

PAPER • OPEN ACCESS

Design and fabrication of optical waveguide as directional coupler using laser cutting CO₂ on acrylic substrate

To cite this article: Sudarsono *et al* 2019 *J. Phys.: Conf. Ser.* **1153** 012100

View the [article online](#) for updates and enhancements.

You may also like

- [Suppressing the crosstalk between racetrack resonators by grating assisted couplers for WDM sensing](#)
Xuezhi Zhang, Junfeng Jiang, Kun Liu et al.
- [Investigation on the multi-hole directional coupler for power measurement of the J-TEXT ECRH system](#)
Wenting WENG, , Donghui XIA et al.
- [InGaN directional coupler made with a one-step etching technique](#)
Xumin Gao, Jialei Yuan, Yongchao Yang et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Design and fabrication of optical waveguide as directional coupler using laser cutting CO₂ on acrylic substrate

Sudarsono¹, Gatut Y, Hasto S, Gontjang P, Diky A, Nurrisma P, Susilo I, Iim F, Ali Yunus R, Yono HP

Physics Department, Institut Teknologi Sepuluh Nopember,
Jl. Arief Rahman Hakim, Surabaya 60111, INDONESIA

E-mail: sudars29@gmail.com

Abstract. CO₂ laser cutting machine can provide convenience on making various souvenirs and decorations and billboards. CO₂ Laser cutting machines are widely used for cutting and grafting in some materials such as polymer, glass, paper, fabric and some non metallic materials. In this study using CO₂ laser cutting to create a directional coupler channel. In the process of making the canal done with engraving on acrylic substrate with 4.2 mW laser power and speed 10 mm/seconds and then repeated three times. Directional coupler fabrication is done variation of interaction length 20 mm, 25 mm, 30 mm, 35 mm and 40 mm. The result of directional coupler fabrication resulted in a coupling ratio of 49.8: 50.2 at 25 mm interaction length with input A2. Directional coupler fabrication with CO₂ laser cutting machine provides easy interaction length setting as it can be made with the engine and the results are in accordance with the desired design.

1. Introduction

Technological advances are very rapid in various fields, especially in the field of telecommunication demands the rapid dissemination of information data. Distribution of data information one of them by utilizing optical fiber, so much research has been done to support the development of optical fiber as a medium of telecommunications. Much research has been done to produce optical waveguides such as spin coating, ion exchange, UV lithography, doctor blading, UV-curing and more [1, 2]. In addition to research on optical waveguide making methods, there are also many researches to develop opus devices such as directional coupler [3], Y splitter [4], multimode interference (MMI) [5], Wavelength Division Multiplexing (WDM) [6], division multiplexing mode (MDM) [7]. Much of the research has been done for the fabrication of the directional coupler as a power divider, several methods have been developed, including fused biconical tapered (FBT) [8], side polishing, polymer rectangular waveguide and heating and pressing [9].

The development of laser technology that can be utilized in various fields such as telecommunications, transportation, medicine and industry. In the field of industry one of the emergence of CO₂ laser cutting machine that can be used on cutting and graving on some materials such as polymer, glass, paper, cloth and some non metal materials [10]. With CO₂ laser cutting machine can provide convenience on making various souvenirs and decorations and billboards. In addition to applications in the field of industry is also a lot of research on CO₂ laser cutting for some applications such as the manufacture of Microfluidic channels and multimode power splitter [11, 12]. The use of CO₂ laser cutting can provide ease in making patterns because the design and manufacturing process is controlled by using both computer speed and laser power [13, 14]. Experiments and studies of theories on direct-write on PMMA have been studied by D. Yuan and S. Das S. In addition Prakash and S. Kumar has also conducted experimental



investigations and analysis of multi pass modeling with CO₂ lasers in PMMA [16, 17]. From some of the research, in this research, the utilization of CO₂ laser cutting in the process of making directional coupler. This method was chosen in the study because with ease in the fabrication process in accordance with the desired design. Also with this method the length of bias interaction is more appropriate to the desired. Directional coupler fabrication utilizes fiber optic multimode type FD 620-10 placed on polymethyl methacrylate (PMMA) substrate commonly referred to as acrylic[11,18].

