An On-Chip, Laser-Integrated Quantum Light Source

Photonics is a compelling approach for quantum technologies, due to photons' robustness to decoherence, sophisticated information-processing tools operable at room temperature, existing fiber optic networks and mature fabrication technologies. State-of-the-art nanofabrication facilities can already make compact, robust on-chip photonic devices capable of generating and controlling entangled photons—crucial resources for quantum information processing.[1] A range of nonclassical functionalities has been realized in the lab on photonic chips.

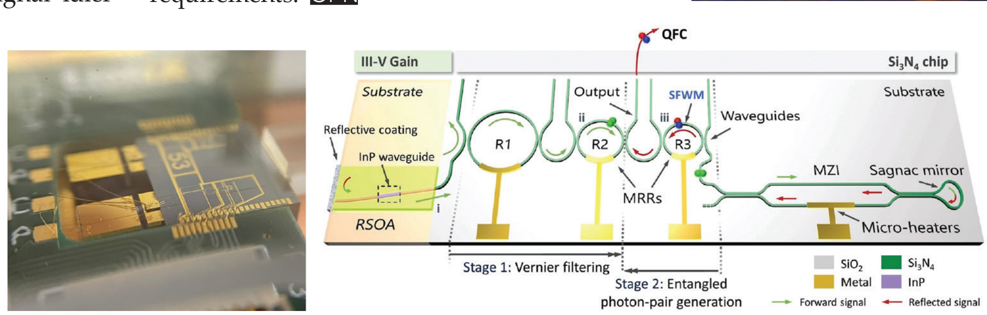
Yet all previously demonstrated quantum photonic sources, on-chip quantum functionalities and integrated quantum photonic processors have relied on external, bulky excitation lasers. These lasers often occupy a large space and are tenuously coupled to the photonic chip, resulting in poor stability over time and losses at the interfaces. The overall system thus becomes non-reproducible, inefficient, impractical and unsuitable for out-of-laboratory use and scalable production. To address these challenges, we recently demonstrated a laser-integrated, fully on-chip quantum light source of entangled qubits and qudits[2] that can provide the required stability and scalability.[3]

Previously, the major technical challenge inhibiting a turnkey system has been the combined integration of a stable, tunable laser with a high rejection filter (to eliminate noise) and an entangled-photon source (creating signal–idler pairs through nonlinear spontaneous parametric effects). Further, the absence of a unique material platform that supports all quantum photonic functionalities—low-loss guiding, filtering, efficient generation of entangled photons, active manipulation—while also providing laser gain has impeded monolithic integration.

Recently, through novel chip design and by leveraging hybrid integration, we realized a laser-integrated quantum light source. The source directly generates frequency-bin entangled photons—that is, a high-dimensional quantum frequency comb[2,4]—through spontaneous four-wave mixing (SFWM). The source consists of an electrically pumped reflective semiconductor optical amplifier (RSOA) based on an InP gain section, extended by a Si_3N_4 low-loss feedback circuit. Three microrings form a Vernier filter that provides a laser side-mode suppression ratio of 112 dB. A Sagnac mirror and reflecting coating at the RSOA form a lasing cavity. Metal microheaters align the rings' resonances at 193.4 THz.

The high noise suppression of the Vernier filter facilitated a high coincidental-to-accidental ratio of ~80 with a remarkable pair-detection rate of greater than 600, over four resonance pairs in the telecom C-band. Quantum interference measurements with visibilities of more than 96%, and quantum state tomography with fidelities greater than 0.98 for 2D Bell states and ~0.85 for 3D Bell states, affirmed the generation of excellent-quality entangled qubits and qutrits.

Our work[2] is the first demonstration of an on-chip, robust, lightweight quantum light source. We believe it will facilitate necessary technological advancements for building quantum processors, quantum internet devices and quantum satellite systems in a fully integrated, stable, scalable and field-deployable format, meeting industry requirements. OPN



Left: Photograph of laser-integrated turnkey quantum light source, of a size comparable to a one-euro coin. Right: Hybrid source consists of an indium phosphide gain medium extended by a silicon nitride feedback circuit. Rings (R1, R2 and R3) form a Vernier filter, connected to a Mach-Zehnder interferometer (MZI). The circuit forms a lasing cavity made of RSOA and Sagnac mirror. R3 generates a quantum frequency comb (QFC) with a free-spectral range of ~200 GHz through SFWM.

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