Matrix Addressing Silicon Photonics Phase Shifters using Heaters with Integrated Diodes

Student paper

Antonio Ribeiro[1,2], Umar Khan[1,2], and Wim Bogaerts[1,2]

[1]*Ghent University - IMEC, Photonics Research Group, Department of Information Technology, Ghent, Belgium*
[2]*Center for Nano and and Biophotonics (NB-Photonics), Ghent, Belgium*

ABSTRACT

We present a matrix addressing approach to drive thermo-optic silicon phase shifters with integrated diodes, allowing time-multiplexed access to the heaters, which reduces the number of pads necessary to drive large silicon photonics circuits. We also demonstrate that such heaters can be driven using digitally modulated signals, which increases the linearity of the phase shift response of the device.

Keywords: heater, phase shifter, diode, multiplexed, SOI.

1 INTRODUCTION

With the increase in complexity and number of elements of large scale photonics circuit, the interfacing with electronics for controlling and read-out can become a limiting factor for the scalability of the system. A circuit with hundreds of phase shifters would need an equally large number of contact pads and voltage sources for driving. This can be challenging to the development of large scale integrated circuits once such contact pads are usually large and occupy a large space in the photonics chip. Also, a great number of wires are needed to connect the active devices to their bondpads, which can add another layer of complexity in the design of the optical device. To circumvent this issue we propose a matrix-based topology for driving thermo-optic phase shifters with integrated diode [1] in the silicon on insulator (SOI) platform. Such approach can reduce the total number of contact pads (and, consequently, of voltage sources) needed to drive large number of phase shifter. The proposed approach permits to drive up to N^2 heaters with $2 * N$ pads, while the conventional approach uses one pad per phase shifters plus one extra pad for common ground.

2 HEATERS WITH INTEGRATED DIODES

One approach to implement a thermo-optic phase shifter in SOI is adding a side strip of doped silicon close to the target waveguide and using it as a resistor. On a typical side heater, the silicon strip is doped with either *P-type* or *N-type* dopants to increase its conductivity. In our design we doped the main body of the heater using *N-type* dopants, and near one of the electrical contacts we used a *P-type* dopant, creating a *PN* junction inside the heater. This approach converts the standard heater to a diode in series with a high resistivity strip. The total length of our heater is $50\mu m$, where $8\mu m$ is used for the *P-type* doped region. The width of the heater is $1.2\mu m$. The heaters are placed close to the target waveguide [Fig. 1(a)], keeping a gap of $0.75\mu m$ between the heater and the waveguide. The gap was chosen to be close enough to increase the power efficiency of the heater and yet avoid the optical mode to leak from the waveguide to the heater. The heater and the waveguide have a different width to minimize coupling due to phase matching.

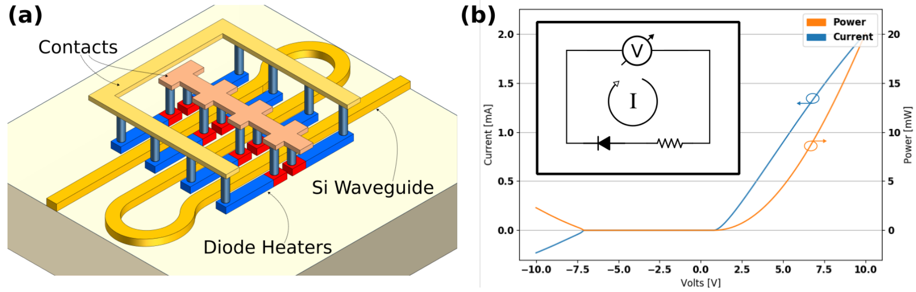

Figure 1. (a) The phase shifter implemented with eight diode heaters placed in parellel. (b) The IV curve showing the diode characteristic of the phase shifter. The measured devices yields negligible when reverse biased up to $-7V$. (b-inset) The equivalent electric circuit of the heater.

