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Fabrication and Characterization of Directional Couplers as Power Dividers

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Abstract*—This paper is about directional coupler fabrication results in a slab structure with a substrate in the form of acrylic glass, a film of nano SnO_2, and cladding in the form of methyl methacrylate (MMA). The length of the interaction area (Lc) directional coupler of the fabrication result is 5 mm with a gap width (g) of 0.353 mm. SnO_2 film is grown by deposition on an acrylic substrate. To facilitate the characterization process, the directional coupler is given an optical fiber as input. SnO_2 film which has been deposited on an acrylic substrate is coated with methyl methacrylate (MMA). Coating of methyl methacrylate (MMA) in SnO_2 film is done by the doctor blade method. Directional coupler fabrication results are used as optical power dividers. The fabricated directional coupler is narrated using a He-Ne laser with a wavelength of 632.8 nm. The characterization mechanism is carried out by taking a photo of the cross section of the directional coupler when given a laser beam input. The cross section photos are processed using ImageJ software to determine the directional coupler intensity distribution on each port. Based on the results of the characterization, the directional coupler with the 5 mm Lc output percentage is 26%, 24%, and 49%.

***Keywords*—Doctor Blade, Methyl Methacrylate (MMA), SnO_2 Nano.**

I. Introduction

In simple optical instruments and systems, light is transmitted between different locations in the form of light that is collimated, illuminated, focused, and scanned by mirrors, lenses, and prisms. The beam flexes and spreads as they propagate even though they can be refocused using lenses and mirrors. However, the largest optical component consisting of such components is often large and difficult to use, and objects that are on the path of light can block or scatter the beam [1].

In some cases, it is an advantage to transmit optical light through the dielectric channel rather than passing free space. The technology to achieve this is known as optical waveguides. The technology was originally developed to serve long-distance light transmission without requiring the use of combined lenses. This technology now has many applications. Some small examples include bringing light through long distances for optical wave communication, biomedical imaging where light must reach a tortuous location, and connecting between miniature optics and optoelectronic components with systems [1].

The basic principle of containment/optical light guidance is simple. A medium with a refractive index n1, attached to a medium with a lower refractive index $n_2<n_1$, acts as a light trap until the optical beam remains confined by total internal reflection many times in the boundary plane between n_1 and n_2. Because this effect facilitates the confinement of light caused in parts of a medium with a high refractive index, it can be used in the manufacture of light channels that guide the transmission of light from one location to another. An optical waveguide is a light channel consisting of a board, plane or cylinder structure in a dielectric material attached to another dielectric material with a lower refractive index. Light is sent across the inner medium without radiating to the enveloping medium. The most widely used waveguides are optical fibers, which contain concentric two-cylinder dielectric materials such as glass [1].

Optical combination is a combination technology on a single substrate ("chip"), various optical components and useful components to generate, focus, separate, combine, isolate, polarize, combine, divert, modulate, and detect light. An optical waveguide provides a link between these components. The chip is an optical version of an electronic integrated circuit. Integrated optics, as its purpose, miniaturizes optics in the same way as integrated circuits for miniature electronics [1].

Planar waveguides are the main components that act as builders of integrated optical circuits and semiconductor lasers. In general, planar waveguides consist of a planar-shaped core surrounded by a cladding with a refractive index lower than the core refractive index [2].

The development of optical communication and technology systems, optical switching and arrays have played an important role in the transmission of information, optical cross-connect (OXC), optical add-drop multiplexers (OADM), and optical channel protection (OLP), which is related to the magnitude their applications in optical signal processing, optical computing, optical instruments, optical equipment and sensors [3].

The process of sending data by utilizing an optical communication system that has a very large bandwidth (bandwidth) will not run optimally if it is not followed by the discovery of adequate optical components. One of these components is a directional coupler that can function as an optical switching, multiplexing, de-multiplexing, splitter and power divider component.

Experiments on the development and design of directional couplers have been widely carried out by previous researchers including transmission in a directional coupler Ti: $LiNbO_3$ 1 × 2 [4], zero gap directional coupler analysis Ti: $LiNbO_3$ for wavelength division multiplexer / de-multiplexer [5], response characteristics analysis of electro-

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optic switches for directional coupler polymers [6], LiNbO3 directional couplers based on photonic cables [7], TE / TM splitter polarization on LiNbO3 photonic cables [8] and many more advanced experiments related to the development and design of directional couplers.

