Low Loss Optical Splitter Based on MMI Effects in Thin Glass Sheets for PCB Integration

Jan-Philipp Roth, Thomas Kühler and Elmar Griese
University of Siegen, Theoretical Engineering and Photonics
Hölderlinstraße 3, 57068 Siegen, Germany
jan-philipp.roth@uni-siegen.de

***Abstract*—We propose a low loss graded-index optical splitter based on multimode interference effects (MMI). Even without further improvements of the manufacturing diffusion process, the derived excess and insertion loss suggest a theoretical feasibility for MMI-elements with a graded-index profile.**

I. Introduction

The continuous increase of data rates has challenged electrical on-board communications in recent years. In order to overcome the related physical constraints, research has focused on optical intra-board communication and optical chip-to-chip interconnects [1]. A promising approach is the embedding of optical components in thin glass sheets by diffusion [2], since it can be easily integrated in common PCB manufacturing processes [3]. Recently, advances were made in the modelling of the diffusion process to support the manufacturing [4], [5]. Optical couplers are fundamental elements for constructing photonic integrated circuits such as power splitters, interferometers or optical transceivers. Multimode-interference-based (MMI-based) couplers can be efficiently used for the realization of $1 \times N$ optical splitters. They are compact in dimensions, have good fabrication tolerances and lower excess loss than conventional Y-branch waveguides [6]. The methods of design and analysis of MMI-based optical components have generally been based on the self-imaging principle in step-index waveguides [7]. Due to the nature of the diffusion process, the resulting components have a graded-index profile. While there have been efforts regarding MMI-based components for efficient power splitting on the basis of other manufacturing technologies [8], [9], the use of a thermal ion exchange process has not yet been extensively studied. Therefore, theoretical calculations are presented that verify the functionality of highly efficient MMI-based power splitters as integrated optical components with a graded-index profile. The obtained results directly relate to the geometrical parameters of the manufacturing process.

II. Splitter design

Self-imaging in MMI-based components is achieved when the input field is periodically reproduced along a multimode waveguide section transversally. These images can be single or multiple reproductions of the exciting image [7]. In Figure 1, the schematic structure of an MMI-based switch is illustrated. The number of input and output waveguides is chosen to fulfill a specific purpose, e.g. power splitting. Figure 2 shows the mask structure of the diffusion process, which is the fundamental tool to determine the device's geometry, its refractive index profile respectively. Since the structure is symmetrical, only one half $(x \geq 0)$ is illustrated. One input waveguide leads the exciting field to a wider multimode waveguide section where the desired interference effects occur. Finally, a tapered waveguide section leads to the output waveguide. It is evident that the geometrical mask parameters directly relate to the optical characteristics of the component. A careful evaluation thereof will provide a fair potential for further optimizations. The resulting index profile of an MMI-based splitter is shown in Figure 3. The mask structure of the diffusion process is illustrated qualitatively as a red border and corresponds to the schematic presented in Figure 2. The waveguide's measured index profile is in agreement with the corresponding FEM simulation of the index profile.

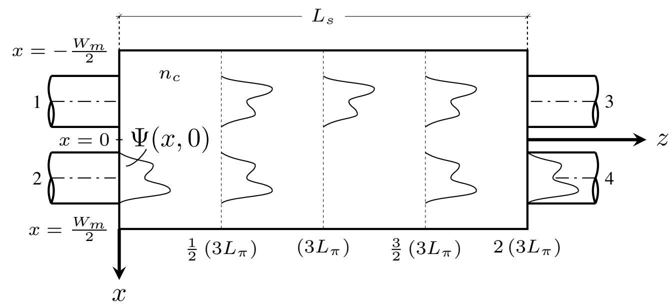

Fig. 1. Schematic structure of a 2×2 optical MMI-Switch [7].

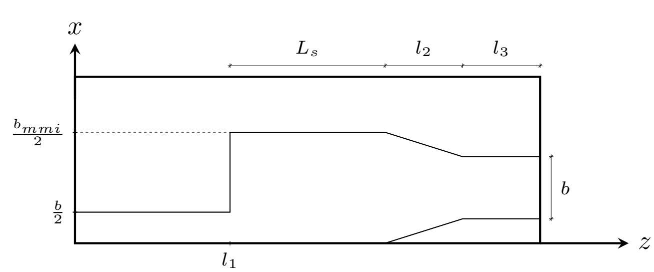

Fig. 2. Mask structure of the manufacturing diffusion process.

