Efficient and Compact Multimode Interior-Ridge Heater for DWDM Systems

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Abstract: We demonstrate using a tapered-hybrid bend to reduce an MZI width by 44 % and increase thermal tuning efficiency by 48 % using a half-etch contact heater compared to a non-contact heater. © 2024 The Author(s)

1. Introduction

Densely integrated systems such as high-bandwidth transceivers and photonic accelerators for high-performance compute highlight the need for compact and low-loss silicon photonic devices. For instance, energy-efficient dense wavelength division multiplexing (DWDM) transceivers driven by Kerr combs require ultra-broadband SiPh devices that approach 100 nm in optical bandwidth to encompass all usable laser lines. These broadband links benefit from transmitting the fundamental mode in multimode waveguides to compensate for dispersion and increase tolerance to fabricated variations in waveguide geometry - improving energy consumption and yield [1,2].

However, using multimode waveguides increase the bend radius and thus the entire system footprint, especially when incorporating a separate devices such as straight thermo-optic phase shifter (TOPS) given certain layout configurations, shown in Fig.2b). Integrating TOPS structures into waveguide bends could reduce the footprint and give flexibility to layout. But TOPs using a double-ridge structure (for electrical contact on either side of the waveguide) suffer from additional radiative losses and increased bend radii. Alternatively, doped Si heaters placed near the waveguide and separated by SiO2 (referred to as ”non-contact” here) are less efficient, due to the thermal conductivity of SiO2 being $\sim$100$\times$ less than Si (1.3 $\mathrm{W/m \cdot K}$ vs. 150 $\mathrm{W/m \cdot K}$) and TiN heaters are not available in all CMOS process [3].

In this work, a tapered-hybrid bend (THB) is used to achieve a smaller bend radius [4] and a doped Si heater is connected to the interior edge of the THB through half-etched Si (referred to as ”contacted” here), acting as a thermally conductive bridge while not affecting the optical mode. This results in a 48 % increase in thermal tuning efficiency compared to a non-contacted design (44.8 mW/π vs. 83.4 mW/π) and a 44 % smaller monitor MZI width in a high-bandwidth transceiver given the same maximum layout dimensions.

2. Results & Application

Fig.1a) shows a 10 µm radius THB bend with a doped Si heater located 1 µm away. The top version is non-contacted and the bottom version in contacted with a Si half-etch region - appearing as green under the microscope. Heater electrical vias are placed at the start end of the bend, allowing consistent connection points between adjacent bends if needed.

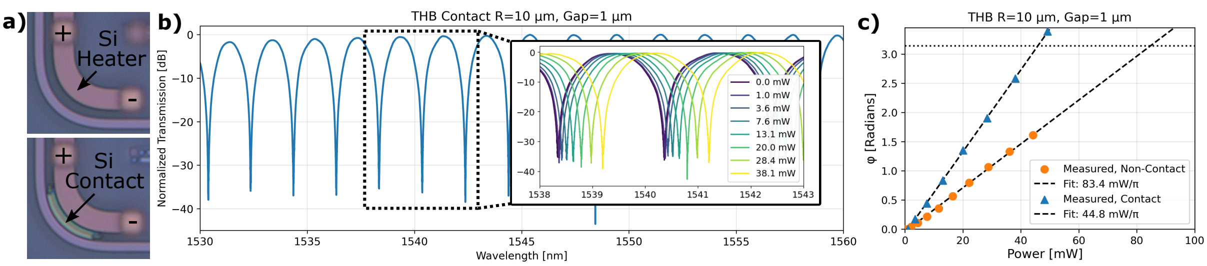

Fig. 1. a) Micrograph of doped Si heater non-contacted and contacted to THB via half-etched Si (green). b) MZI test structure spectrum with inset plot of thermal tuning from 0-1 V. c) Thermal tuning efficiency measurements with a 45% improvement in P_π when heater is contacted.

Results are shown from a 300 mm silicon-on-insulator (SOI) wafer fabricated with AIM Photonics using a standard Si height of 220 nm and half-etch height of 110 nm. Fig.1b) shows the transmission spectrum from an MZI test structure with a large measured extinction ratio of ∼38 dB, indicating low device loss. Cutback test structures measured ∼0.01 dB loss from 1450-1600 nm for both contacted and non-contacted devices, showing that the optical mode was unaffected by the ridge contact. The inset plot shows thermal tuning from 0-1 V with a maximum power of 1.5 W at 6.4 V being applied before the electrical vias burned out. Fig.1c) shows the phase shift in radians given applied power with a 48 % reduction in thermal tuning power for a π phase shift when using the contacted heater.

