Heterogeneously Integrated Si-LN Microring Modulator based on Transfer-printing method

Ying Tan [1,2,3], Margot Niels [1,2,3], Maximilien Billet [1,2,3,4], Tom Vanackere[1,2,3,4], Tom Vandekerckhove[1,2,3,4], Gunther Roelkens[1,2,3], Bart Kuyken[1,2,3], Dries Van Thourhout[1,2,3]

(1) Photonics Research Group, Department of Information Technology, Ghent University-IMEC, Technologiepark 126, 9052 Ghent, Belgium, Ying.Tan@ugent.be
(2) IMEC, Kapeldreef 75, 3001 Heverlee, Belgium
(3) Center for Nano- and Biophotonics, Ghent University, 9052 Ghent, Belgium
(4) OPERA-Photonique CP 194/5, Universitie Libre de Bruxelles (ULB), Bruxelles, Belgium

Abstract *A heterogeneously integrated silicon-lithium niobate microring modulator is realized by transfer-printing LN on a silicon platform. The integrated Si-LN microring modulator has an insertion loss of −1.5dB and an extinction ratio of−37dB. The tuning efficiency is 3.8pm/V.*

Introduction

Silicon photonics with its high integration density, low-loss, low-cost and CMOS compatibility, offers a vast variety of compact and performant devices [1]. Optical modulators, which allow encoding electrical signals on optical carriers, are key components for optical communication. Compact, low-loss, energy efficient, high bandwidth modulators are highly demanded. Traditional silicon modulators exploiting the plasma dispersion effect are limited in speed (up to 50GHz), suffer from AM/FM coupling and have a relatively high loss. Lithium niobate allows for linear phase modulation and has demonstrated high bandwidth modulation beyond 100GHz [2], [3]. High performance TFLN MZI modulators have been demonstrated by several groups over the past years [2]–[5]. However, a TFLN-based MZI modulator is usually longer than 1 cm. Microring modulators could offer a more compact size, which is highly desirable to allow denser integration and cheaper components.

Micro-transfer printing is an emerging technology for heterogenous integration of different types of materials [6-7]. Micro-transfer printing allows to integrate various materials, including III-V semiconductors[8-9], TFLN[10-11], PZT and even readily fabricated devices to the silicon platform. This is promising in terms of realizing high performance components integration on a single platform, while enjoying the benefits of different material systems. At the same time, it is also cost-effective, as it allows for more efficient material usage of often costly source wafers. Taking TFLN as an example, hundreds of coupons could be produced on a1 cm^2 chip.

In this paper, we demonstrate a heterogeneously integrated Si-LN microring modulator realized by transfer-printing LN to a silicon platform. The hybrid Si-LN microring modulator has an insertion loss of −1.5dB and a high extinction ratio of − 37dB. The tuning efficiency of the modulator is 3.8pm/V.

Design and simulation

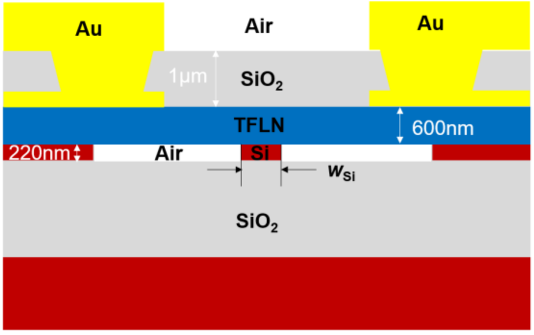

Fig. 1The cross-section of hybrid Si-LN waveguide.

Fig. 1 show the cross-section of the proposed hybrid Si-LN waveguide. The hybrid Si-LN waveguide consists of a 380nm×220nm silcon waveguide and a 600nm thick thin-film lithium niobate slab. The silicon waveguide is defined by $3\mu m$ wide trenches.

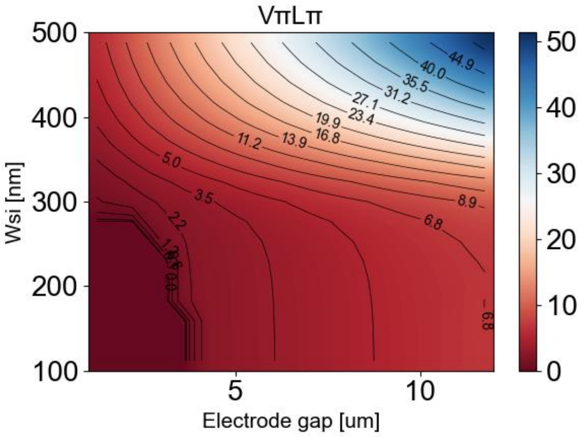

Fig. 2 Simulated VπLπ vs wsi and Elelctrode gap.

