On-chip Differential Phase Monitoring with Balanced Photodiodes

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***Abstract*—We present on-chip differential phase shift monitoring between delay lines of a phased array using integrated balanced photodiodes. We compare the results of the differential measurement to a measurement using an external reference Mach-Zender interferometer.**

***Keywords*—Phase shift monitoring, Silicon photonics, Germanium photodiodes, Balanced photodiodes.**

I. Introduction

Accurate phase difference measurement is an important tool that can be used in a broad application range in integrated photonics. The information about the phase difference between two signals can be used in a feedback system to either correct the phase difference or achieve a desired relative phase shift between the signals. This functionality is important for applications in sensing, optical computation or optical beam forming using phased arrays. We demonstrate a device in a full silicon photonics platform that can perform phase shifting monitoring using a multi-mode interferometer (MMI) and balanced photodiodes. We referenced this relative phase shift measurement against an external Mach-Zender interferometer (MZI) configuration. At the end we compare the results obtained by the on-chip measurement with the external MZI.

II. Concept and Design

We start from a situation where we have multiple optical delay lines, each equipped with an individual thermo-optic phase shifter. Each line is connected to an off-chip grating coupler, and it is important that the relative phases between the lines can be controlled accurately in a dynamic, adaptive way. Therefore, we have implemented differential phase monitors between each two delay lines.

The differential phase monitor taps a fraction of the light from each delay line, close to its output, using a directional coupler. Between each pair of lines, the taps are then connected to a 2×2 MMI. The waveguides that connect the directional coupler tap to the MMI have the same length to preserve the phase difference between the signals, and are kept as short as possible. The 2 outputs of the MMI are connected to the balanced photodiodes, which are arranged in a push-pull configuration. Figure 1 shows the schematic of the circuit.

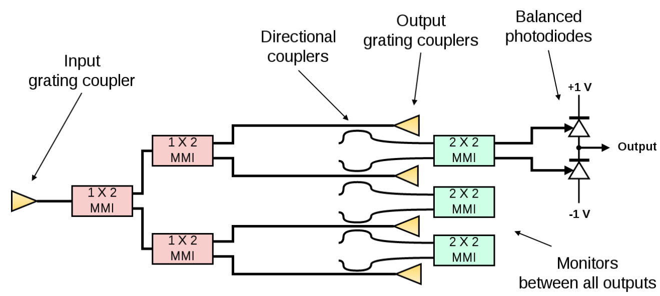

Fig. 1. PLACEHOLDER - Schematic diagram of the circuit.

III. Fabrication

The devices were fabricated in IMECs silicon photonics full platform (ISIPP25G [1]) on an SOI wafer with 220nm silicon on a 2μm buried oxide. First, the passive waveguides are processed using three etch steps: A complete 220nm etch, a partial 160nm etch and a partial 70nm etch. Dopants are implanted for side heaters and modulators and, in a next step, the germanium photodetectors are implanted. Heaters and photodetectors are connected through metal bondpads using a single layer of Cu interconnects. A microscope image of the fabricated device is shown in Figure 2.

IV. Design of Experiment and Measurement

To characterize the phase monitor we measure the phase shift induced by the thermo-optic tuners. To assess the impact of the integrated tuners on neighbouring waveguides (thermal crosstalk), we also measured the phase shift at the output using an external reference interferometer.

To operate the circuit in both configurations we used a laser source at 1550nm, vertically coupled to the circuit through grating couplers. The light was collected from the output of the circuit using the same approach.

A. On-chip configuration

To realize the on-chip measurement we first split the light in the circuit over the different delay lines: one arms acts as reference and adjacent arm is thermally tuned. Then we use the integrated phase monitor to extract the phase difference

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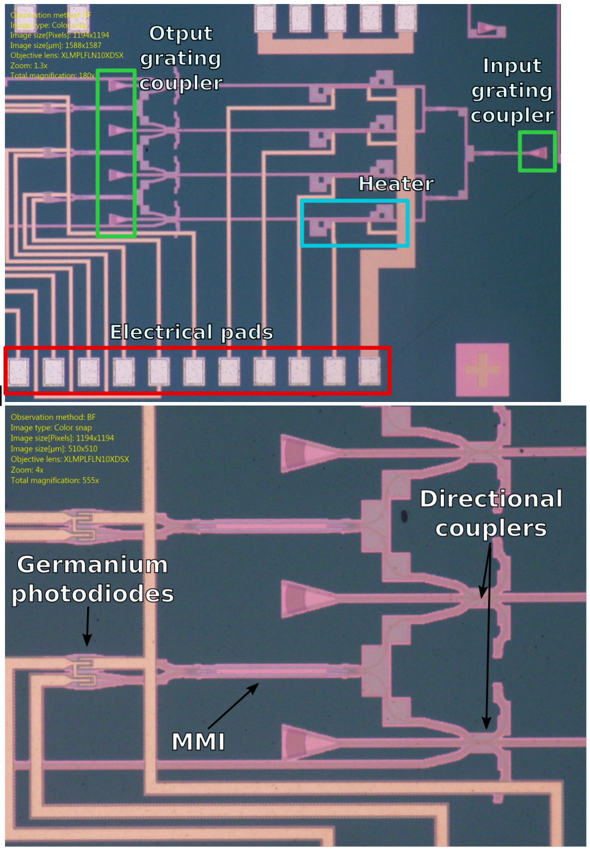

