On-chip Generation and Coherent Control of Complex Optical Quantum States

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Complex quantum states based on entangled photons are essential for fundamental investigations of physics and are at the heart of a variety of applications in quantum information science, including quantum-based computing, telecommunications, and metrology. Recently, integrated photonics has become a leading platform for the scalable, cost-efficient, and stable generation and processing of optical quantum states. However, on-chip sources are currently limited to basic two-dimensional (qubit) two-photon states, whereas scaling the state complexity requires access to states composed of several (>2) photons and/or exhibiting high photon dimensionality.

Here, we show that the use of integrated frequency combs (on-chip light sources with a broad spectrum of evenly-spaced frequency modes) based on high-Q nonlinear microring resonators can provide solutions for such scalable complex quantum state sources. In particular, by using spontaneous four-wave mixing within the resonators, we demonstrate the generation of bi- and multi-photon entangled qubit states over a broad comb of channels spanning the S, C, and L telecommunications bands, and coherently control these states using fiber-based interferometry to perform quantum interference measurements and state tomography [1]. Furthermore, we demonstrate the on-chip generation of entangled D-level (quDit) states, where the photons are created in a coherent superposition of multiple highly-pure frequency modes [2, 3]. Specifically, we confirm the realization of a quantum system with at least a one hundred dimensional Hilbert space. Moreover, using off-the-shelf telecommunications components, such as electro-optic modulators and programmable filters, we introduce a platform for the coherent manipulation and control of frequency-entangled quDit states. Our results suggest that microcavity-based entangled photon state generation and the coherent control of states using accessible telecommunications infrastructure introduce a powerful and scalable platform for quantum information science.

