Design and Simulation of Multilayer GRIN Lens for Light Coupling Applications in Photonic Integrated Circuits

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We propose the use of a multilayer gradient index (GRIN) lens for coupling a diode source into a printed waveguide. Ray tracing results show that the optical aberration of the lens is small enough and the output beam can be coupled to the waveguide with high efficiency.

1 Introduction

Despite the huge developments in electronic circuits in many aspects, they are not able to comply with the increasing demand for higher data transfer rates. Due to the properties of copper wires, communication data rates are limited in electronic circuits. The constraints in electronic circuits have motivated researchers to investigate optical solutions. Consequently, attention has been drawn to semiconductor-based photonic integrated circuits (PICs). However, extending the range of applications of PICs requires introducing materials with different optical and mechanical properties, such as transparency and flexibility. For this reason, optical photopolymer materials are suitable alternatives to silicon for fabrication of printed optical waveguides with customized mechanical properties. Moreover, optical circuits can support a high integration level without the need to further assembly steps. For instance, it is possible to print optical waveguides from different materials on flexible substrates [1]. Besides, some studies have realized integration of light source on flexible substrates [2]. Nevertheless, fabrication of fully integrated optical circuits requires integration of all units in a PIC. One of the missing pieces in this puzzle is an integrated structure for coupling the light into a printed waveguide. This paper presents a novel coupler structure which can be implemented using additive manufacturing techniques.

2 Proposed structure

In this work we present a novel technique for light coupling in PICs. The structure can be considered as a multilayer GRIN (gradient index) lens, which is a stack of layers from different materials. While in normal GRIN lenses the refractive index varies continuously, in the designed structure the index is constant within each layer and only varies layer by layer.

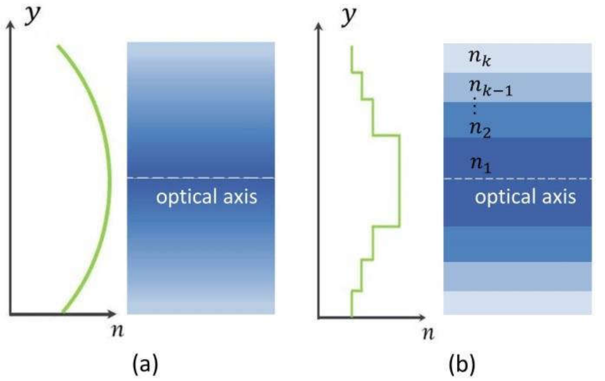

Fig. 1 *Refractive index profile of a) commercial GRIN lens b) multilayer GRIN lens.*

Depending on the incident angle, each incoming beam ray experiences total internal reflection at a certain layer interface. In other words, each ray propagates within a certain set of layers. Adjusting the dimensional and optical parameters of the layers makes it possible to minimize the aberration and hence to minimize the beam size. The advantage of the layered design is that it can potentially be fabricated through multi-material additive manufacturing techniques, which facilitates the integration of the coupler in flexible optical circuits.

3 Simulation

The output beam specifications strongly depend on the structure parameters. The proposed coupler structure which is composed of 4 layers is simulated in Zemax. The output beam characteristics are optimized by varying the refractive index and dimensional parameters of the structure, as shown in Fig. 2.

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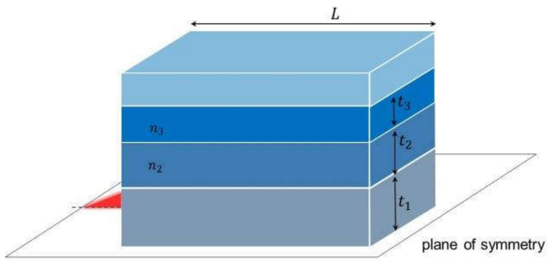

Fig. 2 *The schematic of the designed structure. The labeled parameters are variables in the optimization.*

The optimization process pursues 2 goals:

1. *Maximizing the power of the output rays with divergence angles lower than 15 degrees: Printed optical waveguides have typically 15 degree acceptance angle [1, 3], hence the measured value is the power which can be coupled to a printed waveguide.*
2. *Minimizing the output beam radius: The size of printed waveguides is typically in the hundreds of micrometers [1, 4]. This requires the collimation of the beam so that it fits into the waveguide core.*

4 Results and discussion

Varying the parameters in the structure is necessary for optimizing the output beam considering the aforementioned criteria. Fig. 3 illustrates the optimized ray tracing result.

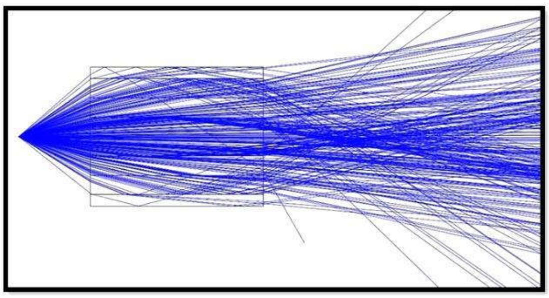

Fig. 3 *The ray path in the optimum case.*

In the simulations, a source diode inputs light with divergence angle 30º and 1 W total power. The optimized output beam has a radius of 0.157 mm (RMS). Moreover, for beam input incidence angles between 0º and 15º the power is 0.68 W. At the lens output this parameter is measured to be 0.74 W. However, as it can be inferred from Fig. 4, the output beam is not single mode anymore and the beam shape has significantly changed.

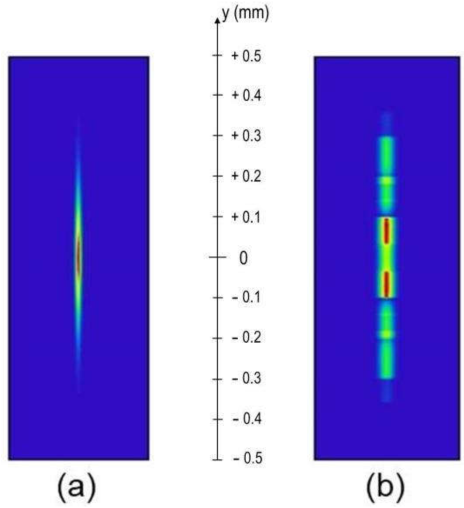

Fig. 4 *The beam profile at (a) input surface of the coupler (b) output surface of the coupler.*

5 Conclusion

In this paper a new light coupling technique is proposed, which can be implemented through additive manufacturing techniques for integration into flexible optical circuits. The parameters of the proposed structure are optimized using Zemax ray tracing, so that it serves as coupler for printed optical waveguides.

Acknowledgements

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