Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 55 (2021) 949–954

Transportation Research Procedia

www.elsevier.com/locate/procedia

14th International scientific conference on sustainable, modern and safe transport

3D Optical Splitter based on MMI

Tomáš Mizera[a,*], Dušan Pudiš[a], Anton Kuzma[b,c], Dana Seyringer[d], Peter Gašo[a], Patrik Miček[a], Stanislava Serecunova[b,c,d,e]

[a] *Department of Physics, Faculty of Electrical Engineering and Information Technology University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia*

[b] *Institute of Electronics and Photonics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, 812 19 Bratislava, Slovakia*

[c] *International Laser Centre, Bratislava, Ilkovičova 3, 812 19 Bratislava, Slovakia*

[d] *Research Centre for Microtechnology, Vorarlberg University of Applied Sciences (FHV), Hochschulstr 1, 6850 Dornbirn, Austria*

[e] *V-research GmbH, Stadtstrafe 33, 6850 Dornbirn, Austria*

Abstract

In this paper, we propose and simulate a new type of three-dimensional (3D) optical splitter based on multimode interference (MMI) for the wavelength of 1550 nm. The splitter was proposed on the square basis with the width of 20 x 20 μm^2 using the IP-Dip polymer as a standard material for 3D laser lithography. We present the optical field distribution in the proposed MMI splitter and its integration possibility on optical fiber. The design is aimed to the possible fabrication process using the 3D laser lithography for forthcoming experiments.

Peer-review under responsibility of the scientific committee of the TRANSCOM 2021: 14th International scientific conference on sustainable, modern and safe transport

Keywords: MMI splitters, 3D MMI splitters, polymer, DLW

1. Introduction

Photonics play crucial role in modern transportation design, interconnections and safety. Also photonics covers the important elements in railroads and highways inspection. Lasers, smart imagers and computers for data

* Corresponding author. Tel.: +421 41 513 2301.
E-mail address: mizera@fyzika.uniza.sk

Peer-review under responsibility of the scientific committee of the TRANSCOM 2021: 14th International scientific conference on sustainable, modern and safe transport
10.1016/j.trpro.2021.07.181

processing offer a range of capabilities for transportation industry Inozemtsev et al. (2002). The transport solutions using optical components and connections increase a need for optical splitters or switch matrices for switching, protection switching, cross connection, and dynamic variable optical distribution. It is desirable that such splitters have large optical bandwidth, small physical dimensions, large fabrication tolerances and good performances. Such properties lead to reduction of optical network system costs and improve the efficiency Al - Hetar et al. (2010), Nuck et al. (2019).

There are two main approaches used to split single input optical signal into N output signals. The most obvious way is to use a cascade of one-by two waveguide branches (also called Y-branches) but the processing of the branching point, where two waveguides start to separate, is technologically very difficult Seyringer (2010). In contrast to the Y-branching approach Fig.1, in multimode interference (MMI) splitters the splitting of the optical signal is based on a self-imaging effect (superposition of modes with different propagation velocities) appearing inside of the multimode section Seyringer (2010). While MMI splitters are designed for a precisely specified wavelength, the Y branches operate with broad spectrum. Optical splitter based on MMI splitters, have gained considerable popularity in recent years Al - Hetar et al. (2010). There is a growing interest in MMI splitters in a design of photonics circuits due to huge potential in new optical communications systems such as Fiber to the Home, not only for optical internet but also for videoconferencing, multichannel video services. The MMI splitters are also getting more popular due to many advantages, including an easy design, compact size, low loss, etc. Prajzler et al. (2010). MMI splitters have low wavelength dependent loss, as well as low polarization dependent loss and suitability for device integration which are the subject of interest in high capacity network Al - Hetar et al. (2010). Such MMI splitters offer a large splitting number of outputs and stable splitting ratio, ensuring good uniformity over all the output signals Seyringer (2010).