A practical reduction in footprint is illustrated using a monitor MZI structure from a scalable transceiver architecture targeting 1.024 Tbps per fiber. Fig.2a) shows a portion of the overall transceiver layout, containing 4 arrays of 64 disk modulators and 3 arrays of 2 stage interleavers (with additional interleavers, disk modulators, and disk filters not shown). Fig.2b) shows the monitor MZI structure designed with a 1200 nm wide waveguide with the imbalance arm accommodating a straight double-ridge TOPS and 14 µm radius Euler bends. Using the multimode THB heaters with a smaller bend radius of 10 µm, a more compact width is achieved given the same length dimensions given layout constraints. This results in a 44 % reduction in monitor MZI width which reduces the overall chip area.

3. Conclusion

We demonstrate a compact, low-loss, efficient thermal phase shifter using an interior-ridge THB geometry. A 48 % improvement in tuning efficiency is measured compared to a non-contact design and a 44 % reduction in width from an existing monitor MZI structure from a Tbps transceiver. This design can also be applied to smaller single mode bends to further improve tuning efficiency and footprint for densely integrated DWDM systems.

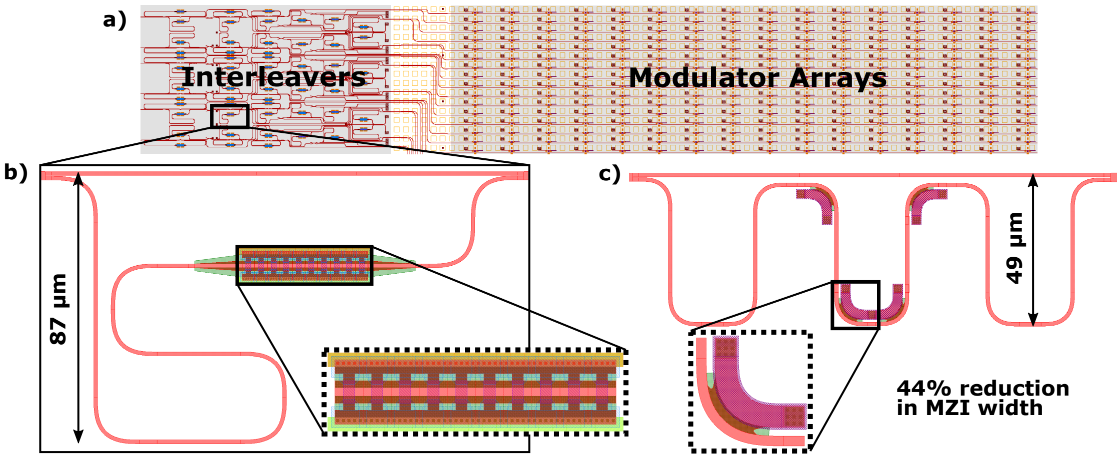

Fig. 2. a) Layout of transmitter interleaver and modulator arrays. b) Monitor MZI with straight double-ridge TOPS and R=14 µm Euler bends. c) Modified monitor MZI with R=10 µm THB heater.

References

1. Y. Wang *et al.*, “Silicon photonics chip i/o for ultra high-bandwidth and energy-efficient die-to-die connectivity,” in *2024 IEEE Custom Integrated Circuits Conference (CICC),* (2024), pp. 1–8.
2. Y. Wang *et al.*, “Dispersion-engineered and fabrication-robust soi waveguides for ultra-broadband dwdm,” in *Optical Fiber Communication Conference (OFC) 2023,* (Optica Publishing Group, 2023), p. Th3A.4.
3. N. C. Harris *et al.*, “Efficient, compact and low loss thermo-optic phase shifter in silicon,” Opt. Express **22**, 10487–10493 (2014).
4. K. Jang *et al.*, “Universal cmos-foundry compatible platform for ultra-low loss soi waveguide bends,” in *2023 Optical Fiber Communications Conference and Exhibition (OFC),* (2023), pp. 1–3.

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