High-Speed Lithium Niobate Modulator on Silicon Nitride using Micro-Transfer Printing

Tom Vanackere,[1,2,*] Tom Vandekerckhove,[1,2] Laurens Bogaert, [1] Maximilien Billet,[1,2] Stijn Poelman,[1] Stijn Cuyvers,[1] Joris Van Kerrebrouck,[3] Arno Moerman,[3] Olivier Caytan,[3] Sam Lemey,[3] Guy Torfs,[3] Gunther Roelkens,[1] Stéphane Clemmen,[1,2,4] and Bart Kuyken[1]

[1] *Department of information Technology (INTEC), Photonics Research Group, Ghent University–imec, 9052 Ghent, Belgium*

[2] *OPERA-Photonique CP 194/5, Université Libre de Bruxelles (ULB), Bruxelles, Belgium*

[3] *INTEC, IDLab, Ghent University–imec, 9052 Ghent, Belgium*

[4] *Laboratoire d'Information Quantique, Université Libre de Bruxelles, 1050 Bruxelles, Belgium*

**Tom.Vanackere@ugent.be*

Abstract: A high-speed modulator on silicon nitride is demonstrated using 2 mm-long micro-transfer printed lithium niobate coupons. This device has a 3-dB bandwidth >50GHz, and an insertion loss of 3.3 dB that allowed us to transmit 70 Gb/s.

1. Introduction

Lithium niobate (LN) is one of the most popular materials for modulators due to its high Pockels coefficient, wide transparency window and low losses. Integrated lithium niobate modulators have achieved 100 GHz bandwidths at CMOS compatible driving voltages [1]. However, lithium contamination is preventing the thin film LN platform from entering CMOS fabrication facilities. Hybrid integration of LN on silicon and silicon nitride (SiN) is looking to alleviate this issue by bringing the LN processing to the back-end of the fabrication process. Wafer bonded LN has also shown great modulator operation [2] but has limitations concerning efficient material usage, co-integration with other materials and requires processing after the bonding process. Micro-transfer printing (TP) is a hybrid integration technique that allows for the integration of fabricated devices [3] and thin films [4] in the back-end, which has already been used for lithium niobate [5,6]. Here we demonstrate the first hybrid LN-on-SiN high-speed modulator, fabricated using TP, reaching over 50 GHz bandwidth and 3.3 dB insertion loss.

2. Design and Fabrication

To prepare the 300 nm X-cut thin film coupon of LN for printing, the material is etched into 2 mm by 40 μm rectangles including mechanical attachements on the side called tethers. LN adiabatic tapers are added to both sides of the coupon to reduce the transition losses going from SiN to LN (Figure 1c). These tapers are designed to be robust to a lateral misalignment of up to 500 nm which is the typical alignment accuracy of a transfer printing tool. The oxide layer underneath the thin film is then etched away using hydrofluoric acid to release the coupon. The free-hanging coupons can then be picked up and printed using an elastomeric stamp. We print the coupons on a SiN circuit fabricated using ebeam lithography. The coupons are printed directly on top of the SiN platform. The Mach-Zehnder interferometer (MZI) with the transfer printed LN is shown in Figure 1a. The hybrid LN-on-SiN mode is guided by the SiN waveguide as shown in Figure 1b. Gold electrodes are later added to enable the electro-optic modulation using the Pockels effect. The waveguide and electrodes are designed to optimize the half-wave voltage-length product ($V_\pi L_\pi$) at 6.3 Vcm. The differential mode of the electrodes are also designed to be impedance matched and velocity matched to the optical mode.

3. Measurements and Results

In comparison to reference SiN waveguides, the hybrid waveguides including LN coupons introduce 2.7 dB loss. The measured insertion loss can mostly be attributed to roughness induced by the etching process. Nevertheless, the tapered structure still offers an improvement over the taperless transition. The MZI structures have about 0.6 dB extra loss over the waveguides which is explained by an excess loss of 0.3 dB for each multimode interferometer. Even though the two coupons on the MZI arms have been printed separately they are well aligned since the extinction ratio of the modulator near 1550 nm is 39 dB indicating only a 0.2 dB difference in loss in both arms. The device has a V_π of 15 V which is a little better than simulated. This can be explained by the electrodes that have been fabricated with a slightly smaller gap than designed. The electrode characteristics have been measured up to 67 GHz and are plotted in Figure 1d. The characteristic impedance is close to the desired 100 Ω and the effective index is also close to the optical group index from simulations. The small signal measurements show a 3 dB bandwidth of more than 50 GHz after which the measurements hit the noise floor of the equipment due to