PMMA has excellent transparent optical properties[18], so it is widely used in the optical field as optical devices such as multimode splitters, multilayer optical waveguide and other optical devices such as those performed by M. Rezem[14]. Martin F. Jensen's research has also been conducted on the use of CO₂ lasers to produce cavity and microstructures on PMMA surfaces with laser smear movements [19]. In this study design and fabrication of directional coupler using CO₂ laser cutting on PMMA substrate. In this research is done by removing cladding on the fiber side to be towed. This method is expected to provide a small power loss and does not alter the fiber structure. The length of the resulting interaction is also more precise because the design is done using a computer program before printing using a CO₂ laser cutting machine on the acrylic substrate.

2. Experimental Methods

In the research there are several steps performed to produce directional coupler that is design and fabrication, optical fiber preparation and characteristic of directional coupler channel and testing result of fabrication directional coupler.

2.1 Design and Fabrication Channel directional coupler

The first stage of this research is to create a directional coupler design using Corel Draw software before printing on the acrylic substrate as shown in Figure 1 (a). The process of fabrication of directional coupler channel using BS-1490 engraving cutting machine with specification engraving area 1400x900 mm, engraving speed 0-6400 mm / minutes, laser power 60W / 80W / 120W, resolution ratio 0.025mm, resetting positioning accuracy + 0.01 mm, wavelength of 10.6 μ m and operating temperature 0°C- 45°C.

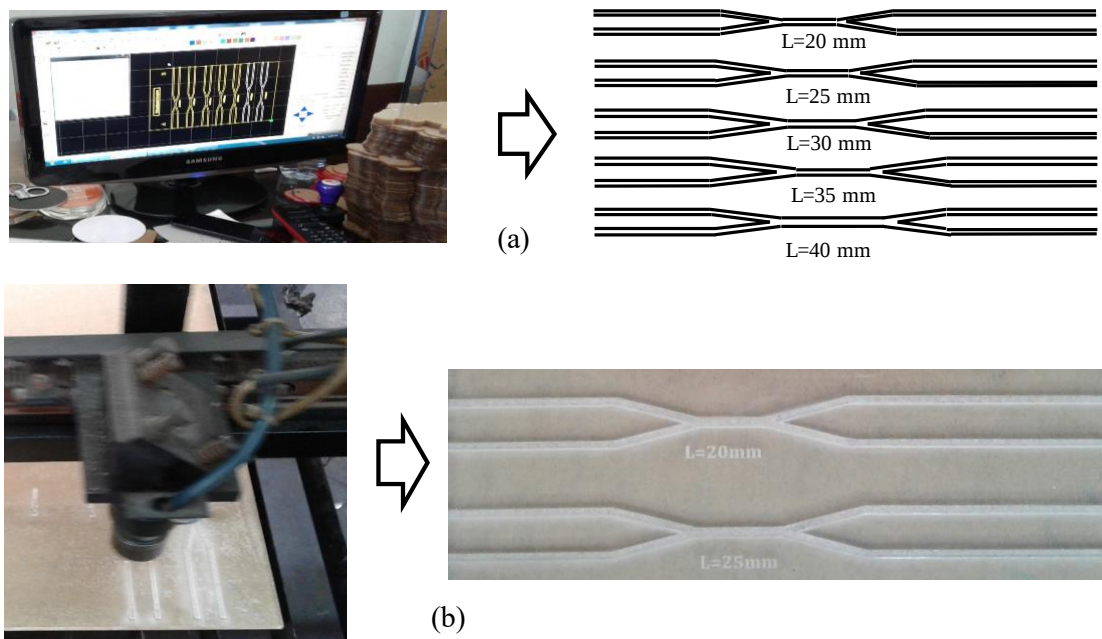


Figure 1. The process of (a) directional coupler design, (b) Fabrication of channel as directional coupler

The fabrication process is done by graving using a speed of 10 mm/seconds and power of 4.2W. This process is repeated to obtain a channel with a width and depth equal to the diameter of the optical fiber. The fabrication process of directional coupler channel with CO₂ laser cutting is shown in Figure 1 (b). In this research five variations of interaction length are 20 mm, 25 mm, 30 mm, 35 mm and 40 mm as shown in Figure 1(a).

