Low-cost fabrication of optical waveguide as directional coupler using CO₂ laser cutting

Asnawi¹
Department of Physics
Universitas Negeri Surabaya
Surabaya, Indonesia
¹asnawi@unesa.ac.id

M. S. Muntini, Yono Hadi Pramono²
Department of Physics
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
²yonohadipramono@gmail.com

Abstract—Engraving of polymer materials using cutting laser is a popular process in some manufacturing industries. This research presents the manufacture of waveguides channels on polymethyl methacrylate (PMMA) substrate using CO₂ cutting laser process. The CO₂ laser engraving machine has cost effective and takes less time than other tools in waveguide channels fabrication. In this work, we integrated optical components such as waveguide for directional coupler application using tin oxide which is embedded and interconnected in PMMA substrate. In the fabrication channels waveguide with grafir on PMMA substrate with 4.2 mW laser power and speed 10 mm/s and then repeated two times. The waveguide channels profile is made with curvature angle variation for branching (17°, 36° and 54°). Characterization of waveguide directional coupler is done by measuring the density of the output at each port cross-section of the waveguide directional coupler when given an input beam He-Ne laser (632.8 nm). The results directional coupler fabrication using CO₂ laser cutting machine can achieve optimum with a very small loss of 3.3% when compared to the straight waveguide. Thus, CO₂ laser cutting processing as an optical waveguide fabrication can produce channels on PMMA material more effectively.

Keywords—CO₂ laser cutting; directional coupler; optical waveguide

I. INTRODUCTION

The development of polymer material-based optical waveguides has experienced great growth over the past years due to the simplicity of handling and production at low costs [1-3]. At present, channel optical waveguides are being made using a variety of advanced materials to get optimal results. Waveguide fabrication enables the manufacture of high quality microchannels on polymer substrates including acrylic or polymethyl methacrylate (PMMA) [4] with wall surface roughness of the material which cannot be ignored. It is possible to fill channels on optical waveguides as cores with metal oxides in this case TiO₂, ZnO, SnO₂ and so on [5] make it new in the integrated optics field. One of the optical waveguide applications as a directional coupler (DC).

Directional coupler is one of the main components in optical signal processing systems and fiber optic communication systems that can function as optical switching, multiplexing, demultiplexing, splitter and power divider components [6]. There are several types of power dividers including Y-branch [7] X-crossing [8] and multimode interference (MMI) [9-10]. Optical waveguides of oxide material in this case Tin Oxide (SnO₂) implanted in the channel polymer channel in this case acrylic. SnO₂ one of the semiconductor metal oxide films has attracted considerable interest because of its electrical conductivity and good optical properties [11] with an energy gap gap that is greater than 3.6 eV [12] and is transparent [13]. Several methods that have been used to make wave guides with SnO₂ nanoparticles are CO₂ laser cutting methods [14], chemical spray pyrolysis [15-16], chemical bath deposition [17], chemical vapor deposition [18] and spin coating [19].

In this paper, nano-size SnO₂ material as an oxide material is deposited so that it is embedded in the waveguide channels with a function as core [20] on acrylic substrates and PMMA as polymer material used by a waveguide cover. After determining the dimensions of the dimensions of the waveguide design, the tracing paper mask is printed by means of a graphical process [21] to carve microchannels. Machining with CO₂ lasers involves the removal of material by thermal processes. Infrared radiation excites vibrational and rotational levels in irradiated waveguides, because the settings in this fabrication are very challenging to the results of the waveguides to be made. Thus, it is very important to choose materials that respond in ways that are beneficial for CO₂ laser irradiation. This CO₂ laser irradiation causes the thermal properties of the material disposal process, in this case the formation of waveguides is made according to the design [22].

The process of coating SnO₂ on the waveguide substrate is carried out by depositing the gel SnO₂ solution into the hole in the acrylic channel. When the SnO₂ solution is deposited on the directional coupler channel, one directional coupler port is provided with 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. After being coated, the acrylic substrate from the directional coupler waveguide is heated to 100°C. SnO₂ film material as the core waveguide directional coupler which has been formed in microchannels coated with a layer of PMMA. To characterize experimentally waveguides...
by providing the laser beam with a wavelength of 632 nm is inserted into an optical fiber.

