Robust photon-pair generation in topological waveguide arrays

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High-dimensional entangled states of light offer powerful opportunities for quantum information technologies, ranging from fundamental tests of quantum mechanics to advanced computation and communication protocols. In this context, the spatial degree of freedom stands out as particularly suited for on-chip integration. Traditional photonic circuits generate and manipulate photons in a step-by-step fashion, using a sequence of discrete optical components. By contrast, nonlinear waveguide systems offer a promising alternative where photons can be generated and interfere in a continuous manner, unveiling novel capabilities within a reduced footprint. We have exploited this concept to implement a compact and reconfigurable source of path-entangled photon pairs based on SPDC in AlGaAs nonlinear waveguide arrays (Fig. 1a,b). A classical pump injected into selected waveguides generates photon pairs via SPDC, which then tunnel between neighboring waveguides during propagation, implementing quantum walks. A multi-pump configuration enables tuning of the output quantum state to implement a broad range of spatial correlations [1,2].

We then investigate how topological effects can enhance the robustness of such sources against fabrication imperfections [3]. Specifically, we study nonlinear waveguide arrays implementing the Su–Schrieffer–Heeger (SSH) model (Fig. 1c). By combining experiments and theory, we systematically compare homogeneous arrays, arrays hosting trivial defect modes, and topological SSH arrays. We show that disorder strongly affects the SPDC resonance spectrum in the first two cases, while the topological configuration preserves a highly stable resonance even in the presence of significant disorder, reducing fluctuations in the resonance wavelength by more than an order of magnitude (examples of measured spectra in Fig. 1d). We develop an analytical model that captures the origin of this robustness in the band-structure properties of the interacting modes. Finally, we show that such arrays can operate as robust photon-pair sources, enabling stable interference between multiple sources and the generation of high-dimensional entangled states with high fidelity [3]. These results establish nonlinear waveguide arrays as a promising platform for exploiting the interplay between topology and nonlinearity in integrated quantum photonic circuits.

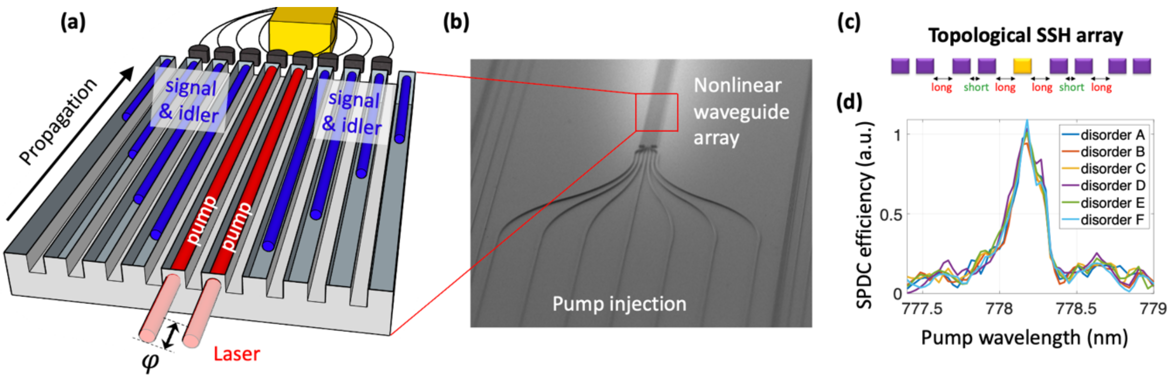

Fig. 1: *(a) Sketch and (b) SEM image of an AlGaAs nonlinear waveguide array. (c) Cross-section of a topological SSH array, and (d) measured SPDC resonance spectra in presence of disorder.*

References

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[2] A. Raymond et al., **Optics Express** 33, 45869 (2025)
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