Semiconductor metal oxides such as tin oxide (SnO), zinc oxide (ZnO) and indium oxide (InO) have been widely studied because they show useful optical and electronic properties [9]. SnO2 is a non-stoichiometric semiconductor with Eg (energy gap) > 3.6 eV at room temperature with a tetragonal structure. The SnO2 layer has unique characteristics such as high transmittance at visible wavelengths, low resistivity, high stability compared to other transparent conductive oxides (TCOs). The SnO2 layer is widely used in optoelectronics applications such as window film coatings, photocatalysts, organic LEDs, gas sensors and solar cells. There are several methods for preparing SnO2 thin films, including molding techniques, chemical vapor deposition, reactive evaporation, dc and rf sputering, laser pulse ablation, thermal evaporation, organic metal deposition, sol-gel deposition and spray pyrolysis [9].

Research and development of directional couplers in the above exposure certainly requires laboratory equipment that supports the fabrication and characterization of an adequate directional coupler component and requires no small amount of funds.

On the other hand, fabrication and characterization of directional couplers with slab structure based on polystyrene and polymethyl methacrylate (PMMA) polymers have been carried out using spin coating method. The resulting directional coupler is multimode with a copling length of 0.18 cm, the measurement results and 20.84 μm simulation results [10]. The study was continued with the fabrication of wave guides TiO2 nano y-branch with lithography method as a power divider and obtained the value of power loss for the y-branch channel of 43.4% [11]. And the study was continued result of absorbance and transmittance using UV-Vis known that the highest absorption (262 nm), average transmittance (91 %) and the thickness of the film obtained 131.6 µm [12].

Based on the results of the research described, it is possible to experiment with directional coupler structure of slab structure as a power divider using nano SnO_2 film.

II. METHOD

Fabrication and directional coupler characterization as a power divider begins with the preparation of an acrylic glass substrate. The preparation stage includes making a substrate that is acrylic cutting with a thickness of 2 mm in size according to the design. Acrylic cutting is done using a laser cutter. It aims to make the acrylic edge look neater.

The pattern of each waveguide to be fabricated is formed through a engraving process. This process is similar to a laser cutter, only the power used in the engraving process is not as large as at the time of cutting, so the substrate that is engraved is not cut off. The acrylic design that will be used is presented in Figure 1.

Figure 1. Acrylic Design.

The directional coupler waveguide pattern is formed through laser engraving and laser cutting. For the directional coupler, two layers of acrylic are required with the details of the bottom for engraved acrylics and the top for cut acrylics.

The directional coupler design above is used as the bottom waveguide channel. As for the upper waveguide channel, the same acrylic design is used but not through the engraving process. The upper waveguide channel is made by cutting acrylic that has been previously designed with a laser cutter. The result of the acrylic pattern cut is then affixed to the top of the acrylic engraved with glue.

Two acrylics that have been pasted are then smoothed on the pieces of the used pieces using emery paper at a smoothness level of 180, 360, 600, 1200 and 5000 mess. The refining process is carried out until the cut acrylic part looks flat and smooth. After the edges of the acrylic are smooth, acrylic is cleaned using soapy water and then washed with distilled water then dried.

Then the acrylic was put on a beaker which contained 96% alcohol as much as 100 ml and then cleaned using ultrasonic cleaner for 60 minutes. After 60 minutes acrylic is dried using drayer. Acrylic substrate cleaning is intended to allow acrylics to be free from materials that are not only able to be cleaned with water. Clean or not the acrylic substrate affects the test results of the sample to be coated.

The preparation of SnO_2 solution was carried out by mixing the solvent and SnO_2 binder, where ethyl cellulose ([$C_6H_7O_2$ (OH) 3-x (OC_2H_5) x] n) acted as a binder and isopropanol (CH_3) 2CH (OH) as a solvent from SnO_2. The preparation of this solution was carried out by dissolving 0.13 gr ethyl cellulose and 3 ml isopropanol. Then the stirring process was carried out using a magnetic stirrer hotplate for 1 hour with a heating temperature of 50 °C. The duration of stirring is intended so that the binder and solvent are completely mixed without any small lumps in the solution being made. Provision of a heating temperature is done so that the solution is more easily mixed, noting that the temperature is used below the melting point of ethyl cellulose (160 °C-210 °C) and isopropanol (82.2 °C).

After making the solution from the mixture between the solvent and the perfectly mixed SnO_2 binder, then 0.25 grams of nano SnO_2 powder are added. Then stirring for 1 hour with a heating temperature of 50 °C using a magnetic stirrer hotplate. The duration of stirring is intended to allow the SnO_2 powder to dissolve and cannot be distinguished between solutes and solvents. If the SnO_2 solution has become a gel, the solution is ready to be deposited on an acrylic substrate.

