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Low-cost fabrication of optical waveguide as directional coupler using CO_2 laser cutting

Asnawi[1]
Departement of Physics
Universitas Negeri Surabaya
Surabaya, Indonesia
[1]asnawi@unesa.ac.id

M. S. Muntini, Yono Hadi Pramono[2]
Department of Physics
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
[2]yonohadipramono@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 CO_2 cutting laser process. The CO_2 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 subtrate 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 (17º, 36º and 54º). Characterization of waveguide directional coupler is done by measuring the intensity 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 CO_2 laser cutting machine can achieve optimum with a very small loss of 3.3% when compared to the straight waveguide coupler channel. Thus, CO_2 laser cutting processing as an optical waveguide fabrication can produce channels on PMMA material more effectively.**

Keywords—CO_2 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 TiO_2, ZnO, SnO_2 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 (SnO_2) implanted in the channel polymer channel in this case akrylic. SnO_2 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 SnO_2 nanoparticles are CO_2 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 SnO_2 material as an oxide material is deposited so that it is embedded in the waveguide chanels 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 CO_2 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 CO_2 laser irradiation. This CO_2 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 SnO_2 on the waveguide 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 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. SnO_2 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 CO_2 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.

Fig. 1. CW CO_2 laser cutting machine

Gas shielding in CO_2 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.

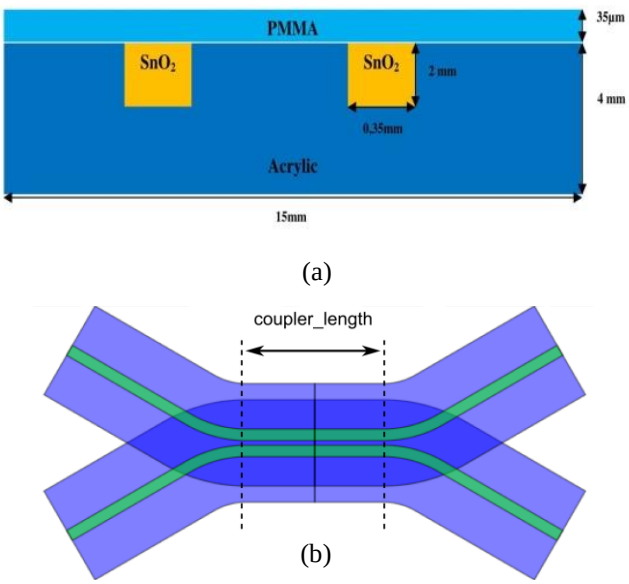

Fig. 2. (a) Cross section Waveguide DC (b) Schematic diagram waveguide.

The optical waveguide design of the finished acrylic substrate was pureed on the cutting-edge pieces using an abrasive. The smoothing process was done until the cut acrylic part looks flat and smooth. After the acrylic edges were smooth, acrylic was cleaned with water then was washed and cleaned with distilled water. The acrylic substrate was soaked in 96% alcohol for 30 minutes and dried using hotplate at 50°C for 10 minutes. The removal of the acrylic substrate was intended to allow acrylic to be free from materials that could not be cleaned just by water. Cleanliness of the glass substrate affected the test results of the sample which would be deposited.

Preparation of SnO_2 nanopowder (<100nm particle size with code 1002099194) was carried out by mixing solvents and binders SnO_2, where ethyl cellulose ($[C_6H_7O_2(OH)_{3-x}(OC_2H_5)_x]n$) from Sigma Aldrich-USA acted as a binder and isopropanol $[(CH_3)_2CH(OH)]$ of JT Baker product as solvent of SnO_2 [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, SnO_2 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 SnO_2 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 SnO_2 on an acrylic substrate. The process of planting the SnO_2 layer on the acrylic substrate was carried out by depositing a solution of SnO_2 that had become gel into the hole on the acrylic channel. When the SnO_2 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 SnO_2 was heated to a temperature of 100°C. The purpose of heating was to remove the solvent in the solution SnO_2 (melting point isopropanol 82.2°C). SnO_2 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 SnO_2 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

Blue) component value. Processing of the red component data (He-Ne light source) on the RGB value was done by dividing the red component data into two parts i.e. the right and left. The average value of the red component data for the right and left was the output value of each manufactured waveguide directional coupler port.

The intensity distribution of the light beam processing results in cross section in the form of data on the optical wave component value of RGB (Red Green Blue). The data processing component of red color on the RGB values is done by dividing the red color component data into two outputs right and left output. The average value of the red component data at each output is the output value of each fabricated directional coupler waveguide port.

III. Results and Discussion

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_2 in optical waveguides. Less severe layers of SnO_2 in the film are caused when the partial heating process of the SnO_2 solvent evaporates and creates a hole in the optical waveguide. Before coated with a SnO_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

TABLE I. Percentage of output intensity of port1 and port2 from directional coupler optical waveguide

DC Type	Θ (°)	Input	Intensity Output (%)		Losses (%)
			1	*2*	
A	17	100	40,0	50,3	3,3
B	36	100	27,6	53,6	10,7
C	54	100	48,9	30,7	8,7

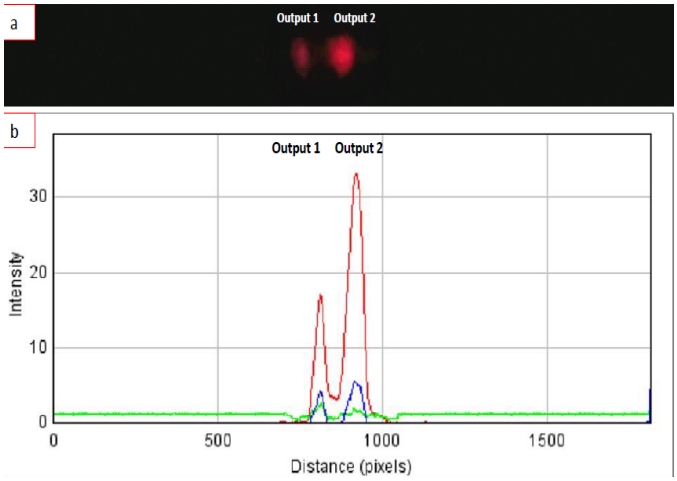

Fig. 3. Directional coupler with a branching angle of 36° (a) Output port 1 and output port 2 waveguide. (b) Plot RGB output 1 and output port 2 waveguide.

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_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

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 < 25º will produce output on the output channel with almost the same intensity of distribution.The average percentage of optical waveguide output at directional coupler is 50%, 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 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 chanels 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.

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