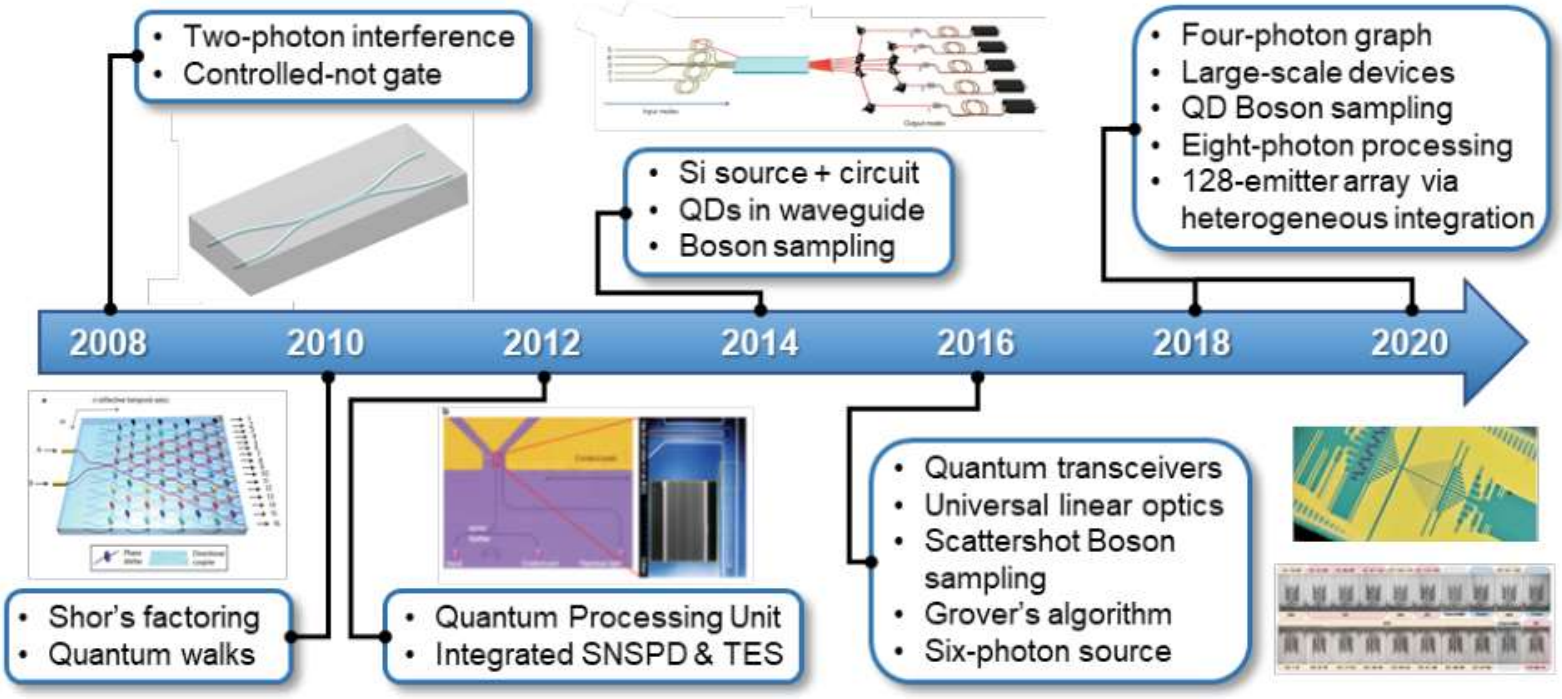
Quantum gates in integrated optics: architecture & implementation