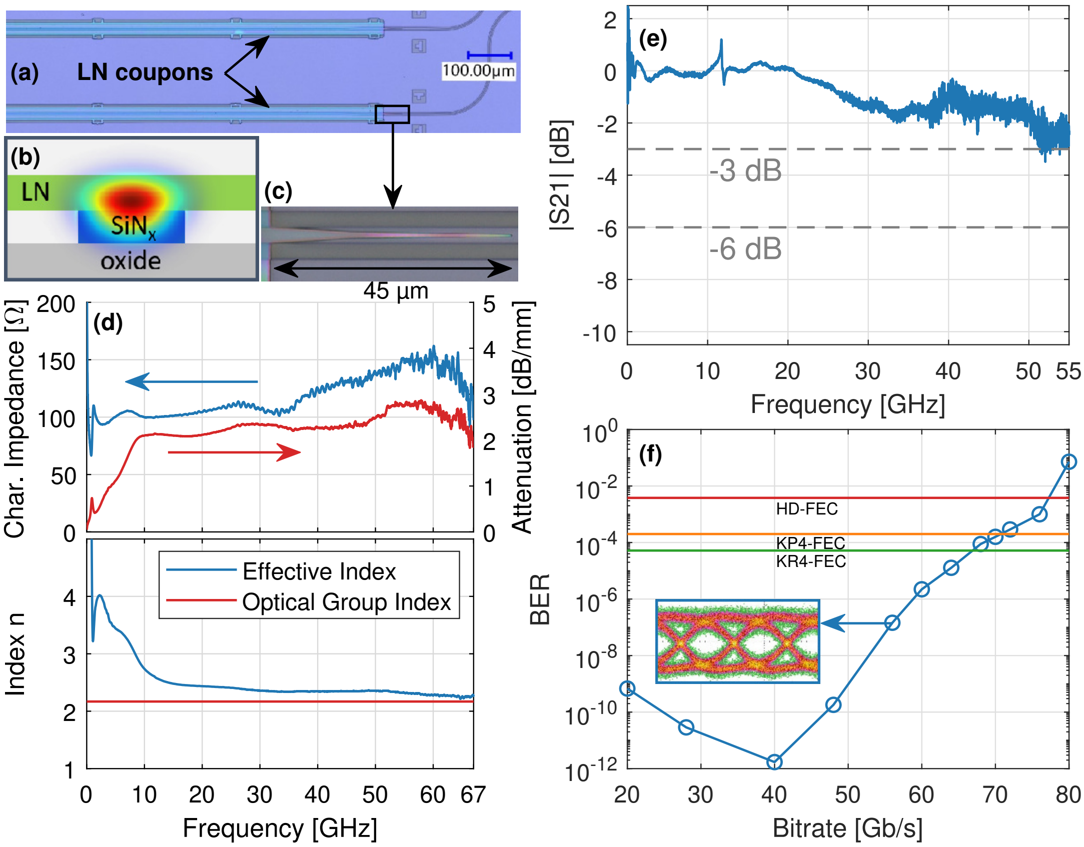

Fig. 1. (a) Microscope image of half of the printed LN coupons in the Mach-Zehnder structure. (b) Hybrid SiN/LN mode profile (c) Zoom of the taper (d) Electrical parameters of the differential mode in the electrodes. (e) Small signal response of the modulator (f) NRZ bit error rates of the eye diagrams generated using the modulator compared to bit error rates required for conventional forward error corrections.

the large V_π (Figure 1e). We were able to transmit up to 70 Gb/s NRZ with a BER below KP4-FEC. The bit error rates (BER) for different bit rates are shown in Figure 1f as well as an example eye at 56 Gb/s (BER=1.4e-7).

4. Conclusions

We report on a high-speed hybrid LN-on-SiN modulator fabricated using micro-transfer printing with a bandwidth in excess of 50 GHz. Adiabatic LN tapers improve the coupling of the SiN-to-LN transition, resulting in 3.3 dB insertion loss and 39 dB extinction ratio. The performance can be improved with longer coupons.

5. Acknowledgements

Tom Vanackere, Tom Vandekerckhove and Stijn Cuyvers are PhD fellows of the Research Foundation Flanders (FWO). Stéphane Clemmen is a research associate of the Fonds de la Recherche Scientifique - FNRS. We also thank the European Research Council (ERC) for the funding in the context of the ELECTRIC project.

References

1. C. Wang *et al.*, “Integrated lithium niobate electro-optic modulators operating at CMOS-compatible voltages,” Nature **562**, 101–104 (2018).
2. M. He *et al.*, “High-performance hybrid silicon and lithium niobate mach–zehnder modulators for 100 gbit s-1 and beyond,” Nat. Photonics **13**, 359–364 (2019).
3. G. Roelkens *et al.*, “Micro-transfer printing for heterogeneous si photonic integrated circuits,” IEEE J. Sel. Top. Quantum Electron. pp. 1–15 (2022).
4. M. Billet *et al.*, “Gallium phosphide-on-insulator integrated photonic structures fabricated using micro-transfer printing,” Opt. Mater. Express **12**, 3731–3737 (2022).
5. T. Vanackere *et al.*, “Micro-transfer printing of lithium niobate on silicon nitride,” in *2020 European Conference on Optical Communications (ECOC),* (IEEE, 2020), pp. 1–4.
6. Z. Li *et al.*, “Photonic integration of lithium niobate micro-ring resonators onto silicon nitride waveguide chips by transfer-printing,” Opt. Mater. Express **12**, 4375–4383 (2022).