The waveguide width wsi is chosen by

minimizing the half-wave voltage length product $V_\pi L_\pi$ and metal-induced propagation loss. Under the chosen parameter, the $V_\pi L_\pi$ is around 8V·cm (as in Fig. 2). The hybrid Si-LN waveguide could still achieve relatively compact bend. When the bending radius is over $15\mu m$, the bending loss is negligible. For the microring design, a racetrack configuration is adopted to maximize the modulation efficiency. As the modulation efficiency is determined partly by the confinement of the mode in LN and by the alignment of LN extraordinary axis with the electrical field.

Heterogeneous integration

Heterogeneous integration of thin-film lithium niobate on the silicon on insulator platform, involves the fabrication of a source chip and a target chip. The source chip is fabricated from a x-cut TFLN wafer, which consists of a 600nm lithium niobate layer, a 2µm thick silicon dioxide layer and a silicon substrate. The target chip is an E-beam fabricated SOI chip with 220nm thick silicon.

The source chip was fabricated by creating suspended structures in x-cut TFLN wafer. The suspended structure, which we call coupons, are suspended via the tether system. Then the TFLN coupon is picked up by a PDMS stamp and transferred to the target wafer. The target chip was fabricated using two ebeam lithography and ICP etching steps, to define the waveguides and shallowed etched grating coupler. Fig. 3 is a microscope image of a LN coupon printed on the silicon target chip. We can see the coupon is cleanly picked up from the source wafer, breaking at the tethers. We can also see the TFLN layer is uniformly attached to the silicon target even though no adhesive bonding layer was used in this case. After removing the resist, a thin-layer of TFLN with rectangular shape is locally printed on the microring.

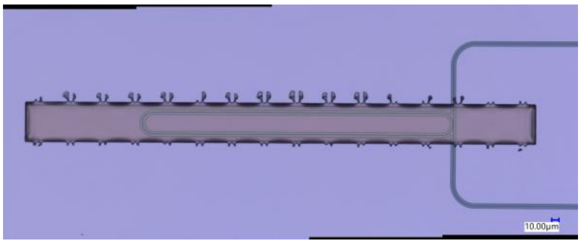

Fig. 3 The microscopic image after the TFLN coupon is printed on the silicon target chip.

Bottom electrodes were fabricated through a metal lift-off process. A 1um layer of SiO_2 was deposited using PCVD as the top cladding. To access the bottom electrodes on LN, we opened vias in the cladding. Then another lift-off process was used to define the top contact electrodes (see Fig. 4).

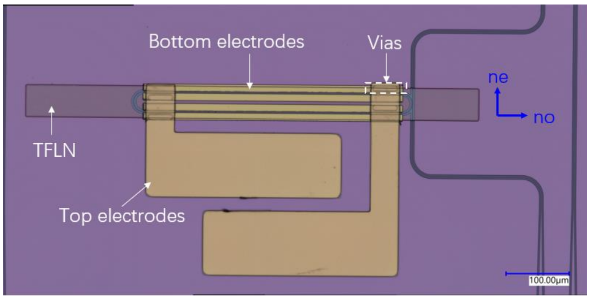

Fig. 4 Microscope image of the fabricated device.

Measurements

We first measured the passive performance of the heterogeneously integrated Si-LN microring modulator. The device was characterized using a tunable laser and a power meter. The light is delivered to the chip by grating couplers. Fig. 5 is the measured transmission spectrum. The insertion loss of the device is around 1.5 dB (relative to a straight waveguide). The extinction ratio of the resonance is up to − 37dB. The microring has moderate quality factor around 10^4, which is suitable for optical modulation.

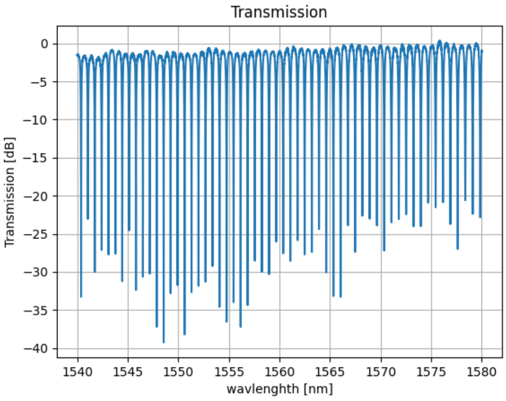

Fig. 5 The transmission spectrum of the device.

Then we measured the transmission with different applied voltages, as show in Fig. 6. We applied voltages in the range from−10V to 10V. The resonance of the microring modulator demonstrates a linear shift with a tuning efficiency of 3.89pm/V, as show in **Fig.** 7.