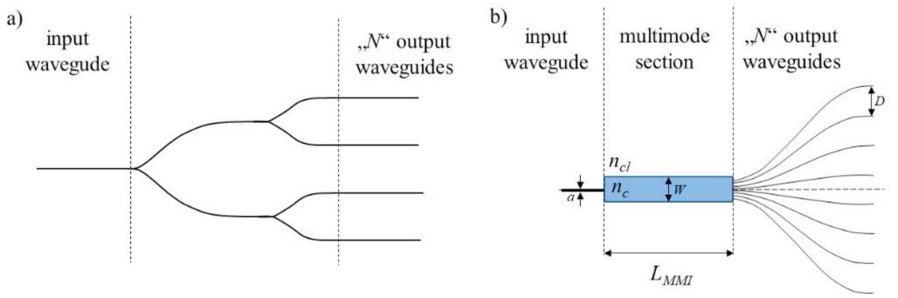

Fig. 1 Comparison of individual types of spitters: a) Schematic design 1 x 4 Y-branch splitter and b) geometry of a MMI splitter Nourshargh et al. (1998), Seyringer (2010)

There are several papers reporting about various materials used in the design and realization of MMI based structures, most of them are semiconductors. Among them only two papers deal with the MMI structure based on polymer materials. Polymers are attractive materials due to suitable optical properties, easy fabrication process and low cost Prajzler et al. (2010). Moreover, all the presented concepts use the two dimensional (2D) splitting. Only first paper showing the 3D splitting was very recently presented by Gaso et al. (2020). This design uses the Y-branch splitting principles arranged in 3D geometry and applied on the optical fibers.

In this paper we report new concept and simulation of 3D optical splitter based on MMI principle and designed for 1550 nm wavelength. The design is aimed to the polymer 3D technology based on IP-Dip polymer. We will consider the knowledge that the splitter at a particular length, L_{MMI}, N interference maximums corresponding to N signals can be obtained as was schematically shown in Fig. 1b. By using modern 3D direct laser writing (DLW) technology we propose new concept of 3D MMI splitter based on IP-Dip polymer.

2. Design and simulation of MMI splitter

The principle of MMI splitter is based on the self-imaging effect which is a basic property of multimode interference. The superposition of the guided modes of a multimode waveguide generates the field distribution along a MMI splitter. For defined length of MMI splitter, L_{MMI}, there occurs single interference maximum similar to input signal known as beat length Sam et al. (2004), Chung et al. (2006):

$$L_{MMI} = \frac{\pi}{\beta_0 - \beta_1} \approx \frac{4n_c W^2}{3\lambda_0} \tag{1}$$

where β_0 and β_1 are the propagation constants of the fundamental and the first-order lateral modes, n_c is the effective refractive index of the MMI core, W is the effective width and λ_0 is the wavelength of the input signal. For defined width W at given wavelength λ_0, we obtain splitting of the input electromagnetic wave into desired number of interference maximums N. The eq. (1) shows the fundamental dependence of the beat length on the square of the effective width. This fact proved to be a good tool for MMI splitter design options with regard to technical parameters.

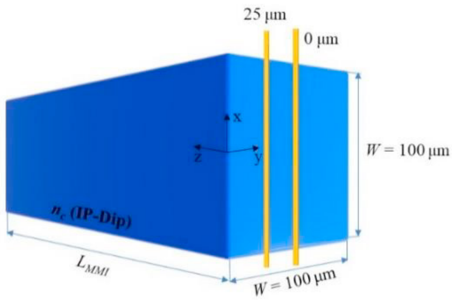

Fig. 2 Design of 3D MMI splitter with square base and cutting planes for simulation.

The 3D beam splitter was designed and simulated using the 3D R-Soft tool. The 3D MMI splitter was proposed with the square base of width $W = 100 \times 100\ \mu m^2$ (Fig. 2). The square base was chosen for suppressing the polarization and wavelength-dependent losses. The refractive indices of the core (n_c) and the cladding (n_{cl}) are n_c = 1.53 (IP-Dip polymer) and n_{cl} = 1 (air) Gissibl et al. (2017).

