High-Efficiency Second Harmonic Generation in Heterogeneously-Integrated Periodically-Poled Lithium Niobate on Silicon Nitride

Tom Vandekerckhove[1,2,*], Tom Vanackere[1,2], Jasper De Witte[1], Isaac Luntadila Lufungula[1], Ewoud Vissers[1], Günther Roelkens[1], Stéphane Clemmen[1,2,3], and Bart Kuyken[1]

1. Photonics Research Group, INTEC, Ghent University - imec, 9052 Ghent, Belgium
2. OPERA-Photonique CP 194/5, Université Libre de Bruxelles, 1050 Brussels, Belgium
3. Laboratoire d'Information Quantique, Université Libre de Bruxelles, 1050 Brussels, Belgium

[*]tom.vandekerckhove@ugent.be

Wavelength conversion processes such as spontaneous parametric down conversion (SPDC) and optical parametric amplification (OPA) are key elements in integrated quantum optics. On-chip integration of these functionalities would allow for increased performance and huge scaling opportunities. However, CMOS-compatible platforms such as silicon and silicon nitride (SiN) lack a $\chi^{(2)}$ nonlinearity due to their inversion symmetry. This work provides a solution by heterogeneously integrating periodically poled lithium niobate (PPLN) onto SiN waveguides through micro-transfer printing (µTP) [1]. The µTP method is a scalable back-end process, allowing the fabrication of the photonic integrated circuit to remain CMOS-compatible.

Starting from a LNOI source wafer with a 300 nm thin-film LN device layer, finger electrodes are deposited with a 3.5 µm period. Through electric field poling, the LN domains are periodically inverted, after which the electrodes are removed with a selective wet etch. Next, 1 mm long rectangular LN slabs are patterned and underetched. These are picked up with a PDMS stamp and printed on top of separately prepared CMOS-compatible SiN waveguides, creating hybrid PPLN/SiN waveguides on a SiN platform, as shown in Figure 1a. The poled domains are imaged above the waveguide with piezoresponse force microscopy (PFM), as depicted in Figure 1b.

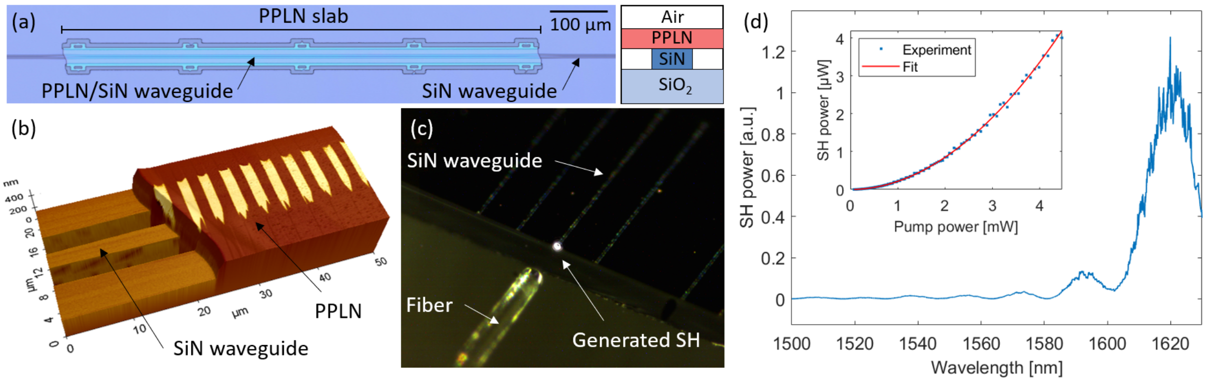

Fig. 1 (a) Microscope image of a transfer-printed PPLN slab onto a SiN waveguide, with a cross section on the right. (b) AFM image with PFM overlay, showing the periodically inverted domains. (c) Picture of the generated SH at the cleaved SiN edge facet. (SH looks white due to color filtering in the camera). (d) SHG spectral response, inset: on-chip SH power vs. on-chip pump power, with a quadratic fit.

The SiN waveguides are cleaved and measured through edge-coupled fibers. Second harmonic generation is observed with quasi-phase matching at 1620 nm, as shown in Figure 1d. The inset depicts the on-chip second harmonic power as function of the on-chip pump power with a typical quadratic behavior. The normalized conversion efficiency is measured to be 2500 %/Wcm^2 which is competitive with the state-of-the-art etched LNOI waveguides [2], and to our knowledge is one of the highest reported efficiencies yet on a SiN platform. A picture of the observed second harmonic exiting the cleaved SiN facet is seen in Figure 1c. Further dispersion engineering combined with the periodic poling will allow to increase the SHG bandwidth for a given phase-matching wavelength, as previously shown on LNOI [3]. While a length of 1 mm was chosen for the current waveguides, it is possible to transfer longer slabs to reach larger absolute efficiencies. These results show the potential of micro-transfer printing to introduce strong $\chi^{(2)}$ nonlinearities onto CMOS-compatible platforms at a back-end level.

References

[1] G. Roelkens, J. Zhang, L. Bogaert, M. Billet, D. Wang, B. Pan, C. J. Kruckel, E. Soltanian, D. Maes, T. Vanackere *et al.*, "Micro-transfer printing for heterogeneous si photonic integrated circuits," IEEE Journal of Selected Topics in Quantum Electronics **29**, 1–14 (2022).

[2] C. Wang, C. Langrock, A. Marandi, M. Jankowski, M. Zhang, B. Desiatov, M. M. Fejer, and M. Lončar, "Ultrahigh-efficiency wavelength conversion in nanophotonic periodically poled lithium niobate waveguides," Optica **5**, 1438–1441 (2018).

[3] M. Jankowski, C. Langrock, B. Desiatov, A. Marandi, C. Wang, M. Zhang, C. R. Phillips, M. Lončar, and M. Fejer, "Ultrabroadband nonlinear optics in nanophotonic periodically poled lithium niobate waveguides," Optica **7**, 40–46 (2020).