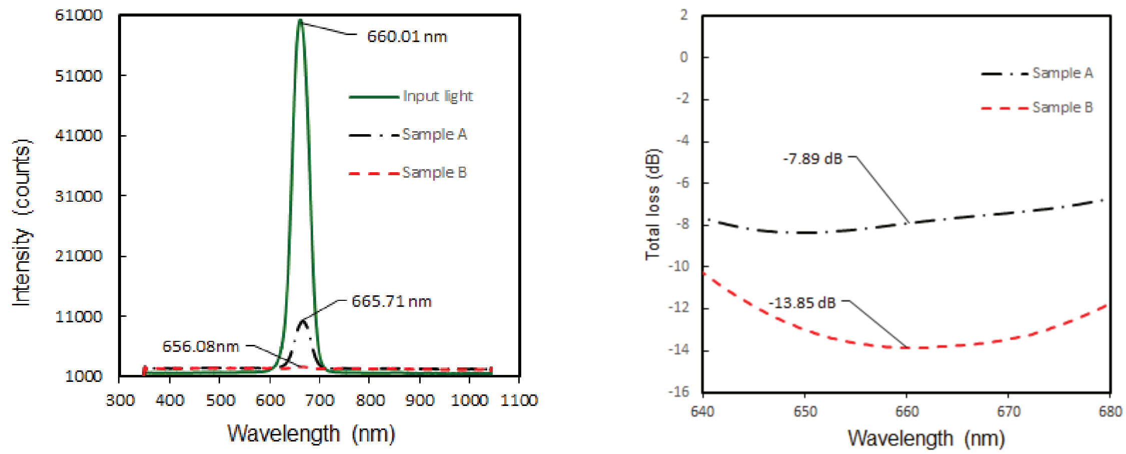
FIGURE 3. Characterization set up.

The value of power loss obtained by comparing the output intensity (I_{out}) with the input intensity (I_{in}) using the following equation:

$$loss\ (dB) = 10\ log\frac{(I_{out})}{(I_{In})} \tag{1}$$

In this case, the input intensity used was the output intensity of POF. Therefore, the propagation loss of POF has been compensated.

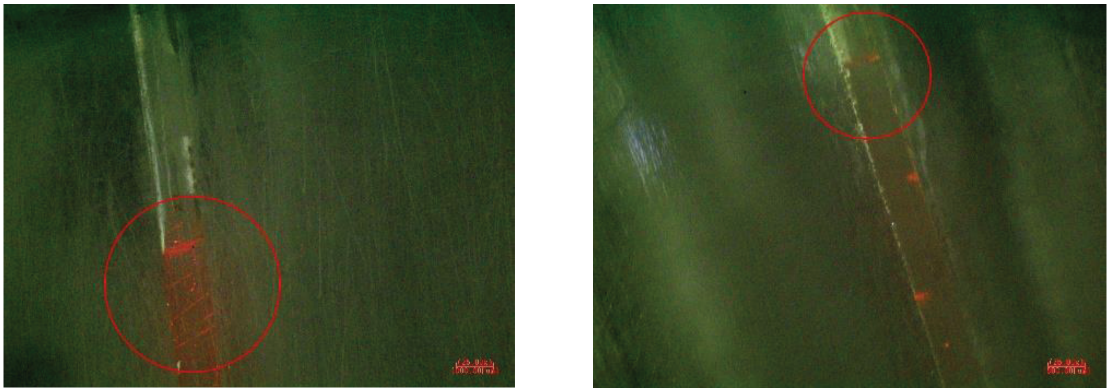
The output spectrum of the waveguides is shown in Fig. 4. It is shown that the peak wavelength of each sample is shifted from the input spectrum and the power decreased. The wavelength shifts are 5.7nm and -3.93nm for sample A and B, respectively. The wavelength shift occurred due to the changes in the propagation angle when light propagates through a medium with a different refractive index [12]. The refractive index value of a material depends on how the electromagnetic fields of the propagation waves interact with the atoms and are attached to the material medium [13].



(a) (b)

FIGURE 4. The output spectrum of waveguide (a) and power loss at wavelength 640nm-680nm (b).

From Fig. 4 (b), at 660nm wavelength, it is observed that waveguide A has the lowest power loss of -7.89 dB and waveguide B has the higher power loss, which is -13.85 dB. These results are reasonable since Eternal has the lowest refractive index, as shown in Tab. 1. Therefore, it also has the lowest propagation constant. Low propagation constant means that light confinement in the waveguide is also low which contributes to high propagation losses. Compared to a 1 × 2 acrylic-based plastic optical fiber coupler with a hollow taper waveguide that has a power loss of -11.15 dB [14], sample A has -3.26 dB lower power. Beside propagation loss, other losses that might contribute to the total loss are power loss at POF-waveguide connections (connection loss) and power losses due to surface roughness. The observation using a CCD microscope when the light was launched into the waveguide (Fig. 5) shows that there was light scattering on the POF-waveguide junction and also light scattering on the surface of the waveguide core. Scattering in the connection area was caused by several factors, such as the difference of the POF cross-section and waveguide cross-section. Since the waveguide is a buried square core waveguide, while the POF has a circle cross-section, then some of the light could not be transmitted but was refracted out from the waveguide. The surface structure of the waveguide and the POF cross-section at the junction also contributes to the connection loss. If the cross-section surfaces are not perfectly flat, then it will affect the incidence angle. If the incidence angle is greater than the numerical aperture (NA) value of the waveguide core, then some of the light is not transmitted into the waveguide core but refracted out. An NA is a dimensionless number that characterizes the range of angles which an optical device can receive or emit light [15]. Scattering on the surface of the waveguide occurred due to an uneven or wavy core surface [16]. This causes the light propagating inside the waveguide core refracted out as shown in Fig. 6.



(a) (b)

FIGURE 5. Light scattering at POF connection with waveguide core in (a) sample A and (b) sample B.

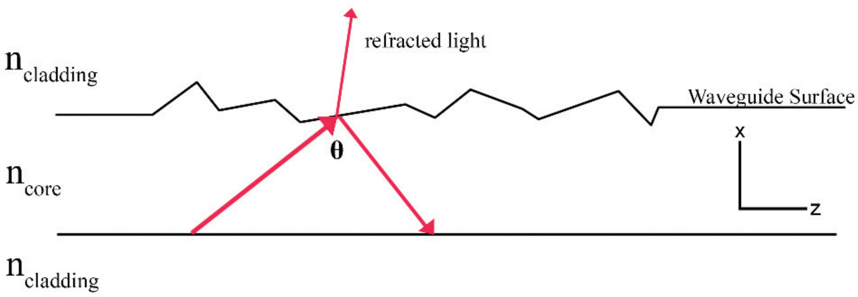


FIGURE 6. Light scattering due to surface roughness.

CONCLUSIONS

Fabrication and characterization of the buried square-core waveguide using PMMA for operation in the visible light area have been carried out. The results show that the waveguide with UPR Yukalac C108b core material has the lowest power loss of -7.89 dB. The peak wavelength for both waveguides were shifted. Power losses can be further reduced, improving fabrication techniques to produce smoother surfaces and better connections that will be carried out in future studies. The waveguide could find application for optical sensor and short distance communication systems in which POF is used.

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