Miniaturization of on-chip interferometers for photonic sensing applications

Nikolaus Flöry[1], Valentin Strässle[1], Markus Halter[1], Thomas Hughes[1], Bahrettin Nas[1], Bradley Visser[2], Jonas Bilal[2], Manuela Wipf[2], Peter Steigmeier[2], Ernest Weingartner[2], Felix Betschon[1]

[1]*vario-optics AG, CH-9410 Heiden, Switzerland*

[2]*Institute for Sensors and Electronics, University of Applied Sciences and Arts Northwestern Switzerland*

ABSTRACT

On-chip photonic integration has opened up the potential for low-cost, high-performance photonic sensor devices [1]. Here, we present a miniaturized on-chip Mach-Zehnder Interferometer (MZI) based on planar polymer waveguide technology. The device can be used for a broad range of applications such as gas-, vibration- or distance-sensing.

KEYWORDS: polymer waveguides, photonic integrated circuits, interferometry, optical sensing

INTRODUCTION

Planar polymer waveguides are emerging as a promising platform for the miniaturization of photonic sensor applications. Their dimensions and optical properties are compatible with optical glass fibers, which eases their use with fiber-based components such as lasers (Fig.1). Improvements in the polymer materials itself as well as innovations in the manufacturing process allow to fabricate customized polymer photonic circuits for operation across a broad wavelength range (450 – 1550 nm).

This opens up new possibilities to realize various kinds of passive devices and functional structures. Among those are customized tapers, splitters and directional and multimode interference (MMI) couplers. In this proceeding, we describe the use of such a MMI coupler in a compact, yet high-performance on-chip interferometer, which is highly robust against environmental influences.

CONCEPT

The presented device is based on a polymer waveguide chip, as shown in Fig. 1c). It features a 1×2 splitter, which divides the input light into reference and measurement beam, as well as a 2×3 MMI coupler, within which the interference signal is created. The entire interferometer structure measures less than 5 mm in length and can be directly packaged and complemented with (opto-)electronic components and accessed via fiber-interfaces or free-space micro-optics.

The operation of a MMI is based on multimode interference within a multimode body. This allows to add multiple singlemode in-/output ports, which simplifies the MZI read-out.

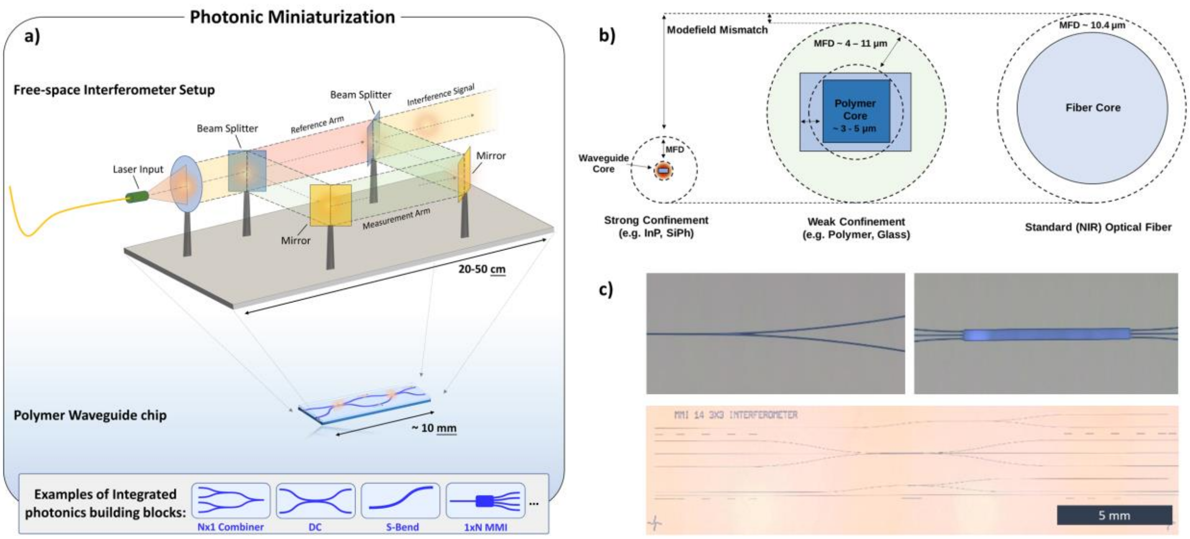

***Figure 1: a)** Concept of photonic integration using planar waveguides **b)** Polymer waveguides (middle) offer the possibility to bridge the gap between PICs (left) and optical fibers (right). **c)** optical microscope pictures of the complete on-chip MZI including a* $\mathbf{1 \times 2}$ *splitter, a* $\mathbf{2 \times 3}$ *MMI coupler and planar*