2.2 Optical Fiber Preparation and Characterization of the directional coupler channel.

In this process is done stripping jacket and fiber optic cladding by using abrasive paper with roughness level 500, 1000, 2000 and last 5000. The fiber optic part peeled is the part that will be coupled that is in accordance with the design of the directional coupler channel. The stripping results in fiber optic bases were observed by using an optical microscope to view the fiber-optic core parts that have been sanded. At this stage in addition to observing the fiber-optic parts that have been peeled also observe the flatness of the basic part of the directional coupler the result of fabrication. After the fiber is finished, the optical fiber is inserted in the directional channel corresponding to the length of the interaction.

2.3 Testing directional coupler

Directional coupler testing is done by guiding laser light with 1310 nm wavelength. In the 1310 nm waveguide scout was observed with the Optical Spectrum Analyzer (OSA). From the test results with OSA then calculated some parameters of directional coupler that is Splitting or Coupling Ratio (CR), Insertion Loss (Lins) and Excess Loss (Le). The set up tool used in the directional coupler testing process is shown as in Figure 2[3].

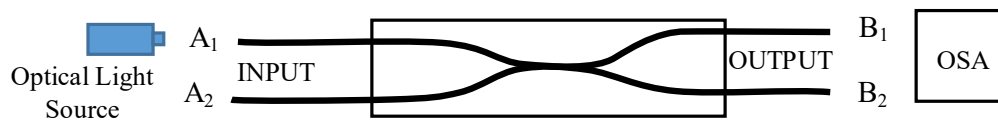


Figure 2. Testing directional coupler using Optical Spectrum Analyzer

In the process of testing the directional coupler is done input variation with inputs A1 and A2, while the observation of output done on B1 and B2 either with input A1 or on A2.

3. Result and Discussion

FIG. 3 is an observation on the basis of a directional coupler using a microscope showing ruggedness, so it needs to be polished on a canal base. As has been explained in the methodology that the process of engraving is repeated three times. In Figure 4 it appears that by repeating the engraving three times the depth of the channel is three times deeper than when one process engraving.

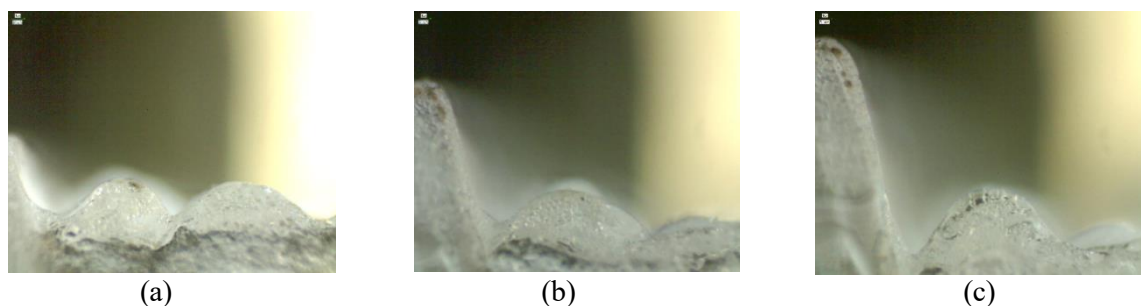


Figure 3. Observation results on the basis of the fabrication directional coupler channel with a CO₂ laser cutting with (a). one time graving, (b). twice graving, (c) three times graving

In this study, in addition to observations on the basis of directional coupler channel is also done observations on fiber optics that have been removed jacket and cladding, results of observation directional coupler shown in Figure 4.