II. METHODOLOGY

A laser system consisting of a continuous 500W CW CO₂ laser and a three-axis CNC-controlled table with a working volume of 1 m x 1 m x 0.1 m (Fig. 1) is used for cutting polymeric / acrylic materials with dimensions (30 mm x 15 mm x 2 mm) made according design size.

Gas shielding in CO₂ laser cutting mainly removes liquid material from the cutting zone and at the same time protects the lens from the smoke emitted due to evaporation of the material so as not to damage the pattern of the waveguide created. In addition, this enables effective coupling of laser light with the acrylic material. Acrylic material which has been dicutting laser as a directional coupler waveguide substrate with a variety of different angle patterns. The design of the optical waveguide as a directional coupler is presented in Figure 2.

![CW CO₂ laser cutting machine](image1)

Fig. 1. CW CO₂ laser cutting machine

Preparation of SnO₂ nanopowder (<100nm particle size with code 1002099194) was carried out by mixing solvents and binders SnO₂, where ethyl cellulose ([C₆H₇O₂(OH)]₃ₓ (OC₂H₅)ₙ) from Sigma Aldrich-USA acted as a binder and isopropanol [(CH₃)₂CH(OH)] of JT Baker product as solvent of SnO₂ [23]. This solution preparation was done by dissolving 0.13 grams of ethyl cellulose and 3 ml of isopropanol. Furthermore, the stirring process used a hotplate magnetic stirrer for 1 hour at a heating temperature of 50°C. Heating process was done at temperatures below the melting point of ethyl cellulose (160°C-210°C) and isopropanol (82.2°C). Therefore, it was much easier for solution smoothly mixed. After the solvent and binder had been evenly mixed, SnO₂ nanopowders added 0.25 grams. Then it was stirred for 1 hour at a heating temperature of 50°C using a magnetic hotplate stirrer. If the solution of SnO₂ had become a gel, then the solution was ready to be implanted on the acrylic substrate.

The optical waveguide as directional coupler was made by implanting a solution of SnO₂ on an acrylic substrate. The process of planting the SnO₂ layer on the acrylic substrate was carried out by depositing a solution of SnO₂ that had become gel into the hole on the acrylic channel. When the SnO₂ solution was deposited on a channel, one optical waveguide port was assigned a multimode fiber optic. Giving optical fiber on channel aimed to facilitate straightening laser light beam for characterization process. Once embedded evenly, the implanted acrylic substrate SnO₂ was heated to a temperature of 100°C. The purpose of heating was to remove the solvent in the solution SnO₂ (melting point isopropanol 82.2°C). SnO₂ film embedded in the acrylic substrate, then coated with Methyl methacrylate (MMA) solution. This MMA coating was carried-out two times with heating at 70°C for 15 minutes for MMA polymerization to PMMA. Thus, the PMMA layer which acted as an optical waveguide cover completely closed the SnO₂ film layer.

The optical waveguide was characterized by inserting a He-Ne laser beam into an optical fiber for subsequent propagation into an optical waveguide. The output of the cross-section of the fabricated optical waveguides was observed using a camera. The next process was the analysis of the output image of the light beam at the optical waveguide output intensity distribution pattern. The intensity distribution of the result of light beam processing at the cross-section of optical wave of directional coupler was RGB (Red Green...
Fabricated optical waveguides can guide laser light well enough, but not well on the other side. This is due to the less linear layer on the surface of SnO\textsubscript{2} in optical waveguides. Less severe layers of SnO\textsubscript{2} in the film are caused when the partial heating process of the SnO\textsubscript{2} solvent evaporates and creates a hole in the optical waveguide. Before coated with a SnO\textsubscript{2} solution, methyl methacrylate (MMA) coating should be performed on the waveguide line starting from the left, center and right on the optical waveguide channel. This layer is made to form an optical waveguide covering layer as a directional coupler application. This cover layer serves to prevent the existence of light scattered in channel directional coupler. The electromagnetic wave propagation in the coupling region is significantly dependent on the geometry of the waveguide channel such as the propagation constant, refractive index and core diameter and cladding. However, in situations where the electromagnetic channel directional coupler is separated, the initial electric field will be disturbed by adjacent channel electrical fields. If the channel of the directional coupler is separated by a certain distance, this perturbation causes the electric field of each channel to spread through the core interface and cladding. This causes the transfer of power from one channel to another or vice versa [24]. Finally, the transmitted light will be greater with a smaller power loss. The size of the optical waveguide is fabricated in microns then the guided waves are multi-mode, as shown in the optical wavelength cross section output of Fig. 3.