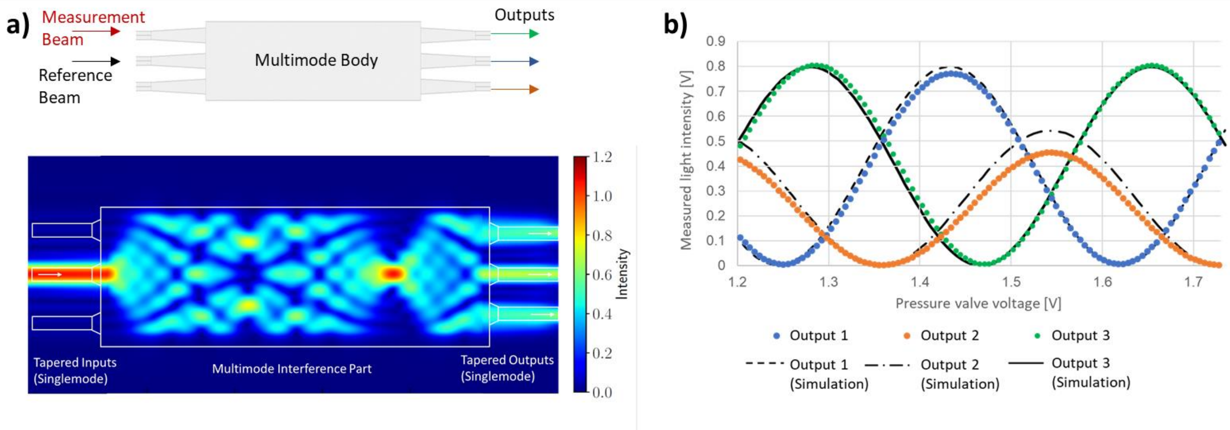

***Figure 2: a)** Schematic and operating principle of a MMI coupler with several ports. Color indicates the electric field distribution as a result of the superposition of different modes. **b)** Simulated data (black lines) and experimental measurements (colored lines) from phase-scans using a pressurized cell to change the optical path difference.*

***Table 1**: Overview & comparison of simulated (Sim) MMI parameters and experimental measurements (Exp).*

	3 × 3 MMI - Coupler			2 × 3 MMI - Interferometer					
	Intensity [%]			*Phase [°]*			*Contrast [%]*		
Channel	***Ideal***	***Sim***	***Exp***	***Ideal***	***Sim***	***Exp***	***Ideal***	***Sim***	***Exp***
1	$33.\dot{3}$	37.0	27.0	0	0.0	0.0	100	99.6	98.6
2	$33.\dot{3}$	26.0	45.0	120	103.6	106.5	100	99.9	99.0
3	$33.\dot{3}$	37.0	27.0	240	212.7	213.0	100	99.7	98.5

In the presented device, a 2 × 3 MMI with 3 output ports is used. In contrast to a regular 2-channel interferometer with 2 detector signals of 180° phase shift, the MMI-based device exhibits 3 detector signals with ideally 120° phase shifts across a full interference period (Fig 2b). As a result, there is no need for active phase stabilization as it is the case in a regular 2-channel interferometer. This allows more compact assemblies and also makes the MMI-based interferometer much more robust against drifts or any environmental influences.

RESULTS AND DISCUSSION

The design of the MMI was simulated and optimized for operation at 1310 nm using Lumerical MODE. Devices were fabricated using vario-optics' singlemode planar waveguide platform and characterized using dedicated optical setups at vario-optics and FHNW. Table 1 shows an overview of the simulated data and experimental characterization of the individual MMI Coupler and the complete device when used as an MZI.

The measurements revealed a good agreement between simulations and experiments, as apparent from the phase scans in Fig. 2b). The intensity distribution of the channels deviates from the ideal case, which can be attributed to fabrication imperfections. It is noteworthy that the operation as an interferometer is not affected by this [2], which can be seen in the phase-differences between the interferometer outputs (Fig 2b and middle column in Table 1) and, most importantly, in the high contrast in all channels (Table 1, right columns).
In summary, the presented MMI-based on-chip waveguide interferometer complements the integrated polymer photonics platform and opens up its use in various photonic sensing applications.

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CONTACT

www.vario-optics.ch
Corresponding author: n.floery@vario-optics.ch / info@vario-optics.ch