Phase shift control with active feedback

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We present a closed feedback loop approach to actively control the differential phase shift induced by a thermo-optic modulator in a silicon on insulator platform. We use an on-chip differential phase shift monitoring using integrated balanced photodiodes to generate the feedback signal to control the phase shifter. In addition to the optical circuit we use a control layer to analyse the feedback signal and adapt the electrical power applied in the thermo-optical phase shifter in order to achieve the desired phase shift.

Introduction

The ability to induce (and maintain with accuracy) a relative phase shift between multiple optical delay lines is an important asset that can be used in a broad application range in integrated photonics. This functionality is important for applications in sensing, optical computation or optical beam forming using phased arrays. We demonstrate a closed feedback approach that makes use of an integrated on chip differential phase monitor[1] in a full silicon photonics platform to improve the accuracy and stability of relative phase shifting between multiple delay lines.

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, originally presented in [1], taps a fraction of the light from the waveguides using a directional coupler. Between each pair of waveguides, 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(b) shows the schematic of the circuit.

Fabrication

The device was fabricated in IMEC's silicon photonics full platform (ISIPP25G [2]) 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 1(b).

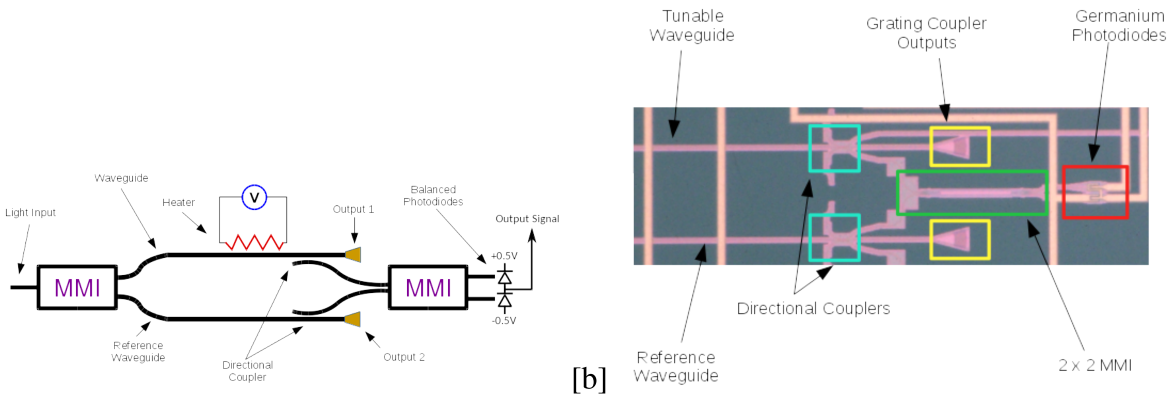

Figure 1: Schematic of the circuit used to measure the relative phase difference between two signals. A change in the phase of the signal in the main waveguide induce by the themo-optic phase shifter can be read as an electric signal from the balanced photodetectors (a). Microscope image of the fabricated device(b).

Experiment Methodology

To operate the circuit we we used a optical source at 1550nm wavelength, vertically coupled to the circuit using grating couplers. We started the experiment by characterizing the phase shift monitor by applying a controlled voltage to the heater to induce a phase shift in one of the arms of the device. The on-chip differential phase monitor translates the relative phase shift to an electric signal. We then recorded the electrical response of phase shift monitor and extracted the relative phase shift between the arms by normalizing the signal and fitting it to a cosine function. In Fig.2(a) we show the measured signal together with the calculated relative phase shift. We repeated the experiment for different ambient temperatures to show how it affects the behaviour of the system. Fig.3 shows the response of the phase shift monitor in a large range of temperature. Notice that the drift between the different measurements is bigger in the right side of the plot (Fig.3(b)). The result shows that the phase shifter presents different responses for distinct ambient temperatures.

