Topologically optimized metasurface for characterizing two-photon distinguishability in a single shot

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In quantum photonics, the indistinguishability between photons is the key feature absent in classical optics. For two photons, the distinguishability is typically characterized by the Hong-Ou-Mandel interference with bulky beam splitters by comparing the photon correlations at different time delays [1]. Metasurfaces containing a thin layer of nanostructures were recently demonstrated for two-photon interference [2], yet their potential for direct characterization of photon distinguishability remained unexplored.

Here, we propose and fabricate a metasurface grating for single-shot characterization of two-photon distinguishability without a need for multiple measurements at different time delays. The metasurface is tailored to interfere two photons from two inputs [Fig. 1(a)]. The two independent density-matrix elements of the input two-photon state $\rho_{1,2}$ [$\rho_2/\rho_1 = 0(1)$: fully (in)distinguishable] are directly related to the output two-photon correlations ($\Gamma_{12,13,23}$) at the outputs. Thus, they can be reconstructed once the metasurface transmission coefficients and output correlations are characterized. By utilizing topology optimization, we designed a free-form 1μm-thick silicon metasurface on a sapphire substrate and then fabricated it by electron beam lithography, see SEM image in Fig. 1(b). The measured transmission amplitudes [Fig. 1(c)] are in agreement with the theoretical design and confirm a high total transmission of 90% in the photon wavelength range 1555-1565 nm . We anticipate that the metasurface design can be further tailored for multi-photon states and additional degrees of freedom, providing versatile ultracompact quantum optical elements for various applications.

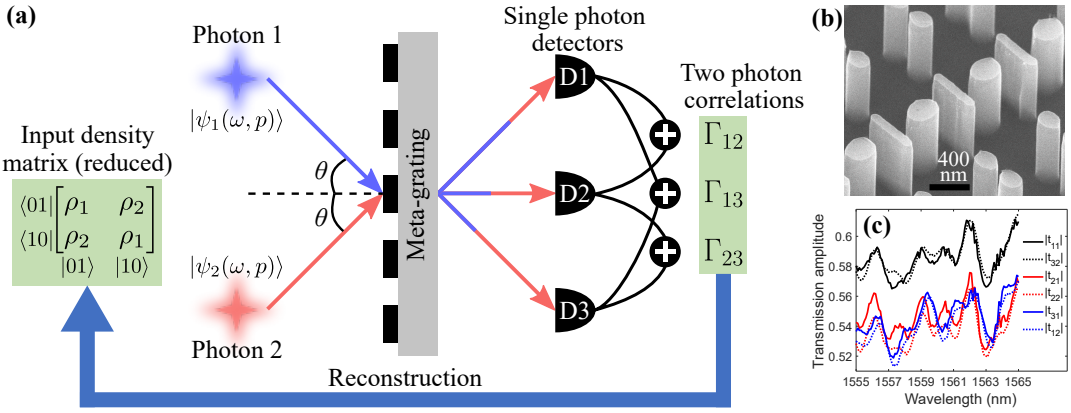

Figure 1: (a) Schematic of the metasurface-enabled single-shot characterization of two-photon distinguishability. (b) SEM image of the fabricated metasurface. (c) Measured transmission amplitudes.

[1] C. K. Hong, Z. Y. Ou, and L. Mandel, Phys. Rev. Lett. **59**, 2044 (1987).

[2] Q. W. Li, W. Bao, Z. Y. Nie, *et al.*, Nat. Photon. **15**, 267 (2021).