Configurable heralded two-photon Fock-states on a chip

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Abstract: We report a monolithic integrated quantum photonic realization on lithium niobate, which enables producing various path-coded heralded two-photon states, showing 94% raw visibility for Hong-Ou-Mandel interference.

Integrated photonics stands as an enabling tool for realizing complex and scalable quantum circuits [1] otherwise unfeasible using bulk approaches. The integration of several identical high-performance photon sources [2] as well as the entangling circuitry for general purpose quantum processing is one the key challenges. Lithium niobate waveguides are known for their superior optical performance, such as low optical transmission losses, large second-order nonlinear coefficients (optics-optics as well as electro-optics) making it a serious contender for the fabrication of top-notch integrated photonics devices for both classical and quantum information applications [3]. Here, we demonstrate the generation of configurable heralded path-coded two-photon states in the telecom C-band. Switching from a two-photon separate state $|1, 1\rangle$ to a N00N state $\sqrt{2}(|2, 0\rangle + |0, 2\rangle)$ is demonstrated through electro-optic phase shift.

Fig. 1. Schematic of the device with its associated pump, filtering and detection environment. HWP: half-wave plate; QWP: quater-wave plate; PBS: polarizing beam splitter; M: mirror; L: lens; C1/C2/C3: evanescently coupled waveguides; V: voltage; H1/H2: heralding modes; S1/S2: heralded modes; FBG: Fibre Bragg Grating filters; SNSPDs: superconducting nanowire single photon detectors; TDC: time-to-digital converter.

Our device consists in a 4 cm-long monolithic lithium niobate chip fabricated by soft-proton exchange [4]. As depicted in Figure 1, the operation principle relies on two integrated heralded single photon sources (HSPS) firing simultaneously, whose single photon outputs are routed toward a tunable coupler for entanglement manipulation by means of two-photon interference. In region I, two periodically poled waveguides (PPLN/w) ensure the generation of non-degenerated photon pairs at the telecom wavelengths of 1310 nm (signal) and 1560 nm (idler) in each waveguide. In region II, two evanescently coupled waveguides (C1 and C2) realize the wavelength demultiplexing of the photons for each pair toward four distinct spatial modes. In region III, signal photons are routed to the outer modes, $H_1$ and $H_2$, towards the heralding detectors. Their associated idler photons are routed to the inner modes, $S_1$ and $S_2$, towards the tunable coupler C3 whose splitting ratio can be tuned by means of electro-optical effect for quantum state engineering via controlled two-photon interference. The four channels show a similar loss of $\sim 10$ dB which mainly consists in on-chip propagation losses $\sim 3$ dB, chip-to-fiber coupling losses $\sim 3$ dB, and additional filtering stage losses $\sim 4$ dB. The specific coupling ratio of coupler C3 of 50:50 and 100:0 operations are obtained for an applied voltage of 34 V and 18 V respectively.
Our device is operated using picosecond laser pulses at 712 nm, at a repetition rate of $R = 76.5$ MHz. The time synchronization of pump pulses entering the chip is ensured, for demonstration purpose only, by a translating delay stage with femtosecond resolution. In Figure 2, we show the experimental 4-fold coincidence count rate histograms as a function of the pulse offset in time for 2 extreme cases: N00N and product states, respectively. The blue colored bars at $t = 0$ correspond to heralded pairs of simultaneous photons whose state can be engineered from product state to path-entangled N00N state. All the subsequent red bars correspond to heralded pairs whose photons are delayed by $N$ times the laser pulse interval.

In this configuration, an interesting metric corresponds to the heralding rate which translates into the number of times the source has emitted a two-photon state usable for any other application such as communication or computation. Experimentally, we obtained an heralding rate of $\sim 200 \text{s}^{-1}$ leading to $\sim 60$ detections per 2h of separated states.

Our results highlight the potential of monolithic integration of photon-pair sources and interferometric functions for practical quantum technology applications. Such low energy cost, flexible photon sources, fast and convenient phase modulators, and reconfigurable waveguide circuits find application in discrete and continuous variable quantum optics [5] but also in hybrid quantum optics [6].

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