Integrated Dual-Mode Interferometer with Differential Single-Mode Outputs

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Abstract: We present for the first time the realization of an integrated dual-mode interferometer containing two differential single-mode outputs. The structure realized in a 250 nm silicon-on-insulator platform enables the monitoring of total optical output power. Hence, the estimation of phase relation becomes tolerant to input power fluctuations and can be realized by a single-wavelength operation even when the optical input power is unknown.

Introduction: For lab-on-a-chip approaches a massive on-chip-parallelization of interferometric structures is a huge benefit. Besides the established Mach-Zehnder interferometer (MZI), the dual-mode or bimodal interferometer (DMI) is utilized in modern biosensors [1]. In general, the detection of a substance concentration with a DMI is based on the estimation of a phase difference at the sensing region end, which is related to the DMI transmission as e.g. explained in [2]. Due to the use of only one waveguide arm, a higher robustness to on-chip-fluctuations of temperature compared to MZIs is achievable in a DMI. Enabling high sensitivities comparable to state-of-the-art devices [3], the development of parallelizable integrated DMIs with a small footprint [4] and low excess loss [2] is an important step to establish DMIs in lab-on-a-chip applications. The measured output power of a DMI with a single-mode output depends on the optical input power and the varying losses in the sensing region. Therefore, the estimation of the phase relation with a single-wavelength laser source is susceptible to damping fluctuations and requires precise knowledge of the input power. These issues can be circumvented by implementing a second differential output as depicted in Fig. 1. Harnessing the total output power with the help of a second single-mode output allows for a stable estimation of phase relations as basis for robust biosensor applications.

Design and Fabrication: DMIs with two single-mode output ports are fabricated at IMS CHIPS Stuttgart on a 250 nm silicon-on-insulator Soitec wafer. Following the design given in Fig. 1, the device contains a mode converter with two curved outputs and tapers to single-mode waveguides. Access waveguides are connected to single-mode fibers via grating couplers. A microscopic image of a fabricated DMI can be seen in Fig. 1 (right), which is structured utilizing electron beam processing. A 1 µm thick SiO_2 cladding is added to protect the device. The dual-mode waveguide of the DMI has the width W and the length L.

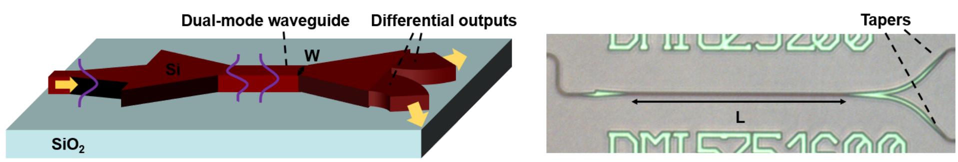

Fig. 1. Schematic view (left) and microscopic image (right) of an integrated DMI with two single-mode outputs. The shown footprint is around 100 µm x 400 µm.

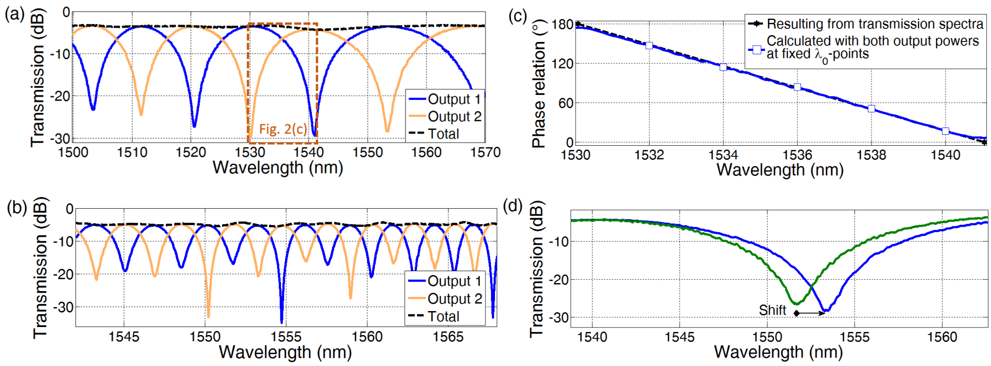

Fig. 2. (a) Transmission spectra of the two differential DMI outputs and corresponding sum with L = 200 µm and W ≈ 625 nm, (b) L = 1700 µm and W ≈ 575 nm. (c) Calculated phase relation for the DMI in (a) by utilizing transmission spectra or both output powers. (d) Shift of the resonance wavelength caused by a top cladding change for the DMI in (a).

Measurements: Evaluating the measured output power spectra of two fabricated DMIs (see Fig. 2(a) and 2(b)), the differential behaviour of the two outputs can be verified. The sum of the two output transmissions is almost constant in the depicted wavelength range. Further, the phase relation in a range of π can be calculated at a single wavelength utilizing both output powers and the phase relation dependent transmission formula. The result is shown in Fig. 2(c) for different wavelengths λ_0 and is in good accordance to the phase relation estimated by evaluating the transmission spectra. Adding an index matching oil on top of the passivated DMI results in a phase shift, thus demonstrating the application of the DMI as sensor (Fig. 2(d)).

Conclusion and acknowledgement: We demonstrate the tracking of total optical output power with parallelizable dual-mode interferometers by implementing two differential single-mode outputs. The fabricated samples provide a robust detection of the phase relation with a single-wavelength source for lab-on-a-chip applications, even with unknown or varying optical input power and waveguide losses. Measured transmission spectra of both interferometer outputs are in good agreement with theory.

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