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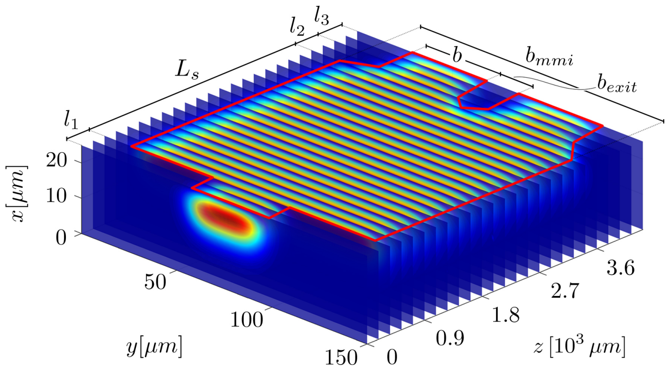

Fig. 3. Exemplary index profile of the MMI-based splitter. The mask structure of the diffusion process is illustrated qualitatively as a red border. Since the substrate material is a three dimensional block, it has been sliced for the purpose of visualization.

III. Mathematical Methods

The splitter's refractive index profile was obtained by solving the diffusion equation numerically with the Finite Element Method [4]. In order to calculate the splitter's excess and insertion loss, a semi-vectorial wide-angle beam propagation algorithm (BPM) for z-dependent structures was used [10]. The input waveguide of the structure was excited with a Gaussian beam. To accurately determine the respective losses of the structure, the input waveguide was extended to minimize coupling effects.

IV. Results and Discussion

The utilization of MMI-based splitters provides an efficient alternative to commonly used Y-branch waveguides [6]. Here, the modification of the width of the multimode section b_{mmi} was studied with respect to the resulting excess and insertion loss. Compared to the step-index case, it is not possible to analytically determine the distance L_s after which an n-fold image of the exciting field is reproduced transversally. Hence, the distance L_s to the point, where the multimode section is split up into two output waveguides via tapered waveguide elements, has to be determined carefully. The interference patterns for different widths of the multimode section show that the influence of the refractive index gradient increases for a larger section width resulting in distorted transversal images. This is in agreement with Figure 4, depicting an increasing

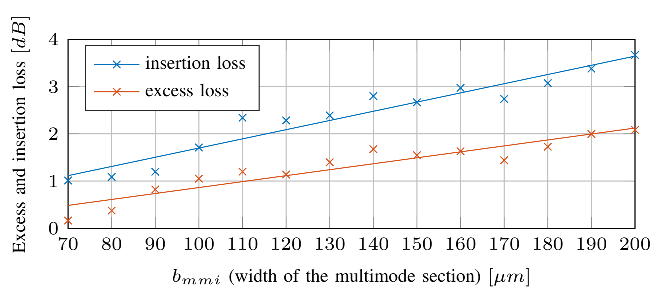

Fig. 4. Excess and insertion loss versus b_{mmi}

excess and insertion loss the larger b_{mmi} is. Notably, at their minimum, excess and insertion loss are as low as $0.16\,dB$ and $1\,dB$ respectively. The obtained curves show a fundamental difference of a graded-index profile compared to the step-index case. Here, the width of the multimode interference section of the structure impacts the splitters' performance in a more fundamental manner. By increasing the width of the multimode section, the excess and insertion loss also increase. This is due to the distortion of the interference pattern in the multimode section by the refractive index gradient. Secondly, the influence of the tapering section also increases. The absolute values of excess and insertion loss are a promising basis for a further investigation of their dependencies on additional parameters of not only the geometrical mask structure but also those of the diffusion process itself.

V. Conclusion

We demonstrated the theoretical feasibility of an MMI-based optical splitter manufactured by a diffusion process. It is remarkable that both excess and insertion loss are very low even without further improvements of the manufacturing process. By correlating additional geometrical parameters with the optical properties of the splitter, its efficiency can easily be enhanced. Another, further approach is the optimization of the parameters of the manufacturing process to improve the quality of the transversally reproduced images along the direction of propagation.

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