2022

Integrated optic quantum technologies



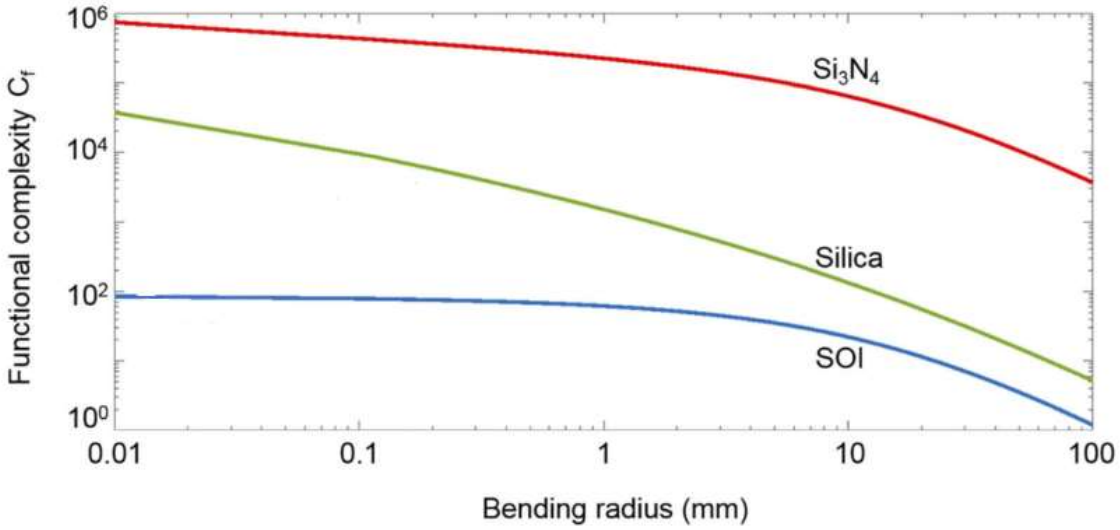
Jianwei Wang, J., Sciarrino, F., Laing, A. et al. Integrated photonic quantum technologies. Nat. Photonics 14, 273–284 (2020). https://doi.org/10.1038/s41566-019-0532-1

Integrated Optics Materials

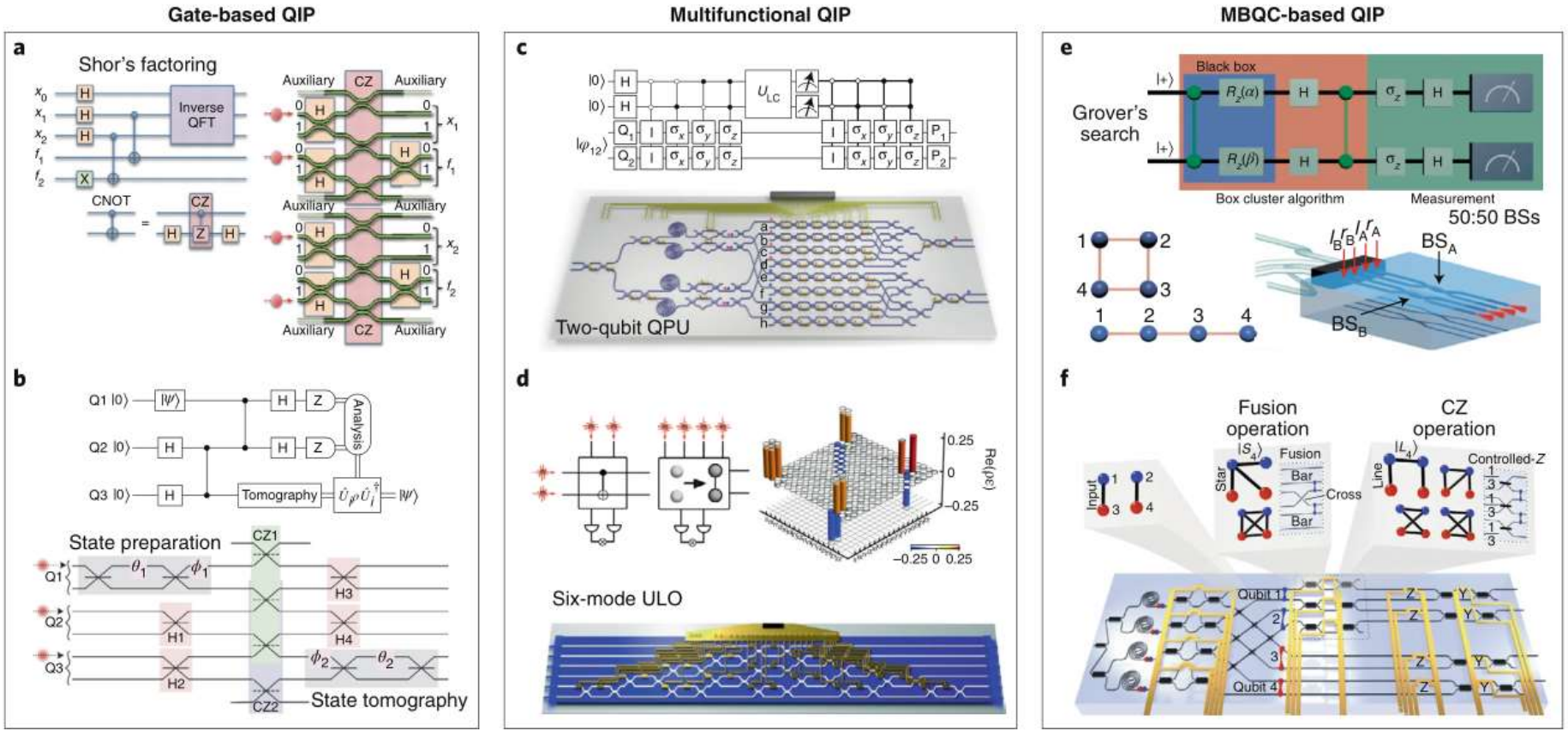
Table 1: Summary of integrated photonics platform parameters.