Directional coupler waveguide fabrication is done by coating SnO_2 solution on an acrylic substrate. The process of coating SnO_2 on an acrylic substrate is carried out by depositing the gel SnO_2 solution into the hole in the acrylic channel. When the SnO_2 solution is deposited on the directional coupler channel, one of the directional coupler ports is given a multimode optical fiber. The provision of optical fiber in the directional coupler channel aims to make it easier to straighten the laser light beam during the characterization process. Once coated, the acrylic substrate coated with SnO_2 is heated to 100 °C above the hotplate stirrer. It aims to remove the solvent used in SnO_2 solution, where the melting point for isopropanol is 82.2 °C.

The formed SnO_2 film is then coated with an MMA layer. This MMA coating is done 2 times, so that the MMA layer completely closes the SnO_2 film. MMA coating serves as a cover on the SnO2 waveguide. Then the heating process at 70 °C for 15 minutes. The heating temperature is maintained so as not to exceed the boiling point of MMA (100 °C). Heating at 70 °C was carried out to polymerize MMA to PMMA.

Testing of SnO2 material transmittance on directional coupler waveguides that have been fabricated is done using Genesys 10S Spectrophotometer UV-Vis. This test is needed to determine the range of wavelengths that are suitable so that light can be transmitted into the SnO2 film properly.

Directional coupler waveguide characterization is carried out by measuring the output of each port from the directional coupler waveguide. Where the He-Ne laser beam is inserted into the optical fiber to propagate / propagate into the directional coupler waveguide. Then a photograph of the fabricated cross section of the directional coupler is taken. The directional coupler characterization set up is shown in Figure 2.

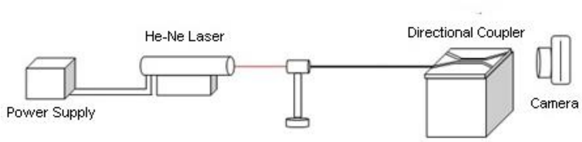


Figure 2. Characterization Set Up.

The next process is image analysis, carried out using ImageJ software to obtain the intensity distribution pattern. From the intensity distribution of processing results with ImageJ software also obtained RGB (Red Green Blue) component value data from the directional coupler cross-sectional photo. Because the light source used by the He-Ne laser has a wavelength of 632.8 nm with a red output, the red component of the RGB value is taken and processed.

Processing of red component data on RGB values is done by dividing the red component data into two, namely the right and the left (ports A2 and B2). This is done because the fabricated waveguide has two output ports (ports A2 and B2). After the red component data is divided into two right and left, the red component data is averaged. The average value of the red component data for the right and left is the output value of each fabricated waveguide port.

To get the port output value (port A1) that returns next to the input port (port B1) is done in the same way as the previous method. It's just that the right part is taken (port A1) because the left side is the intensity of light scattered around the input (port B1) of the directional coupler waveguide.

III. Result and Discussion

In this study directional coupler has been fabricated with a gap width of 1 point (0.353 mm). The copling length of the directional coupler of the fabrication result is 5 mm. The fabricated directional coupler is shown in Figure 3.

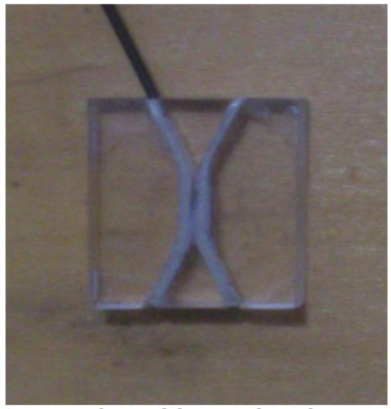


Figure 3. Fabricated directional coupler images.

The fabricated waveguides are characterized by using a He-Ne laser transmitted via optical fiber. The He-Ne laser has a wavelength of 632.8 nm and in the wavelength range of the visible region with red output.

The directional coupler waveguide process begins with taking a cross section of the directional coupler waveguide when given a laser beam. The sketch of the directional coupler waveguide is shown in Figure 4. If B1 is the input, A2, A1 and B2 are outputs and vice versa.