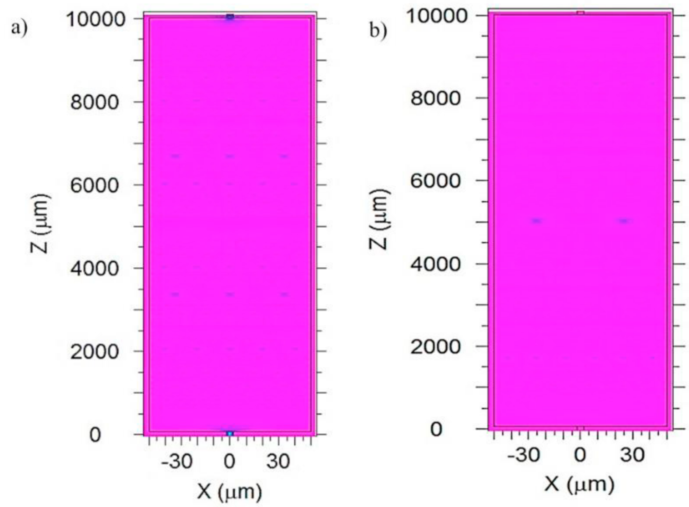

Fig. 3 Simulation of electromagnetic wave intensity distribution in 3D MMI splitter with square base in a) the middle plane (0 µm) and b) off-center plane at 25 µm from middle.

Fig. 3a and b shows a simulation of electromagnetic (EM) wave intensity distribution in a 3D MMI splitter with dimensions of 100 x 100 μm^2 taken at different cutting planes. We can see that the simulation shows the formation of interference maximums created along the MMI splitter. By selecting appropriate length, we can exactly determine number of interference maximums and finally the number of splitting outputs. The simulation shows the different cross sections. In the Fig. 3a, there is a distribution of the optical field for cross section in the middle of the splitter for position $Y = 0$ µm. In the Fig. 3b, there is a distribution of optical field in the cross section in off-centered plane by $Y = 25$ µm from the center. In both simulations, we can observe beat length nearly to $L_{MMI} = 9950$ µm and a periodic change in the distribution of interference optical field along the MMI splitter.

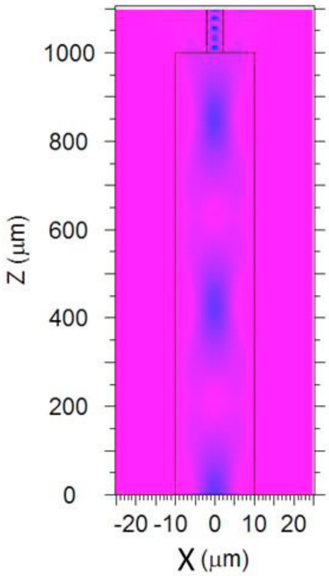

Fig. 4 Simulation of electromagnetic wave intensity distribution in a 3D MMI splitter for a 20 x 20 µm^2 square base

For our application, the suitable length of the interference part would correspond to formation of four interference maximums with the MMI splitter length of app. 3500 µm. Such structure is too long for fabrication process and also for photonic applications. According eq. (1), the beat length and so the length of the MMI splitter is proportional to the width of the splitter W. In the next simulations, we try to reduce width and we suppose also the length reduction. By simulating the different dimensions of the structure, we dramatically reduced the length of the MMI splitter. Simulation of MMI splitter with square basis with width of 20x20 µm^2 is shown in Fig. 4. This width reduction caused considerable shortening of L_{MMI} to 490 µm, which is 20 times less than in the previous simulation. In this case, the length of the interference pattern with for the 4 output channels is app. at position of 215 µm. The structure designed in this way is more suitable for the process of manufacturing an MMI distributor using 3D DLW technology.

In the next simulation, we focused on the field distribution across the MMI splitter. We have found that there is a strong dependence between the width of the input signal and the output pattern. We also verified this fact by simulation in the Lummerical FDTD program.