Material system	λ	Photoluminescence	Loss (dB/cm)	Δn (%)	Fabrication complexity
SOI	Near IR	Indirect	2.4–0.3 [51, 52]	40	Low
Silica-on-silicon	Near IR	–	0.1 [5]	0.5	Low
Si_3N_4	Visible, near IR	Yes	1.5 [53]/5×10^{-4} [54]	18	Medium
$LiNbO_3$	Near IR	No data	10–0.6 [55]	29	High
InP	Near IR	No data	>2 [56]	Varies	Medium

Index contrast is calculated as $\Delta n=(n^2_{core}-n^2_{clad})/(2n^2_{core})$ and serves as a predictor for optical component density. IR, infrared.



Implementations of gate-based QIP

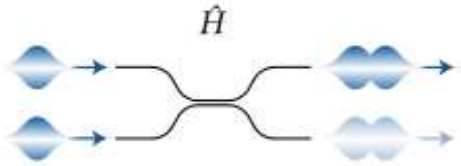


QFT – quantum Fourier transform, QPU – quantum processing unit, ULO – universal linear optic, MBQC - measurement-based quantum computer

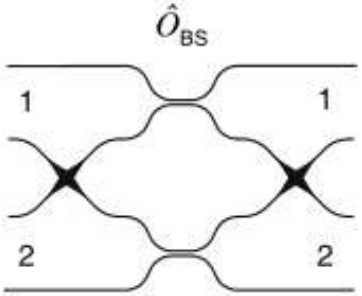
Integrated building blocks for operating photonic states

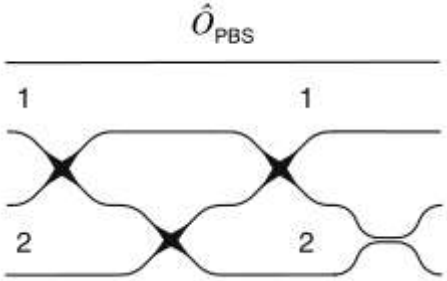
$$P = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\varphi} \end{bmatrix}$$

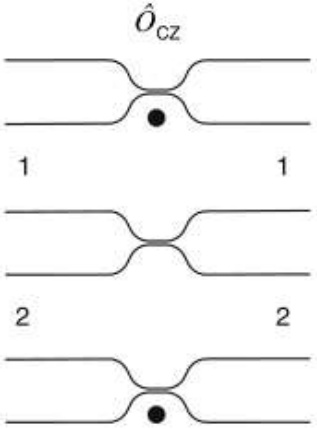
$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$