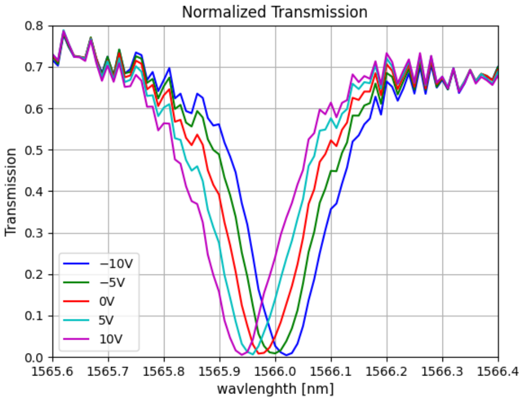

Fig. 6 Measured transmission spectrum for different applied voltages.

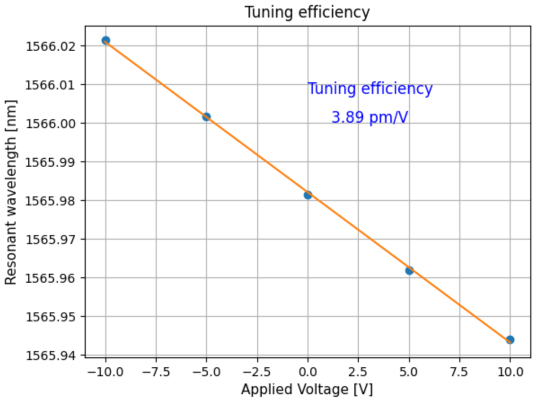

Fig. 7 Tuning efficiency of the device.

Conclusions

We demonstrated an integrated silicon-lithium niobate microring modulator realized by transfer-printing for the first time. The microring modulator has an insertion loss of −1.5dB and extinction ratio of −37dB. The quality factor of the microring is 10^4. The tuning efficiency is 3.89pm/V.

Acknowledgements

This work was supported by the European Union’s Horizon 2020 Research and Innovation Action under Grant Agreement No. 899824 (SURQUID). Special thanks to Muhammad Muneeb, Steven Verstuyft, Liesbet Van Landschoot for their discussion about the fabrication process.

References

[1] D. Thomson *et al.*, “Roadmap on silicon photonics,” *J. Opt.*, vol. 18, no. 7, p. 073003, Jun. 2016, doi: 10.1088/2040-8978/18/7/073003.

[2] M. He *et al.*, “High-performance hybrid silicon and lithium niobate Mach–Zehnder modulators for 100 Gbit s−1 and beyond,” *Nat. Photonics*, vol. 13, no. 5, Art. no. 5, May 2019, doi: 10.1038/s41566-019-0378-6.

[3] X. Wang, P. O. Weigel, J. Zhao, M. Ruesing, and S. Mookherjea, “Achieving beyond-100-GHz large-signal modulation bandwidth in hybrid silicon photonics Mach Zehnder modulators using thin film lithium niobate,” *APL Photonics*, vol. 4, no. 9, p. 096101, Sep. 2019, doi: 10.1063/1.5115243.

[4] F. Valdez *et al.*, “110 GHz, 110 mW hybrid silicon-lithium niobate Mach-Zehnder modulator,” *Sci. Rep.*, vol. 12, no. 1, p. 18611, Nov. 2022, doi: 10.1038/s41598-022-23403-6.

[5] S. Sun *et al.*, “Folded Heterogeneous Silicon and Lithium Niobate Mach–Zehnder Modulators with Low Drive Voltage,” *Micromachines*, vol. 12, no. 7, p. 823, Jul. 2021, doi: 10.3390/mi12070823.

[6] G. Roelkens *et al.*, “Micro-Transfer Printing for Heterogeneous Si Photonic Integrated Circuits,” *IEEE J. Sel. Top. Quantum Electron.*, vol. 29, no. 3: Photon. Elec. Co-Inte. and Ad, pp. 1–14, May 2023, doi: 10.1109/JSTQE.2022.3222686.

[7] B. Corbett, R. Loi, J. O’Callaghan, and G. Roelkens, “Transfer Printing for Silicon Photonics,” in *Semiconductors and Semimetals*, Elsevier, 2018, pp. 43–70. doi: 10.1016/bs.semsem.2018.08.001.

[8] J. Zhang *et al.*, “Transfer-printing-based integration of a III-V-on-silicon distributed feedback laser,” *Opt. Express*, vol. 26, no. 7, p. 8821, Apr. 2018, doi: 10.1364/OE.26.008821.

[9] C. Op De Beeck *et al.*, “Heterogeneous III-V on silicon nitride amplifiers and lasers via microtransfer printing,” *Optica*, vol. 7, no. 5, p. 386, May 2020, doi: 10.1364/OPTICA.382989.

[10] T. Vanackere *et al.*, “Micro-Transfer Printing of Lithium Niobate on Silicon Nitride,” in *2020 European Conference on Optical Communications (ECOC)*, Brussels, Belgium: IEEE, Dec. 2020, pp. 1–4. doi: 10.1109/ECOC48923.2020.9333415.

[11] T. Vanackere *et al.*, “High-Speed Lithium Niobate Modulator on Silicon Nitride using Micro-Transfer Printing”.

.