A Scalable Quadratic Nonlinear Silicon Photonics Platform with Printable Entangled Photon-pair Sources

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Abstract: We present a scalable quadratic nonlinear platform by micro-transfer printing periodically poled lithium niobate on a 200 mm silicon photonics platform. We achieve chip-to-chip reproducibility, deterministic phase-matching and establish printable entangled photon-pair sources.

Introduction

The development of thin-film lithium niobate (LN) rib waveguides combined with quasi-phase-matching through electric field poling has enabled orders of magnitude improvement in conversion efficiencies and has unlocked new dispersion regimes [1]. However, these suffer from an extreme sensitivity to fabrication variations [2]. Non-uniformity along the waveguide limits the achieved conversion efficiencies while fabrication deviations from the intended geometry cause a substantial shift in the operating wavelength, preventing deterministic phase-matching. This prohibits scaling of integrated quadratic nonlinearities to large-scale systems and high-volume manufacturing. In this work, we propose a scalable nonlinear platform based on heterogeneous integration of periodically poled lithium niobate (PPLN) and leverage the superior fabrication tolerances of silicon photonics [3].

A scalable nonlinear silicon photonics platform

The concept of the platform is given in Fig.1. Starting from an LNOI source wafer, electrodes are deposited and the lithium niobate is periodically poled. Next, the electrodes are selectively removed and the PPLN films are patterned and suspended. These are then micro-transfer printed onto exposed silicon nitride (SiN) waveguides on a 200 mm silicon photonics wafer with a PDMS stamp. The outcome is a quasi-phase-matched hybrid PPLN/SiN waveguide (shown in Fig.2b), bringing efficient second-order frequency conversion to silicon photonics.

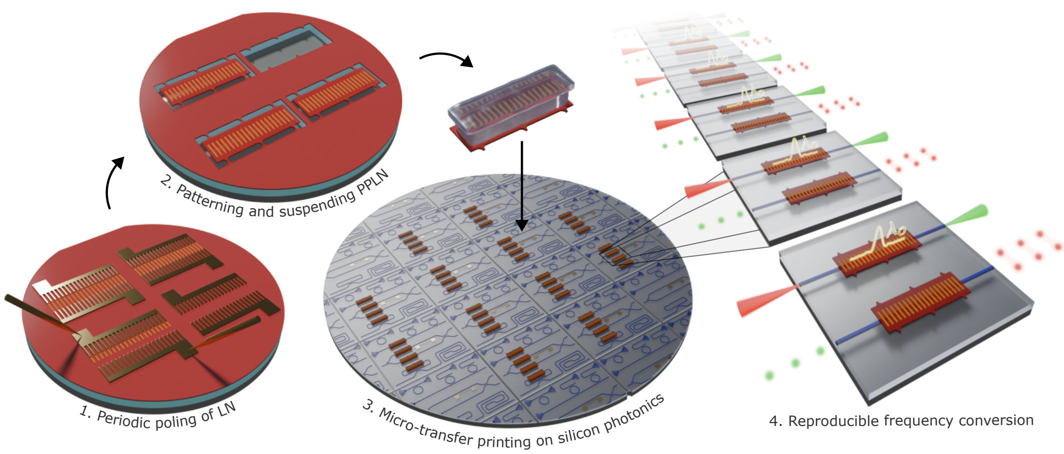

Fig. 1. **A scalable quadratic nonlinear silicon photonics platform. Step 1:** Periodic poling of lithium niobate. **Step 2:** PPLN films are patterned and suspended. **Step 3:** Micro-transfer printing on silicon photonics. **Step 4:** Reproducible frequency conversion and photon-pair generation.