Figure 4. Optical fiber observation results (a) without skipping the laser beam, (b) when passed by a laser beam

In Fig. 4(a) shows that the white portion represents the core of the optical fiber after being rubbed with a scrub paper. While in Fig. 4(b) it appears that the red fiber optic core indicating the area there is a leakage of laser light. This leakage will be utilized for directional coupler fabrication in order to transfer optical power from optical fiber 1 to optical fiber 2. Fiber optic that has been removed jacket and its cladding is placed on directional coupler channel corresponding to the length of interaction so that it is obtained as in Figure 5.



Figure 5. Results of directional coupler fabrication at 40 mm interaction length

One of the observations of optical signal input and output on the directional coupler is shown in Figure 6. The result of characterizing the directional coupler using OSA is shown in Table 1 with the input value of -69.372 dBm.

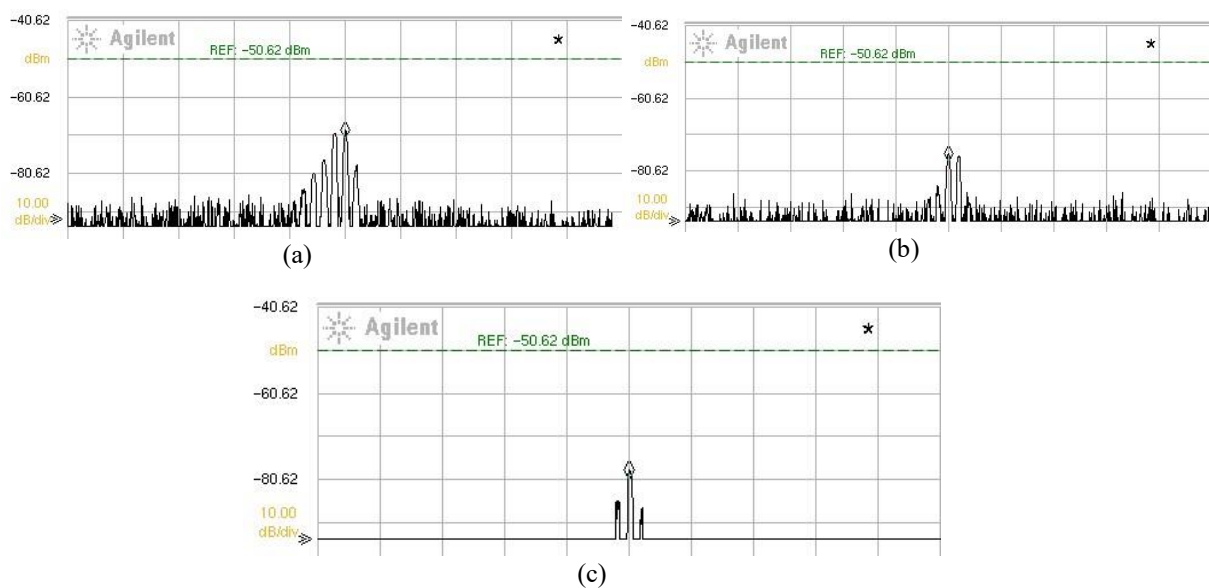


Figure 6. (a) the input signal on multimode optical fiber FD 620-10 with a wavelength of 1310 nm, (b) the output signal at port B₁ input A₁ with length 35 mm interaction; (c) the output signal at port B₂ input A₂ with a 40 mm interaction length

Table 1. Results of directional coupler testing with OSA

Interaction length (mm)	Input	Power on optical fiber 1 (B1) (dBm)	Power on optical fiber 2 (B2) (dBm)	Excess Los (dB)	Insertion loss (dB)
20	A ₁	-86.882	-87.730	14.903	17.51
	A ₂	-86.882	-76.375	6.633	18.358
25	A ₁	-76.638	-86.976	6.882	7.266
	A ₂	-86.665	-87.467	14.665	17.604
30	A ₁	-75.749	-86.374	6.016	6.377
	A ₂	-87.922	-73.458	3.933	17.002
35	A ₁	-75.820	-86.497	6.091	6.448
	A ₂	-85.885	-78.364	8.284	17.125
40	A ₁	-77.394	-85.774	7.433	8.022
	A ₂	-85.774	-74.185	4.521	16.402

The directional coupler parameters for Coupling Ratio (%) of each input can be seen in Figure 7.