### III. RESULTS AND DISCUSSION

Based on these optical waveguide outputs filter the three primary colors of the visible range, red (R), green (G) and blue (B). The fabrication of optical waveguides on directional couplers is used to check the propagation characteristics of the designed directional coupler [25]. Transmission of electromagnetic wave propagation that radiates on optical waveguides is analyzed and calculated to confirm the performance of the directional coupler. The optical spectrum of red on each subsequent waveguide output is averaged to produce the output value on the optical waveguide port of the directional coupler. The directional coupler with a branching angle waveguides 17° (DC type A), in which the light intensity distribution is at port 1 and port 2 has a percentage of output close to 50%:50% to the opposite port to the input port. The value of the percentage of output loss in port1: port2 (33.7%:35.6%), with the percentage percentage of the comparison value, the directional coupler can be used as an optical component that functions as a file splitter. Directional coupler with branching angle 36° (DC type B) has a percentage of output distribution approaching 27%: 53% of the opposite port to the input port, with the percentage percentage output ratio, directional coupler type B can be used as an optical component that functions as a power divider.

The directional coupler (DC type A and type B) waveguides it can be said that the larger the waveguide branching angle, the comparison of the power distribution that moves from one channel to the other channel. However, for DC type 3, the power fraction that moves to port1 or port2 gets smaller. This is due to the amount of input light scattered around the waveguide substrate. Besides that, the use of SnO\textsubscript{2} (tin oxide) material is a material that has nonlinear characteristics. Nonlinear material itself is a material that is able to interact with light, depending on the type of material used [26].

The results of this research on DC type 3 also shows that the return port value in the waveguide is also greater with the magnitude of the branching angle of the waveguide. Thus it can be said that the shorter the coupler path, the more light

#### TABLE I. Percentage of output intensity of port 1 and port 2 from directional coupler optical waveguide

<table>
<thead>
<tr>
<th>DC Type</th>
<th>Θ (°)</th>
<th>Input</th>
<th>Intensity Output (%)</th>
<th>Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17</td>
<td>100</td>
<td>40.0</td>
<td>50.3</td>
</tr>
<tr>
<td>B</td>
<td>36</td>
<td>100</td>
<td>27.6</td>
<td>53.6</td>
</tr>
<tr>
<td>C</td>
<td>54</td>
<td>100</td>
<td>48.9</td>
<td>30.7</td>
</tr>
</tbody>
</table>

![Fig. 3. Directional coupler with a branching angle of 36°](image_url)
will be guided towards the opposite, this is in accordance with the results of research conducted by Fan Lu, where he stated that the waveguide with a crossing angle of $< 25^\circ$ will be guided towards the opposite, this is in accordance with the results of the multi-arm splitter power simulation designed by Simranit Singh et al. [27] Thus, the directional coupler of this design can be used as an optical component that functions as a file splitter.

IV. CONCLUSION

In this paper, beam propagation in a directional coupler based on polymeric material based on the $\text{CO}_2$ laser cutting method can be guided well. The use of SnO$_2$ material, core thickness, waveguide width, gap width and curvature of the waveguides to produce a good coupling. This device has a simple and easy to achieve structure. This shows good performance which is split with small losses (around 3.3%) at a wavelength of 632 nm. The fabrication of the channels directional coupler process step insures very good alignment accuracy and guarantees a low-cost passive coupling and assembly. Beside applications in telecommunication the bi-functionality of the waveguiding layer opens up new applications in the field of sensor technology.

ACKNOWLEDGMENT

This research is supported by the Internation Scholarship Funding Program for Research and Development of Science and Technology at Sepuluh Nopember Institute of Technology (ITS Surabaya).

REFERENCES


