High-dimensional entanglement in large-scale Silicon quantum photonics

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Photons represent a promising platform for multidimensional quantum technologies, offering various degrees of freedom for encoding and processing qudits (e.g., orbital angular momentum, time-bin and frequency [1,2]). We report the experimental implementation of a novel approach for the generation and processing of high-dimensional entangled systems based on large-scale integrated quantum photonics [3]. The experiment is performed using a Silicon quantum photonic chip able to create, control and analyze on-chip high-dimensional entanglement up to dimensions $15 \times 15$ (see Fig. 1A and inset). The photonic chip integrates more than 500 optical elements, including 16 photon-pair sources based on $\chi^3$ non-linearities, 93 phase-shifters and 122 beam-splitters. Bipartite path-encoded high-dimensional systems with an arbitrary degree of entanglement are obtained by the coherent excitation of an array of identical integrated photon-pair sources, and integrated circuits allow high fidelity arbitrary measurements on-chip. In Fig. 1B the tomographies of the generated maximally-entangled states are reported for various local dimensions, and an example for $d = 12$ is shown in Fig.1C presenting a fidelity of 81%. The quality of the generated high-dimensional entanglement and the universality of the photonic processor are further exploited to experimentally implement a wide range of multidimensional applications, such as violation of high-dimensional Bell inequalities [4], self-testing of high-dimensional states, randomness generation and dimensional witnessing.

References