Generation of quantum entangled photons from lithium niobate nonlocal metasurfaces

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Quantum entanglement underpins a broad range of fundamental physical effects and serves as an essential resource in various quantum applications. In optics, the most common source of entangled photons is based on the spontaneous parametric down-conversion (SPDC) process in quadratically nonlinear materials. Dramatic enhancements of nonlinear light-matter interactions were achieved in nanofabricated structures with subwavelength thickness known as metasurfaces, which are also bringing advances to the field of quantum optics [1]; yet the generation with metasurfaces of photons entangled in spatial and other degrees of freedom remained outstanding.

We report the first experimental generation of spatially entangled photon pairs through SPDC from a metasurface incorporating a lithium niobate nonlinear thin film [2] [Fig. 1**a**] that supports high-quality-factor nonlocal guided-mode resonances [Fig. 1**b**]. The photon-pair rate is strongly enhanced by 450 times as compared to unpatterned films [Fig. 1**c**]. We measure the correlations of photon pairs and identify their spatial anti-bunching through violation of the classical Cauchy-Schwartz inequality [Fig. 1**d**], witnessing the presence of multi-mode entanglement.

We also present an original approach to generate polarisation-entangled states, thereby overcoming the fundamental limitation of unstructured lithium niobate crystals that predominantly emit photon pairs with a fixed linear polarisation. We develop a metasurface incorporating two crossed metagratings, designed to emit either $|HH\rangle$ or $|VV\rangle$ polarised photon states [Fig. 1**e**], which superposition results in polarisation entanglement as confirmed by the experimental density matrix reconstruction [Fig. 1**f**]. These results pave the way toward the miniaturisation of various quantum devices by incorporating ultra-thin metasurfaces as room-temperature entangled photon sources.

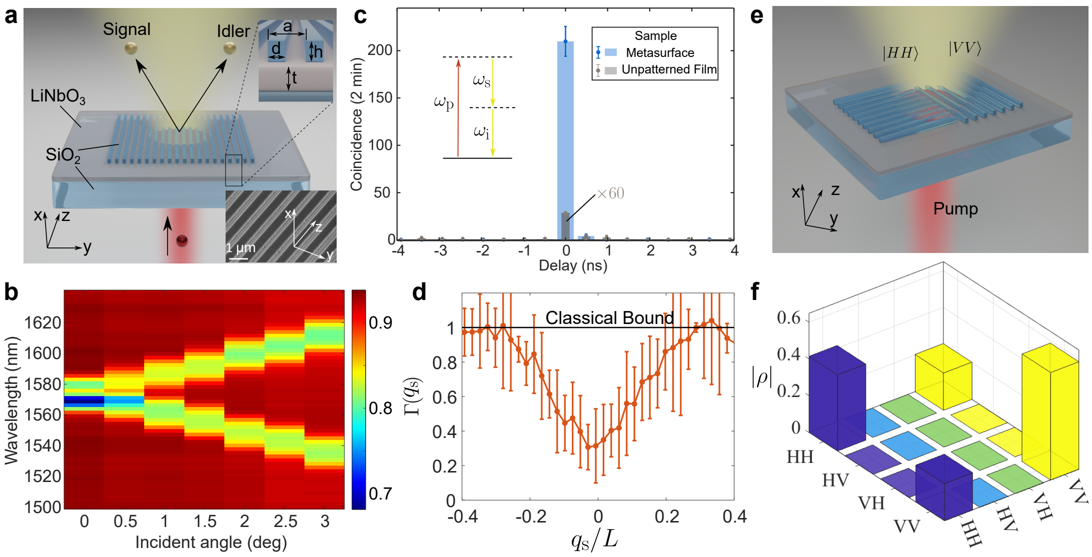

Figure 1: **a** Sketch of spatially entangled signal and idler photons generation from a $LiNbO_3$ thin film covered by a SiO_2 grating and pumped by a continuous laser. Inset shows the SEM image of the metasurface. **b** Measured linear transmission as a function of incident angle and wavelength. **c** Coincidence histograms of SPDC from metasurface and unpatterned film. **d** Violation of Cauchy-Schwartz inequality for values below the classical bound. **e** Generation of polarisation entanglement with two crossed metasurfaces. **f** Absolute value of reconstructed density matrix.

[1] T. Santiago-Cruz, A. Fedotova, V. Sultanov, M. A. Weissflog, D. Arslan, M. Younesi, T. Pertsch, I. Staude, F. Setzpfandt, and M. Chekhova, Nano Lett. **21**, 4423 (2021).

[2] J. Zhang, J. Ma, M. Parry, M. Cai, R. Camacho-Morales, L. Xu, D. N. Neshev, and A. A. Sukhorukov, arXiv 2204.01890 (2022).