$$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

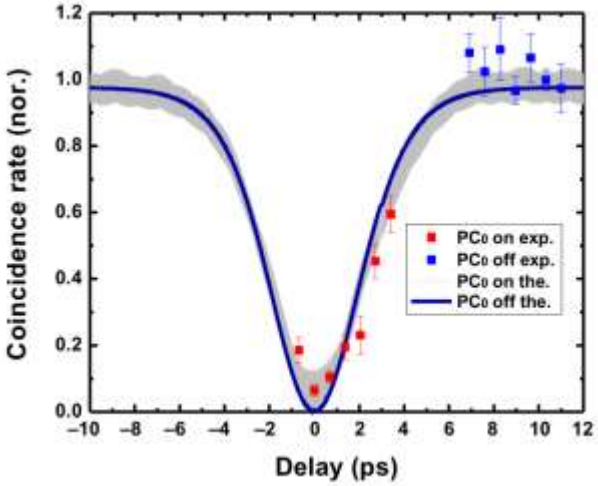


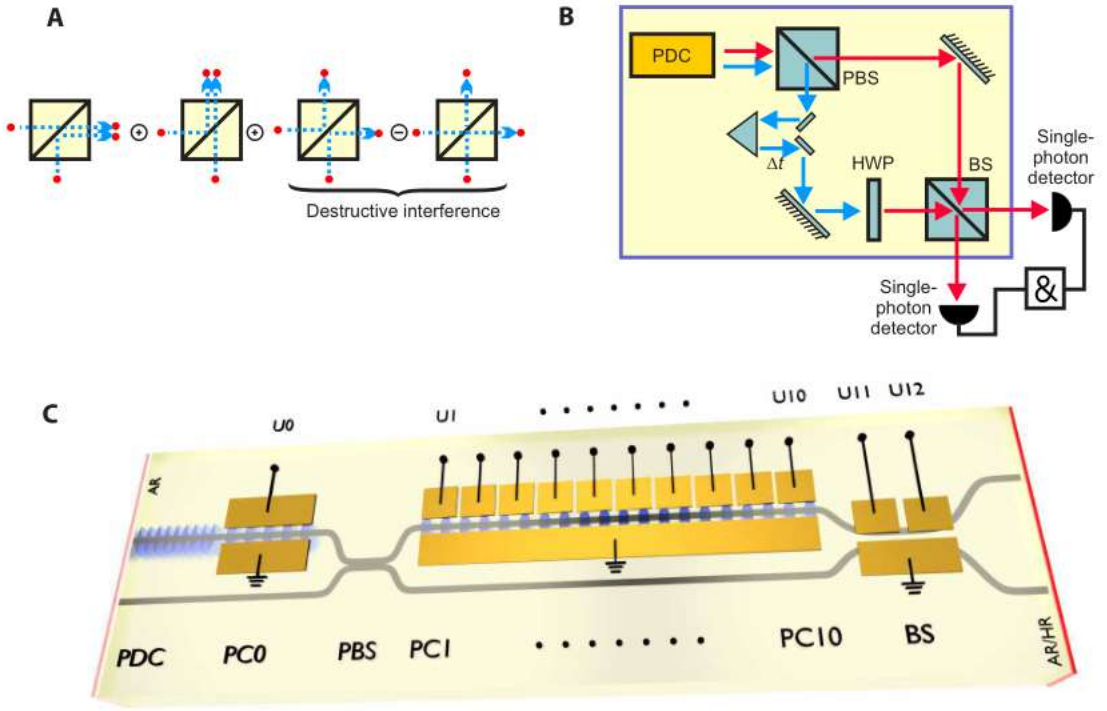




$$CZ = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

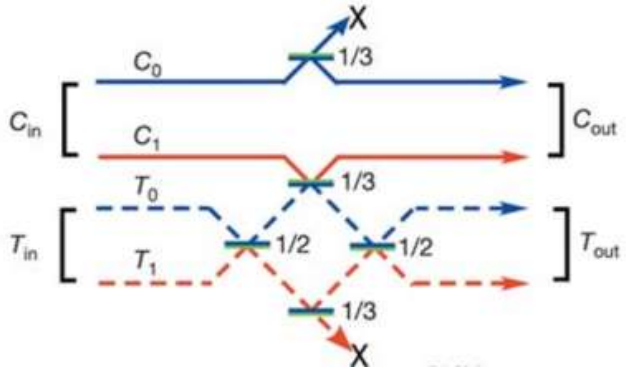
Integrated Mach-Zehnder interferometer

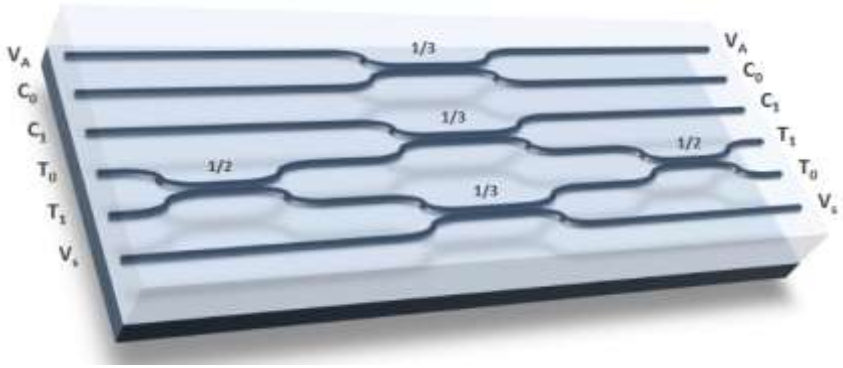




Kai-Hong Luo, Sebastian Brauner. Nonlinear integrated quantum electro-optic circuits. https://doi.org/10.1126/sciadv.aat1451