We also proceeded to extract the time constant response of the feedback mechanism. We applied a square signal to the heater to toggle the induced phase shift between 0 rad and π rad. Then we recorded the transient response at the output of phase shift monitor (Fig.2(b)). The measured values show a rise time of 110μs and a fall time of 100μs. The low speed response response of the circuit is in part due to the use of silicon doped heaters as phase shifters[3]. These value are important to understand the limitation of the current implementation regarding its response time.

To assess the dependency of the induced phase shift to the ambient temperature we proceeded to set the device temperature to 20^{o}C and tune the heater to delivery a specific relative phase shift (either 0 rad or π for our experiments). Then we changed the device temperature from 20^{o}C to 40^{o}C while recording the measured phase shift. Fig.4 shows

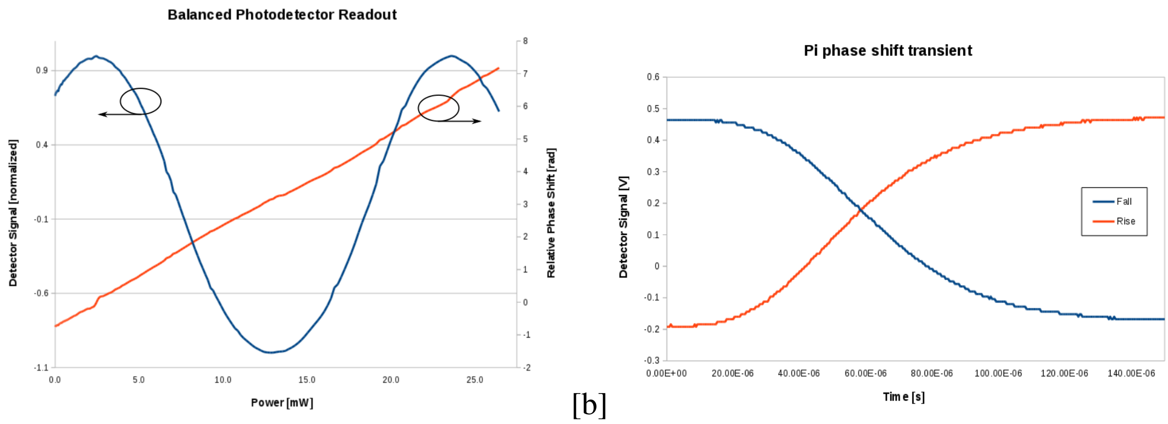

Figure 2: Normalized response from the phase shift monitor when varying the power in the phase shifter heater and the calculated relative phase shift(a). Transient response when applying a square signal toggling the phase shift between 0 rad and π rad.

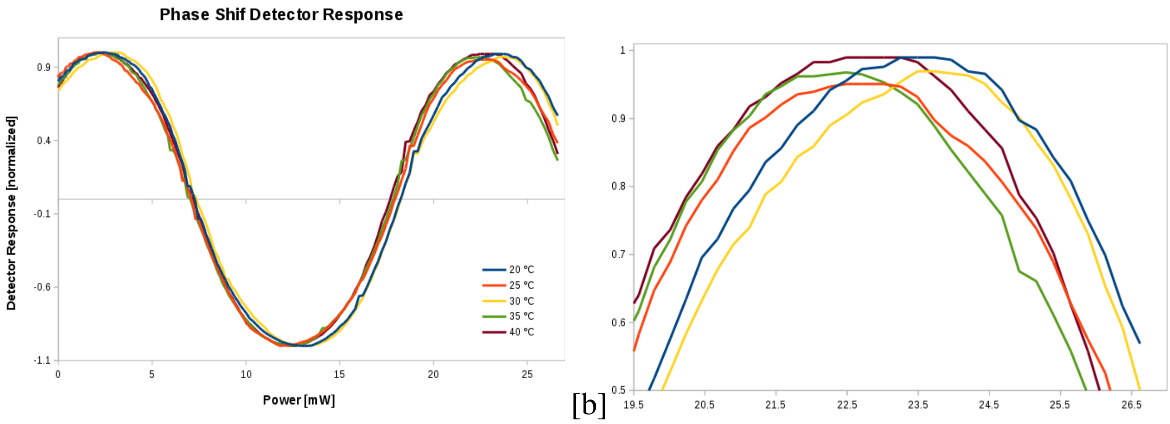

Figure 3: Normalized response from the phase shift monitor for different ambient temperature(a). Zoomed portion of the same measurement, showing the drift between the response for different ambient temperatures.