2.1 Phase-shifter Characterization

The I-V curve of the fabricated heater [Fig. 1(b)] shows a clear diode behavior, with negligible current flow in reverse bias, before the breakdown point, at around $-7V$. From this values, we assume that it is safe to operate the heaters in the $\pm 7V$ range without inducing any phase shift in the heaters connected to the same pads, but with opposite polarity.

The measured resistance at $5V$ was $5.3k\Omega$ and the electrical power delivered at $7V$ was $9.6mW$ per heater. To achieve higher power output without compromising the operational range of $\pm 7V$ we can drive multiple heaters in parallel. We constructed the phase shifter by placing eight heaters in parallel [Fig. 1(a)]. The phase shifter can deliver up to $76.8mW$ at $7V$.

To increase the power efficiency of the phase shifter we routed the waveguide around the heater [Fig. 1(a)] instead of having a single parallel placement. This design ensures that mostly of the heat generated by the heater is applied to the waveguide.

To extract the efficiency of the heater we designed a Mach-Zehnder interferometer (MZI) using the phase shifter as its arm and monitored the power necessary to switch the state of the MZI. From the obtained values we report a πrad phase shift at $20.9mW$, which is a result compatible with the reported values for this technology[2].

2.2 Time-domain Analyses of the Phase Shifters

Heaters are inherently slow when compared to other phase-shifting approaches such as free-carrier modulators[3]. The presented phase shifter has a measured time constant of $97\mu s$ [1]. The plot in Fig.2 shows the induced phase shift for a given driving signal with different frequencies. It is visible from the plot that for driving frequencies above $500KHz$ we don't notice any fluctuations in the induced phase shift over the time. The reason for that is that, for higher frequencies, the signal changes much faster than the thermal constant of the device, which behaves as a low-pass resistor-capacitor (RC) circuit.

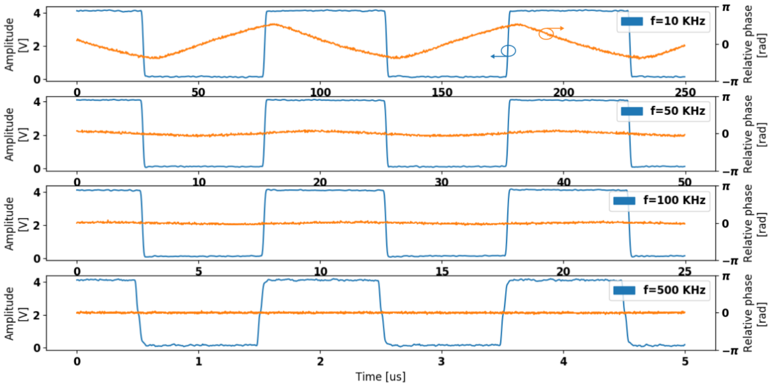

Figure 2. Induced phase shift for a driving signal with different frequencies.

The high time-constant of the heater can be used to operate it using a noncontinuous signal, such as Pulse Width Modulation (PWM). In a PWM-based driving, the delivered power is not proportional to the amplitude of the driving signal (which is constant) but proportional to the duty cycle of the PWM signal instead. To change the induced phase shift we tune the duty cycle of the driving signal. This makes the phase shift linear to the driving parameter (duty cycle), once in a PWM signal the total porwe grows linear to the duty cycle of the signal. This characteristic improves the control of the phase shifter.

3 MATRIX ADDRESSING

To multiplex the addressing of the heaters using a minimum number of pads we designed them in a matrix topology as shown in Fig.3(a). To address a given heater in the matrix it is necessary that the row linked to the respective heater to be placed in low state ($0V$) while the column, connected to the anode of the diode, is set to the required voltage to yield the desired phase shift. To achieve the multiplexing effect it is necessary to synchronize the selection of the row to be addressed with the signal applied to each channel (column) of the matrix in such way that we constantly change which row we are addressing. If such switching is made fast enough (much faster than the time constant of the heaters) each heater will see only the average power delivered over time, allowing us to drive multiple heaters in the same channel.