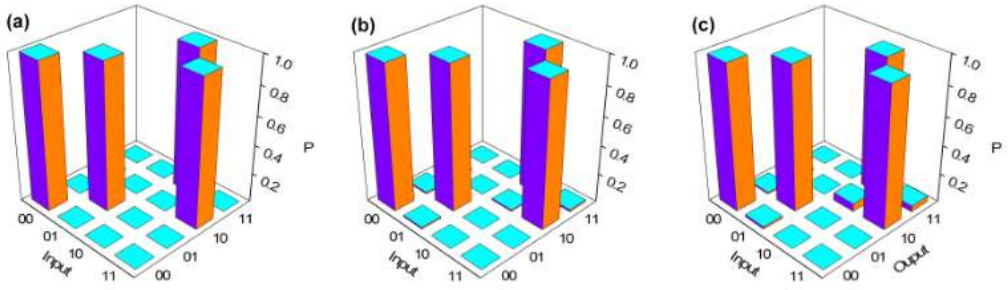
Integrated optical CNOT





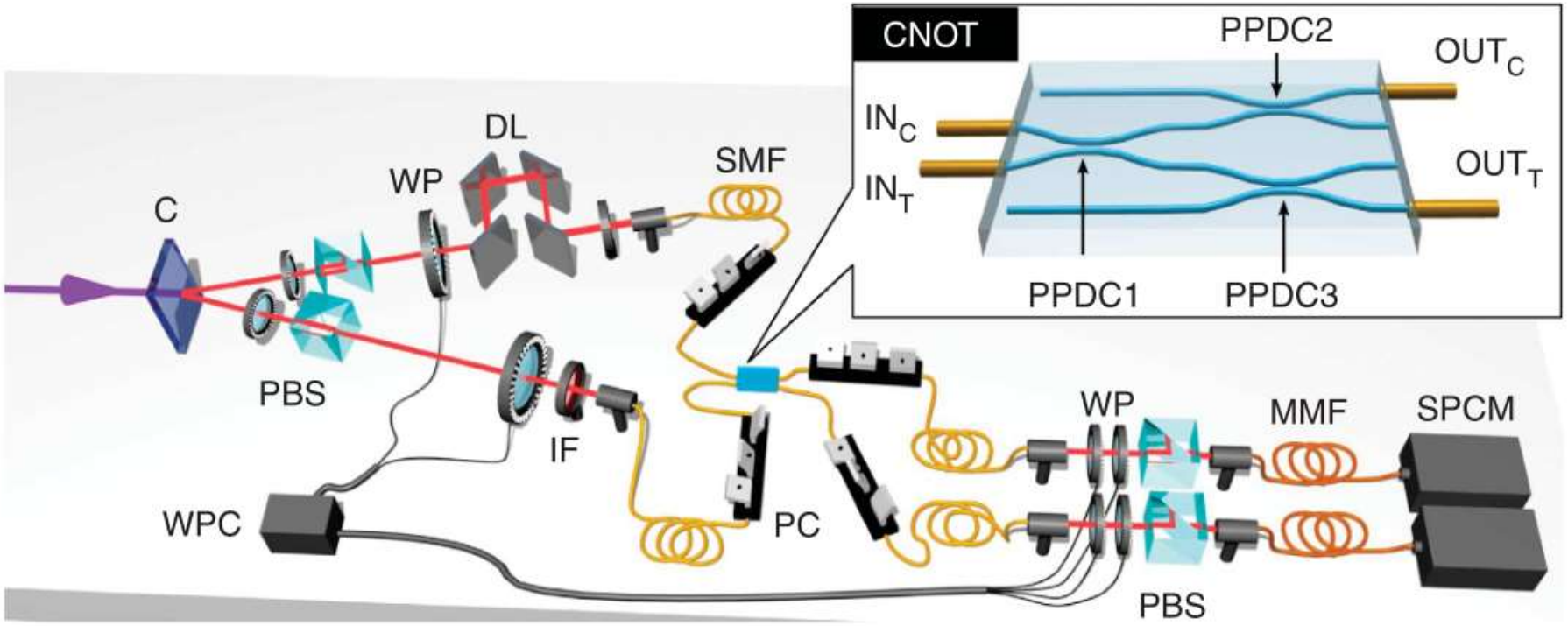
$$CNOT = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$CNOT|00\rangle \Rightarrow |00\rangle,$$
$$CNOT|01\rangle \Rightarrow |01\rangle,$$
$$CNOT|10\rangle \Rightarrow |11\rangle,$$
$$CNOT|11\rangle \Rightarrow |10\rangle.$$