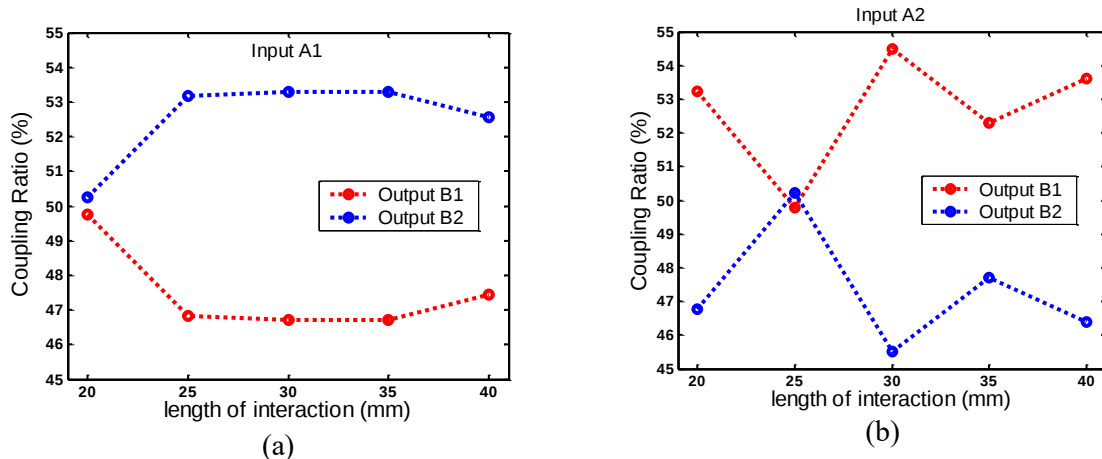
**Figure 7.** Graph Coupling Ratio with (a) input A₁, (b) input A₂

Figure 7 shows that the coupling ratio of the best directional coupler as a power divider is when the interaction length is 25 mm with input A₂. At the length of the interaction the value of the coupling ratio is 49.8: 50.2, with the power on the optical fiber 2 is greater than the power on the optical fiber 1.

4. Conclusion

In conclusion, this research can produce directional coupler on acrylic substrate with CO₂ laser cutting using 4.2 mW power and 10 mm / seconds speed with repetition three times. The resulting directional coupler has a coupling ratio of 49.8: 50.2 at an interaction length of 25 mm with input A₂. Setting the length of interaction with this method is easier because it can be made with the engine and the results according to the desired design.

5. Acknowledgement

The authors would like to thank Department of Physics and LPPM ITS. This research is funded by LPPM ITS. Ministry of Research, Technology and Higher Education Subject to Contract Research Number: 1382/PKS/ITS/2018

6. References

- [1] M. Wang *et al.*, "Fabrication of optical inverted-rib waveguides using UV-imprinting," *Microelectron. Eng.*, vol. 88, no. 2, pp. 175–178, Feb. 2011.