the error, in radians, between the desired phase shift and the measured value. We can notice that the device doesn't maintain the desired phase shift across a large variation in the ambient temperature. Following that, we repeated the experiment but now using the signal read from the on-chip differential phase monitoring as feedback to correct the electric power applied to the phase shifter in order to obtain a more accurate relative phase shift. As it can be again visualized in Fig.4 the use of the feedback loop can improve the stability of the system in a large range of temperatures, reducing the error between the desired phase shift and the obtained value.

Results discussion and Application

We foresee the use of this technique to control, with elevated level of precision, the phase difference between multiple signals for applications like optical phased arrays. The integrated phase shit monitors can be used to guarantee an even phase shift between the outputs of the optical phased array while the feedback system can be used both to compensate

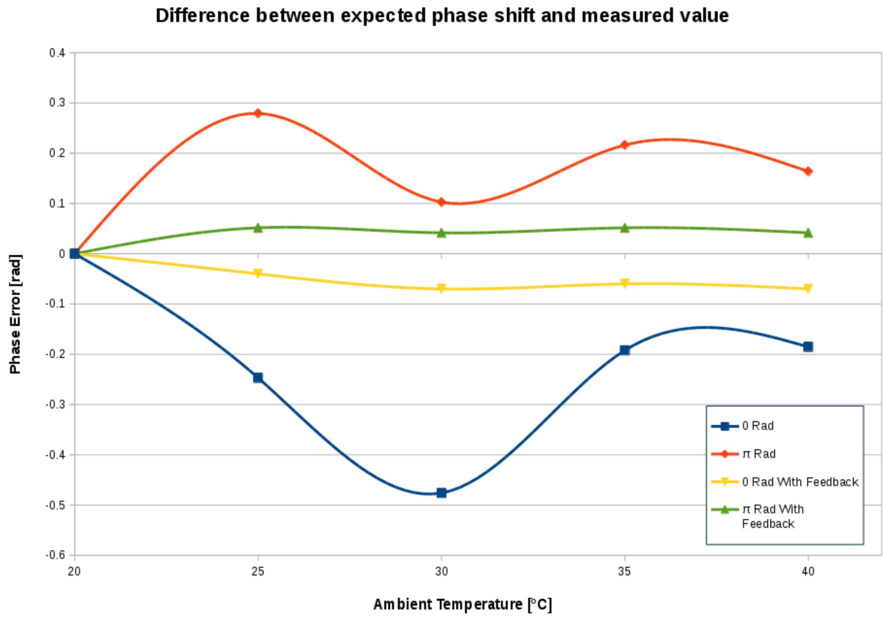

Figure 4: Phase error induced by the change in the ambient temperature. The heater was tuned to delivery a specific phase shift (either 0 Rad or π Rad) at 20^{o}C and the phase shift was measured for different ambient temperatures with and without the feedback system actuating.

for ambient temperature variation and fabrication errors, and also be used to implement reconfigurability of the system, providing an interface between the optical system and the control unit. The ability to do real time adjustment in the phase difference between two optical signals can be used to compensate potential phase errors in the system (caused by long waveguides or fabrication errors) and also to maintain a consistent operation on a large range of ambient temperature variation.

Conclusion

We have demonstrated closed feedback loop to improve the stability of phase shifters using an integrated monitor implemented with a MMI and balanced germanium photodetectors. We demonstrated that the approach can reduce the error in the obtained relative phase shift when tuning the device using heaters in a large ambient temperature variance. We foresee the application of this method for the control of multiple signals for achieving precise relative phase shift, such as on optical phased arrays control.

References

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