For a better phase shift control, the signal applied to each subchannel is not a amplitude variable signal, but a PWM signal with constant amplitude and variable duty cycle. To obtain maximum phase shift with minimum duty cycle we set the value of the amplitude of the PWM signal to the maximum voltage allowed by the diode without reaching the breakdown region when reverse biased ($-7V$). For such configuration we were able to obtain πrad phase shift with a PWM signal with a duty cycle of 27%.

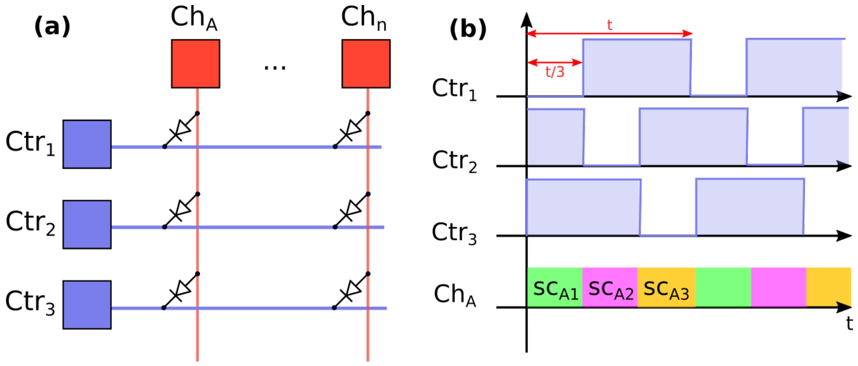

Figure 3. (a) Schematic of a matrix addressing circuit with three control lines (rows) and n channels (columns). (b) Signal representation for the three control lines (Ctr_1,Ctr_2, and Ctr_3) and the signal applied to channel A. The channel signal is subdivided in three subchannels, each synchronized to its respective control line. Each subchannel comprehends an independent PWM signal that controls its respective phase shifter.

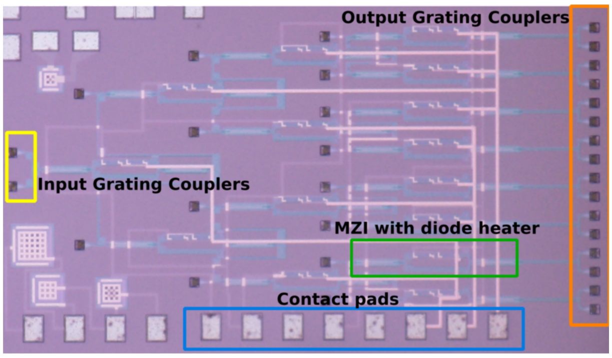

Figure 4. 1×16 multiplexer device fabricated with 15 MZIs. Each MZI is controlled by a phase shifter with integrated diode. The circuit is arranged in a matrix configuration, which allows the control of the 15 phase shifters with 8 pads.

A limiting factor that dictates how many rows can share the same channel is the duty cycle needed for the heater to delivery the maximum desired phase shift. To operate a MZI circuit in a three-rows matrix (such as the fabricated device, shown in Fig.4, and the schematic in Fig.3(a)) the heater has to be able to delivery the πrad phase shift with at most 33% of its duty cycle (as the other two-third of the time will be dedicated to the remaining rows linked to the same channel). As the fabricated device can yield πrad phase shift with a 27% duty cycle, it puts it within the limit for a three rows multiplexing scheme.

3.1 Driving Electronics

The main requirement to drive the circuit is the delivery of the signal that comprehend all the three subchannels synchronized with the control lines. Such circuit can be implemented with a standard Field Programming Array (FPGA). To boost up the output signal to meet the requirement levels ($7V$ amplitude, $20mA$ current) the signal can be amplified using an operational amplifier.

4 CONCLUSIONS AND FUTURE WORK

We demonstrated that the use of heaters with integrated diodes to allow matrix-like addressing for thermo-optic phase shifters in silicon photonics circuits is possible. The high thermal-constant of the phase shifters allows a digital (PWM) driving and also time-multiplexing the actuation of the circuit. A dedicated electronic driver is needed to control the circuit, which can be implemented with standard (FPGA) and a voltage amplifier.

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