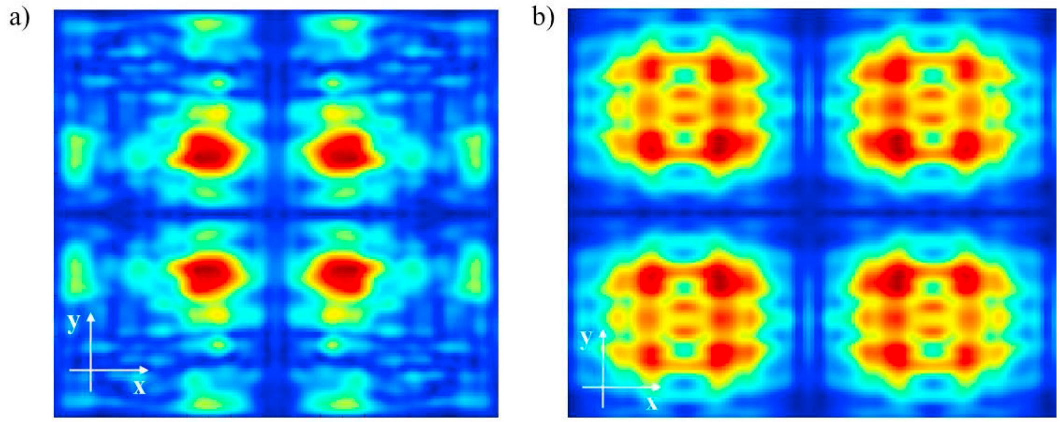

Fig.5 Simulation of distribution electric field intensity of EM wave in a 3D MMI splitter with different input signal widths a) 10 µm and b) 50 µm.

The simulation in Fig. 5 was realized at position of the splitter at L_{MMI} = 215 µm for different input widths. The simulation clearly demonstrates the difference between the different widths of the input signals. The input signal for the simulation in Fig. 5b has a width of 50 µm. The interference pattern shows 4 blurred centers, what would be difficult to couple to the outputs. In contrast, the simulation in Fig. 5a of input width of 10 µm demonstrates clearly identified interference centers.

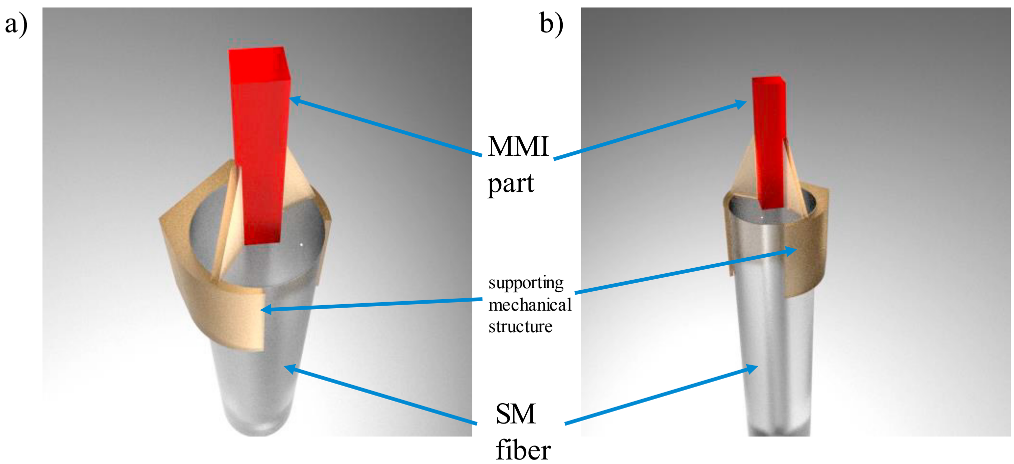

Fig.6 New 3D structure design with respect to the required input signal width

The result issued from the simulation that the width of MMI splitter of 10 µm is suitable is an advantage since the diameter of the core of a single-mode optical fiber is also 10 µm. The proposed design of the MMI splitter considers the direct connection to the end of the optical fiber. It consists of a single mode (SM) fiber the support structure attaching the MMI structure to the end of the fiber (yellow part) and the interference part of MMI splitter (red part) (Fig. 6). Such arrangement with the proposed width of 10 x 10 µm^2 will be used for the next fabrication process using DLW lithography. To achieve the 4 interference outputs the length of the MMI splitting part should be 215 µm according the simulation.