[a]

[b]

Fig. 2. Microscope image showing (a) the full circuit and (b) a zoom into the directional couplers, the MMI and the germanium photodiodes.

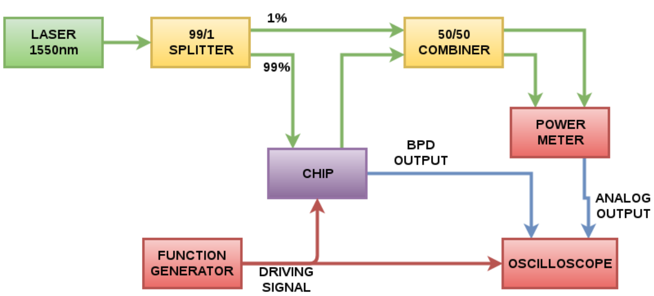

Fig. 3. The measurement setup

between the tuned and the reference arm. The balanced photodiodes are reverse biased with a symmetrical $+1V$ and $-1V$ supply. An oscilloscope was used to monitor the output of the balanced photodetector together with the driving signal.

B. Off-chip MZI configuration

As a reference, and to assess the effect of thermal crosstalk of the thermo-optic tuners, the phase shift induced was also measured using an external MZI configuration. To construct this MZI we used fiber splitters and combiners with the thermally tuned on-chip waveguide in one of the arms of our MZI. Given the insertion losses of the fiber couplers and the on-chip splitter tree, we used a $99/1$ splitter to split the light coming from the laser in two arms. The bigger portion of the light is then injected in the chip via vertical coupling. The second output of the splitter goes directly to the combiner. The light captured from the chip, after the thermal tuning, is then directed to the combiner. The combiner is a 2×2, $50/50$ combiner. Both outputs of the combiner are then connected to a power meter, connected to the oscilloscope. A schematic of the experiment can be visualized at Figure 3.

When we applied voltage to the heater on the chip we induced a phase shift in one of the arms of our external MZI, which resulted in an amplitude modulation at the output of the MZI. With this we obtained an output response in function of the phase shift induced by the thermal tuning of the waveguide.

V. Results

To compare the output of the two measurements we normalized the output of the on-chip signal and of the external MZI. We then plot the response of the measurements in function of the electrical power applied to the heater (Figure 4).

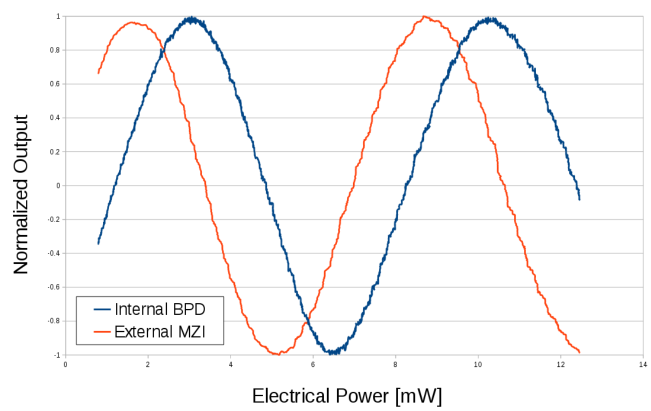

Fig. 4. Comparison between the the output of the on-chip measurement (blue) and the measurement using the external MZI (orange).

The result obtained from the on-chip measurement shows a a phase shift of 0.88 rad/mW, while the same measurement using the external MZI returned a phase shift response of 0.85 rad/mW. This shows both the usefulness of an internal differential phase monitor, and the limited thermal crosstalk of the thermo-optic phase shifters.

VI. Conclusion

We have demonstrated an integrated phase shift monitor implemented using an MMI and balanced germanium photodetectors. We show that it yields accurate results for differential phase shifts when compared with an external measurement. This monitoring can be cascaded in arrays of delay lines and is useful for applications in sensing and control of optical phased arrays.

References

[1] Absil, P. (2015). *Imec iSiPP25G silicon photonics: a robust CMOS-based photonics technology platform.*, Proceedings of SPIE, 9367, 93670V-93670V-6, 2015.