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

Piotr Roztocki(1), Michael Kues(1,2), Christian Reimer(1), Luis Romero Cortés(1), Stefania Sciara(1,3), Benjamin Wetzel(1,4), Yanbing Zhang(1), Alfonso Cino(3), Sai T. Chu(5), Brent E. Little(6), David J. Moss(7), Lucia Caspani(8,9), José Azaña(1) & Roberto Morandotti* (1,10,11)
(1) INRS-EMT, Varennes, Canada
(2) University of Glasgow, Glasgow, UK
(3) University of Palermo, Palermo, Italy
(4) University of Sussex, Falmer, UK
(5) City University of Hong Kong, Hong Kong, China
(6) Chinese Academy of Science, Xi'an, China
(7) Swinburne University of Technology, Hawthorn, Australia
(8) University of Strathclyde, Glasgow, UK
(9) Heriot-Watt University, Edinburgh, UK
(10) University of Electronic Science and Technology of China, Chengdu, China
(11) National Research University of Information Technologies, Mechanics and Optics, St Petersburg, Russia;
e-mail: morandotti@emt.inrs.ca

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.

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