Tunable Entangled Photon States from a Nonlinear Directional Coupler

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Integrated optical platforms enable the realization of complex quantum photonic circuits for a variety of applications including quantum simulations, computations, and communications. The development of on-chip integrated photon sources, providing photon quantum states with on-demand tunability, is currently an important research area. A flexible approach for on-chip generation of entangled photons is based on spontaneous nonlinear frequency conversion, with possibilities to integrate several photon-pair sources [1] and realize subsequent post processing using thermo-optically or electro-optically controlled interference [2, 3]. However, deterministic post-processing can only provide a limited set of output states, whereas quantum gates with probabilistic operation are needed to generate arbitrary two-photon states [4].

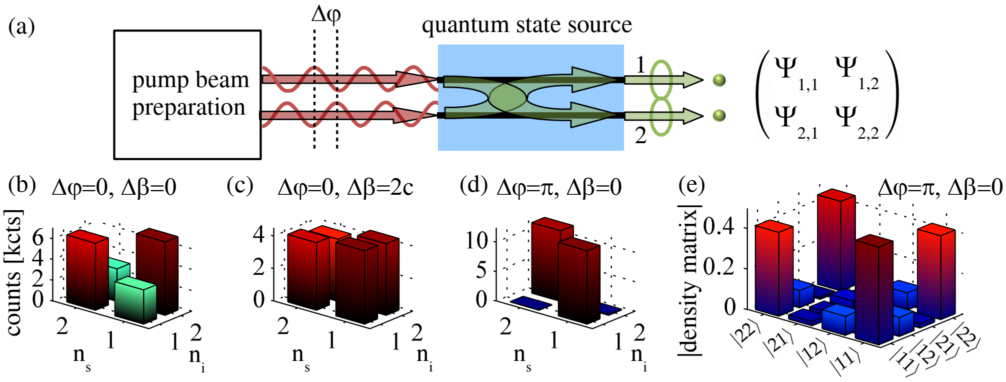

Figure 1: (a) The scheme of an entangled biphoton source based on a nonlinear directional coupler. A classical pump beam is manipulated to generate different biphoton quantum states. (b-d) Experimentally measured output biphoton spatial correlations, given in kilo-counts per 5 minutes integration time, under different conditions demonstrating: (b) dominant spatial anti-bunching, (c) even distribution of photon pairs, and (d) a N00N state. (e) Measured absolute value of density matrix ρ for the N00N state.

In this work, we propose and experimentally demonstrate an integrated photon-pair source enabling wide-range optical tunability of the output entangled state, without a need for quantum gates and fundamentally exceeding the range of on-chip generated biphoton quantum states accessible in previous studies. We achieve this by combining the processes of spontaneous parametric down-conversion (SPDC) and interference of the generated photons in a quadratic nonlinear waveguide coupler in lithium niobate, see Fig. 1(a). Two coherent pump beams of 671 nm wavelength with a phase difference of $\Delta\varphi$ excite this directional coupler, generating biphotons through SPDC. Importantly, the generated photons simultaneously couple between the waveguides with the coupling strength c, leading to nontrivial quantum interference and entangled output states [5]. We achieve the output state tunability by using two control parameters: the pump phase difference $\Delta\varphi$ and the SPDC phase mismatch $\Delta\beta$. We have characterized the generated biphoton states by spatial correlation measurements and quantum tomography, and observed a good agreement with our theoretical predictions. In Fig. 1(b-d) we present correlation measurements for several generated states. Quantum tomography of the generated N00N state demonstrated in Fig. 1(e) shows the high fidelity of our source.

In summary, we demonstrated a tunable integrated biphoton source, where a wide-range tunability is achieved by controlling the classical pump beam. The quantum states of the generated biphotons can be all-optically tailored towards specific applications without post-processing.

References

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