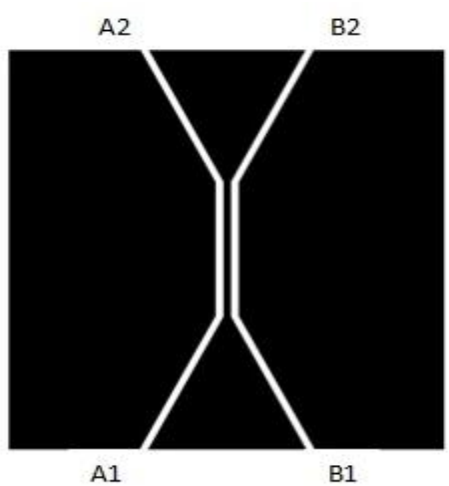
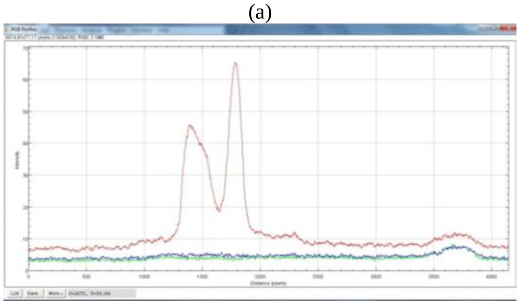


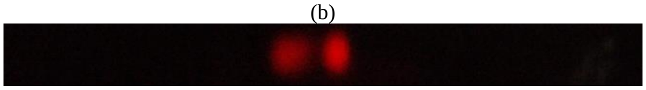
Figure 4. Sketch of the directional coupler waveguide.

The cross-sectional image for ports A2 B2 and A1 B1 along with the RGB plot of the 5 mm directional coupler waveguide with 5 mm length is shown in Figure 5.

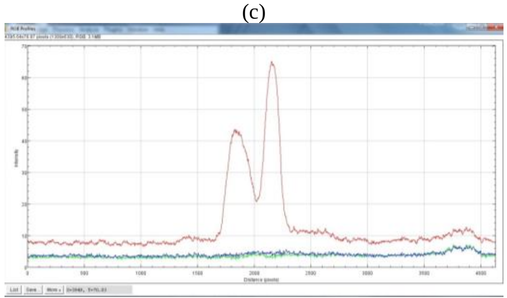
(a)



(b)



(c)



(d)

Figure 5. Directional coupler waveguide with 5 mm coupling length with input B1 (a) B2 B2 port (b) RGB B2 A2 port plot (c) A1 B1 port (d) RGB port A1 B1 plot.

Figure 5. (a) is a cross section of the directional coupler with input port B1. The left side is the intensity distribution of the B2 port and the right is the intensity distribution of the A2 port. Figure 5. (a) then processed with ImageJ software so that Figure 3.3 (b) is obtained. Figure 5. (b) explains that the directional coupler waveguide output output for B2 port is higher than A2 port, this is because the wave propagation on B2 port does not pass through the gap found in the directional coupler so that the guided power is greater than the A2 port even though there is several beams of light scattered around the acrylic substrate. The gap found in the fabricated directional coupler has a thickness of + 0.353 mm with a height of + 2 mm made of acrylic.

Figure 5. (c) is a cross section of a directional coupler waveguide for port A1 B1. Based on the RGB plot in Figure 5. (d) it can be seen that the intensity distribution of port B1 is higher than port A1. This is because port B1 acts as input when characterization is performed.

From the RGB plot, each directional coupler port gets red, green and blue (RGB) component data from the cross section of the output port. The red component data is then separated by dividing it on the right and left, considering the directional coupler output port consists of two ports, A2 and B2. The red component data on the right and left side are then averaged so that the output value of each directional coupler waveguide port has been fabricated. The percentage value of output is obtained by dividing the average value of each port by the number of all ports and multiplied by 100%.

The output values of each port and the percentage of directional coupler waveguide output with a copling length of 5 mm are shown in Table 1.

TABLE 1.
DIRECT OUTPUT COUPLER EACH OUTPUT PORT

Input	Output (%)			Output (%)		
	A1	**A2**	**B2**	**A1**	**A2**	**B2**
B1	23.7	21.9	43.9	26.5	23.5	49.1

Based on Table 1, it can be seen that for a directional coupler with a combined length (copling length) of 5 mm has a percentage of output approaching 50%: 25% of the opposite port to the input port is port A1, with a percentage ratio on port B2: A2 that is 49, 1%: 24.5%. This difference is caused because not all modes can be moved to the next port (A2) through a gap measuring 0.353 mm or 1 point. When the intensity distribution is observed from the tip of the waveguide, the even mode TE_0 displays one bright spot in the middle, and the even mode TE_1 displays three bright spots. In general, even modes TE_N display 2n+1 bright spots.

IV. CONCLUSION

From the results of fabrication and characterization of the waveguides that have been carried out, it can be concluded that directional couplers have been successfully fabricated by the sol-gel deposition method and coated with methyl methacrylate (MMA) by the doctor blade method. This directional coupler fabrication can guide He-Ne laser light with a wavelength of 632.8 nm. The output of each directional coupler waveguide port is 26%, 24% and 49%, respectively for ports A1, A2 and B2.

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