Programmable 8×8 linear optical network based on silicon nitride waveguides for quantum information processing

Caterina Taballione[1], Tom A. W. Wolterink[2], Jasleen Lugani[2], Andreas Eckstein[2], Bryn A. Bell[2], Robert Grootjans[3], Ilka Visscher[3], Dimitri Geskus[3], Chris G. H. Roeloffzen[3], Jelmer J. Renema[4], Ian A. Walmsley[2], Pepijn W. H. Pinkse[4] and Klaus-J. Boller[1]

[1] *Laser Physics and Nonlinear Optics, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands*
[2] *Ultrafast Quantum Optics and Optical Metrology, University of Oxford, OXI 3PU Oxford, UK*
[3]*Lionix International BV, PO Box 456, 7500 AL Enschede, The Netherlands*
[4]*Complex Photonic Systems, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands*

On-chip universal linear optical networks based on tunable beam splitters and phase shifters are well suited for quantum information processing (QIP) due to their phase stability and reconfigurability. Many examples and demonstrations have been given on different material platforms such as silicon-on-insulator (SOI) for, e.g., bosonic transport simulation [1] and doped silica for, e.g., universal linear optics [2].

Here, we report the demonstration of an 8×8 mode transformation circuit for quantum information processing implemented in a photonic processor based on single-mode stoichiometric Si_3N_4 waveguides [3] with propagation loss as low as 0.2 dB/cm. The advantage of this platform compared to others is the unique combination of high index contrast, ultra-low straight-propagation loss and spectrally wide-transparency range (Fig. 1). Our photonic processor, fully reprogrammable and remotely controllable, consists of 128 thermally tunable elements arranged in a square mesh, enabling any 8×8 transformation.

We observe on-chip quantum interference with high visibility, i.e., ~76%, on various beam splitters within the photonic processor, and we show bosonic coalescence/anti-coalescence on a 4×4 subsystem. Finally we implement high-dimensional single-photon quantum gates over the whole mode structure of the processor obtaining an average fidelity of ~95%.

Our findings demonstrate the suitability and reliability of low-loss, integrated linear optical photonic processors based on Si_3N_4 waveguides. These results show the high potential of Si_3N_4 for the development of large universal linear optical quantum circuits.

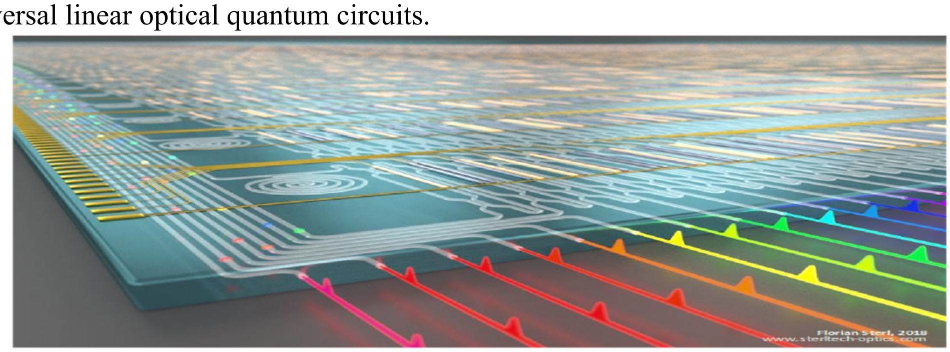

Figure 1: Artist's impression of a silicon nitride waveguide programmable linear optical network. The high index contrast enables a dense waveguide arrangement with the unique combination of ultra-low straight-propagation loss. The wide spectral transparency range makes silicon nitride suitable for quantum light sources, from the visible to the mid-infrared.

References

[1] Harris, N.C., et al., "Quantum transport simulations in a programmable nanophotonic processor" Nature Photonics **11,** 447 (2017).

[2] Carolan, J., et al., "Universal linear optics" Science **349** (6249), 711 (2015).

[3] Roeloffzen, C.G.H., et al., "Low-Loss Si3N4 TriPleX Optical Waveguides: Technology and Applications Overview" IEEE JSTQE **24** (4), 1-21 (2018).