- [2] H.-H. Kim *et al.*, “Fabrication of tapered waveguide by ashed photoresist,” *Microelectron. Eng.*, vol. 88, no. 8, pp. 2721–2724, Aug. 2011.
- [3] R. Ahmed, A. A. Rifat, A. Sabouri, B. Al-Qattan, K. Essa, and H. Butt, “Multimode waveguide based directional coupler,” *Opt. Commun.*, vol. 370, pp. 183–191, Jul. 2016.
- [4] Z. Wu *et al.*, “Design and fabrication of polymer-based 1×4 Y-branch splitters,” *Opt. - Int. J. Light Electron Opt.*, vol. 127, no. 23, pp. 11427–11432, Dec. 2016.
- [5] C. Dung Truong, T. Anh Tran, and D. Han Tran, “A design of triplexer based on a 2×2 butterfly MMI coupler and a directional coupler using silicon waveguides,” *Opt. Commun.*, vol. 312, pp. 57–61, Feb. 2014.
- [6] J. Ji, Q. Huang, K. Wang, M. Xu, and C. Jiang, “Transmission performance analysis of WDM systems based on bismuth-doped phosphate glass fiber amplifiers,” *Opt. Fiber Technol.*, vol. 40, pp. 101–107, Jan. 2018.
- [7] C. D. Truong, M. T. Trinh, H. B. Dang, and V. T. Nguyen, “Numerical investigation of polarization insensitive two-mode division (De)multiplexer based on an asymmetric directional coupler,” *Photonics Nanostructures - Fundam. Appl.*, vol. 23, pp. 50–57, Feb. 2017.
- [8] B. Stepanov, O. Benderov, T. Tebeneva, G. Snopatin, M. Spiridonov, and I. Scripachev, “Chalcogenide optical fiber couplers made by FBT method,” *J. Non-Cryst. Solids*, vol. 480, pp. 23–27, Jan. 2018.
- [9] J. Tang *et al.*, “All-fiber-optic VOC Gas Sensor Based on Side-polished Fiber Wavelength Selectively Coupled with Cholesteric Liquid Crystal Film,” *Sens. Actuators B Chem.*, Jul. 2018.
- [10] L. D. Scintilla, L. Tricarico, A. Wetzig, and E. Beyer, “Investigation on disk and CO₂ laser beam fusion cutting differences based on power balance equation,” *Int. J. Mach. Tools Manuf.*, vol. 69, pp. 30–37, Jun. 2013.
- [11] S. Prakash and S. Kumar, “Fabrication of rectangular cross-sectional microchannels on PMMA with a CO₂ laser and underwater fabricated copper mask,” *Opt. Laser Technol.*, vol. 94, no. Supplement C, pp. 180–192, Sep. 2017.
- [12] D. Patko, Z. Mártonfalvi, B. Kovacs, F. Vonderviszt, M. Kellermayer, and R. Horvath, “Microfluidic channels laser-cut in thin double-sided tapes: Cost-effective biocompatible fluidics in minutes from design to final integration with optical biochips,” *Sens. Actuators B Chem.*, vol. 196, pp. 352–356, Jun. 2014.
- [13] M. Moradi, O. Mehrabi, T. Azdast, and K. Y. Benyounis, “Enhancement of low power CO₂ laser cutting process for injection molded polycarbonate,” *Opt. Laser Technol.*, vol. 96, pp. 208–218, Nov. 2017.
- [14] M. F. Jensen, M. Noerholm, L. H. Christensen, and O. Geschke, “Microstructure fabrication with a CO₂ laser system: characterization and fabrication of cavities produced by raster scanning of the laser beam,” *Lab. Chip*, vol. 3, no. 4, pp. 302–307, Nov. 2003.
- [15] S. Prakash and S. Kumar, “Experimental investigations and analytical modeling of multi-pass CO₂ laser processing on PMMA,” *Precis. Eng.*, vol. 49, pp. 220–234, Jul. 2017.
- [16] D. Yuan and S. Das, “Experimental and theoretical analysis of direct-write laser micromachining of polymethyl methacrylate by CO₂ laser ablation,” *J. Appl. Phys.*, vol. 101, no. 2, p. 24901, Jan. 2007.
- [17] A. Madani and H. R. Azarinia, “Design and fabrication of all-polymeric photonic waveguides in optical integrated circuits,” *Opt. - Int. J. Light Electron Opt.*, vol. 138, pp. 33–39, Jun. 2017.
- [18] T.-F. Hong, W.-J. Ju, M.-C. Wu, C.-H. Tai, C.-H. Tsai, and L.-M. Fu, “Rapid prototyping of PMMA microfluidic chips utilizing a CO₂ laser,” *Microfluid. Nanofluidics*, vol. 9, no. 6, pp. 1125–1133, Dec. 2010.
- [19] D. Mihalache, D.-M. Baboiu, and D. Mazilu, “Propagation effects in nonlinear strip optical waveguides,” *Opt. Commun.*, vol. 110, no. 1, pp. 67–74, Aug. 1994.