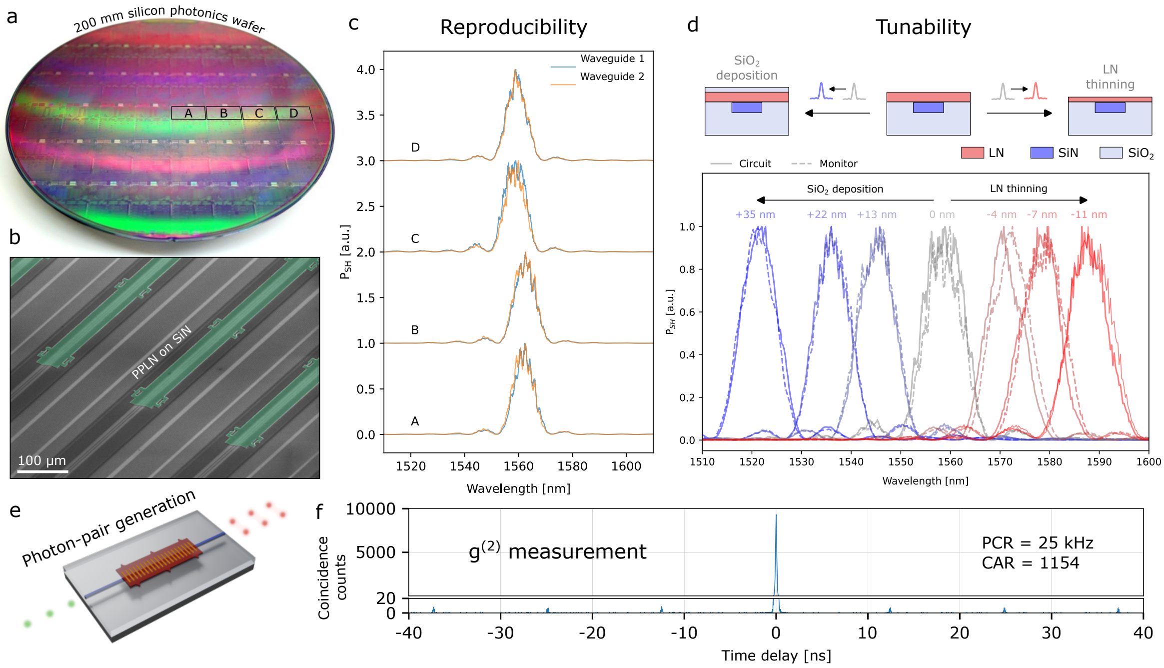

Fig. 2. **Reproducibility, tunability and photon-pair generation. a** Photograph of the 200 mm silicon photonics wafer. **b** False-color SEM of printed PPLN films on silicon nitride waveguides. **c** Reproducible phase-matching over a full 200 mm wafer radius. **d** Tuning mechanism for deterministic phase-matching. **e** Sketch of photon-pair generation. **f** $g^{(2)}$ correlation measurement.

Reproducibility and tunability for a scalable platform with printable photon-pair sources

Our hybrid approach eliminates the fabrication variations associated with the shallow etch involved in fabricating LNOI rib waveguides. Lateral confinement is provided by the fully etched SiN waveguides with superior CMOS-based uniformity, leaving the initial LN film thickness as dominant factor of variations. With the micro-transfer printing method, PPLN films from the same local region on the LNOI source can populate a full 200 mm wafer, thereby minimizing film thickness variations between devices. To demonstrate, we achieve reproducible phase-matching over a full radius of the wafer (Fig.2c). While consistent over the wafer, original deviations from the intended LN film thickness will cause an offset in phase-matching. To obtain deterministic phase-matching, we implement a wafer-scale single-step tuning mechanism that is able to blue- and red-shift the operating wavelength over 100 nm through cladding tuning and LN thinning, respectively (Fig.2d). We demonstrate control by tuning the phase-matching from 1520 nm to 1590 nm. The achieved reproducibility combined with the deterministic phase-matching enables scaling to large-scale and high-volume manufacturing. Lastly, given the platform's potential for generating complex entangled states, we characterize spontaneous parametric down-conversion. Fig.2f shows a correlation measurement with a Hanbury Brown-Twiss setup, obtaining a pair coincidence rate (PCR) of 25 kHz with a coincidence-to-accidental (CAR) ratio of 1154 for an on-chip average pump power of -40.0 dBm. This establishes a printable entangled photon-pair source.

Conclusion

We have developed a scalable quadratic nonlinear platform that leverages the CMOS processing control of silicon photonics. We achieve reproducible and deterministic phase-matching, and establish printable entangled photon-pair sources. This paves the way towards large-scale and high-volume manufacturing of integrated quadratic nonlinearities.

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References

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