3. Conclusion

In this paper, we proposed and simulated new concept of 3D optical splitter based on multimode interference for the wavelength of 1550 nm. The optimal MMI splitter was designed on a square base with a width of 20 x 20 μm^2 using IP-Dip polymer as a standard material for 3D laser lithography. The proposed MMI splitter produce evident interference maximums at distance of 215 μm, what was determined as the length of MMI splitter. The MMI splitter was also investigated for different input widths. As the optimal the 10 μm input width was used also for the final concept of the MMI splitter and was designed with supporting structure for direct application on the optical fiber.

The prepared design is promising for the possible fabrication process using the 3D laser lithography. After fabrication process, it will be necessary to verify its optical properties by scanning the shape of the output optical field using near-field optical microscope.

Acknowledgements

This work was supported by the Slovak National Grant Agency under the projects No. VEGA 1/0540/18 and No. VEGA 1/0069/19 and the Slovak Research and Development Agency under the project No. APVV-16-0129 and No. APVV-19-0602.

References

Inozemtsev, V., G., Shilin, V. A., Syster, V., G., 2002. Photonics in transportation, Proc. SPIE 4761, Second Conference on Photonics for Transportation.

Al-Hetar, Abdulaziz , Mohammad, Abu bakar , Supa'at, Abu , Shamsan, Z.A., 2010. A New Structure of Mmi Polymer Thermo-Optic Switch with a High Refractive Index Contrast. Progress In Electromagnetics Research B. 24. 103-120.

Nuck, M., Kleinert, M., Conradi, H., de Felipe, D., Zawadazki, C., Scheu, A., Kresse, M., Brinker, W., Keil, N., Schell, M., 2019. 3D photonic integrated 4x4 multi-mode interference coupler, Proc. SPIE 10921, Integrated Optics: Devices, Materials, and Technologies XXIII, 109211C.

Seyringer, D., 2010. Low loss and high uniformity multimode interference splitter operating in a wide wavelength band, 9th International Conference on Optical Communications and Networks (ICOCN 2010), Nanjing, 2010, pp. 383-386.

Prajzler, V., Lyutakov, O., Hüttel, I., Špirková, J., Jeřábek, V., 2010. Design of Polymer Wavelength Splitter 1310 nm/1550 nm Based on Multimode Interferences, Radioengineering, Vol. 19, 606-609.

Nourshargh, N., Starr, E. M., Onc, T. M., 1998. Integrated optic 1x4 splitter in SiO2,/GeO2, Electronics letters Vol. 25 No. 15.

Gašo, P., Pudiš, D., Seyringer, D., Kuzma, A., Gajdosova, L., Mizera, T., Goraus, M., 2020. 3D Polymer Based 1x4 Beam Splitter, Journal of Lightwave Technology. PP. 1-1. 10.1109/JLT.2020.3026170.

Sam, Y. L., WON, Y.H., 2004. A compact and low-loss 1 x 2 wavelength MUX/DEMUX based on a multimode-interference coupler using quasi state, Microwave and Optical Technology Letters, 2004, vol. 41, no. 2, p. 615–627L.

Chung, W., Lee, S. L., Lin, Y. J., 2006. Principles and application of reduced beat length in MMI couplers," Opt. Express 14, 8753-8764.

Gissibl. T., Wagner. S., Sykora. J., Schmid. M., Giessen. H., 2017. Refractive index measurements of photo-resists for three-dimensional direct laser writing," Opt. Mater. Express 7, 2293-2298.