NQSTI
National Quantum Science and Technology Institute

Development of Integrated Quantum Single-Photon Sources

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Abstract: We report integrated photon-pair sources based on Spontaneous Four-Wave Mixing in silicon nitride photonic circuits (750–850 nm), developed within project HYPERION (NQSTI, Spoke 8) toward fully room-temperature photonic quantum processors.

Rotonium is a deep tech quantum computing startup developing integrated photonic quantum processors designed to full room temperature operations. The architecture encodes quantum information onto multiple degrees of freedom of the single photon, especially Orbital Angular Momentum (OAM), enabling higher-dimensional qudit encoding on a single photonic integrated circuit (PIC). By jointly manipulating these degrees of freedom, deterministic multi-qubit gate operations such as CNOT and controlled-Z are realized without requiring nonlinear photon-photon interactions, overcoming a fundamental limitation of conventional linear optical quantum computing [1]. Detection relies on CMOS-compatible Single-Photon Avalanche Diodes (SPADs) operating in the visible spectrum, removing the need for cryogenic single-photon detectors. The result is a fully room-temperature quantum computing platform targeting deployment in Space, Weight, Power and Cost (SWaP-C) constrained environments for industrial applications.

To be ready for quantum applications, all the core subsystems, photon source, quantum gate layer, and detectors, that compose a quantum photonic processor must be integrated in a chiplet approach. On-chip generation of correlated photon pairs is therefore a prerequisite for the transition from current laboratory-scale rack prototypes to compact quantum processors. Currently, no European manufacturer provides integrated single-photon sources designed for visible-wavelength, room-temperature quantum photonics, a technological gap that this work directly addresses.

Within the HYPERION project, funded under the National Quantum Science and Technology Institute (NQSTI, Spoke 8) and carried out in collaboration with the Nanoscience Laboratory of University of Trento, we are developing integrated photon-pair sources based on Spontaneous Four-Wave Mixing (SFWM) in silicon nitride (SiN) photonic circuits [2,3], targeting the 750-850 nm wavelength range. Silicon nitride is chosen for its broad transparency across the visible and near-infrared, negligible two-photon absorption, and full compatibility with CMOS foundry processes. The design strategy explores both resonant and non-resonant source architectures: microring resonators in various coupling configurations provide narrow-bandwidth, high-brightness pair generation, while waveguide geometries offer broadband operation and simpler spectral engineering. Both approaches are complemented by integrated on-chip filtering stages designed to achieve pump rejection ratios exceeding 100 dB with minimal insertion loss.

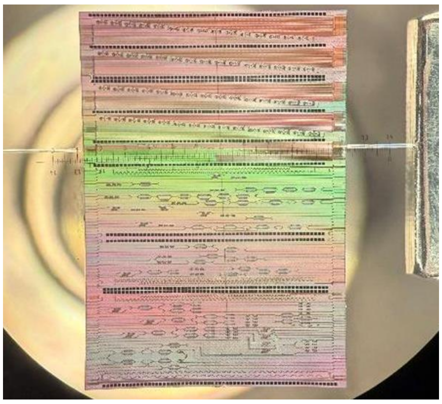

Fig. 1 Picture of a photonic integrated circuit viewed through a microscope lens during testing.

Multiple circuit variants have been designed and fabricated on a commercial SiN platform, yielding a comprehensive library of building blocks currently undergoing nonlinear and quantum-optical validation. These integrated sources represent key building blocks in Rotonium's roadmap toward a fully room-temperature photonic quantum processor deployable beyond the laboratory.

References

[1] T. C. Ralph, N. K. Langford, T. B. Bell, e A. G. White, «Linear optical controlled-NOT gate in the coincidence basis», *Phys Rev A*, vol. 65, fasc. 6, p. 062324, jun. 2002, doi: 10.1103/PhysRevA.65.062324.

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[3] L. G. Helt, M. Liscidini, e J. E. Sipe, «How does it scale? Comparing quantum and classical nonlinear optical processes in integrated devices», *J Opt Soc Am B*, vol. 29, fasc. 8, pp. 2199–2212, aug. 2012, doi: 10.1364/JOSAB.29.002199.