Anthony Laing et al. High-fidelity operation of quantum photonic circuits. Appl. Phys. Lett. ***97****, 211109 (2010);* https://doi.org/10.1063/1.3497087

Integrated optical CNOT



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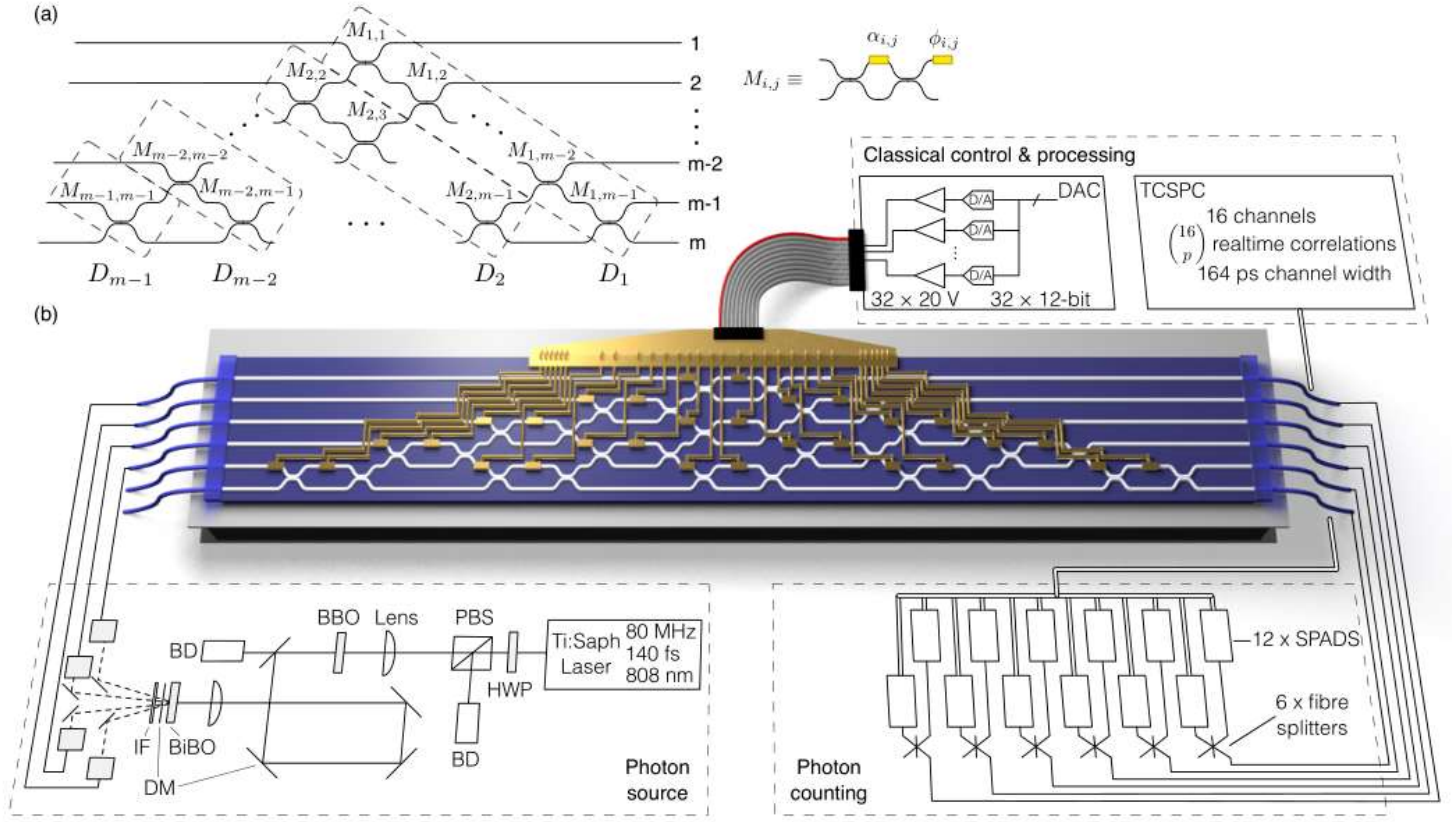
Universal Linear Optics



Jacques Carolan et al. Universal Linear Optics https://arxiv.org/abs/1505.01182

Universal Linear Optics