Generating Spatially Entangled Qubits using Quantum Nonlinear Holography

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Abstract: We experimentally shape the quantum correlations of spatially entangled photon pairs in a two-dimensionally patterned $KTiOPO_4$ crystal using nonlinear holography. Our method enables multi-dimensional engineering of quantum states directly using patterned nonlinear photonic crystals, introducing the field of quantum nonlinear holography.

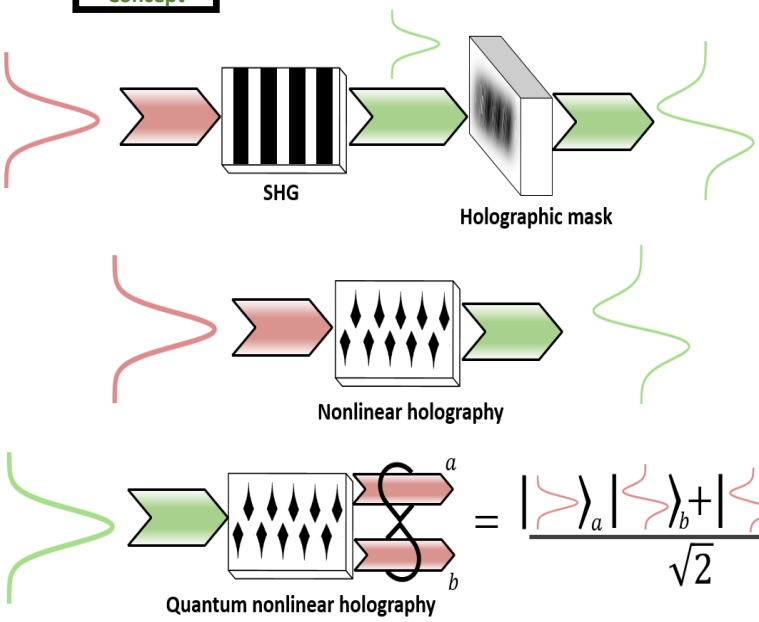
Concept

Conceptual Illustration of quantum nonlinear holography.

a) In holography, a pump with frequency ω_p enters a nonlinear crystal and converts to a second harmonic. The second harmonic is then shaped using coded holographic mask.

b) In classical nonlinear holography. The second harmonic is shaped entirely inside the nonlinear crystal by the modulated nonlinearity [1,2].

c) In quantum nonlinear holography, The quantum correlations between different spatial transverse modes of down converted photons is engineered using the modulated nonlinearity, leaving the pump frequency intact.



Fabrication and experimental set up

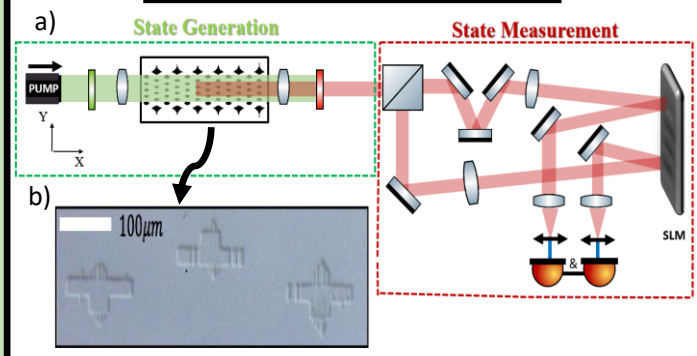
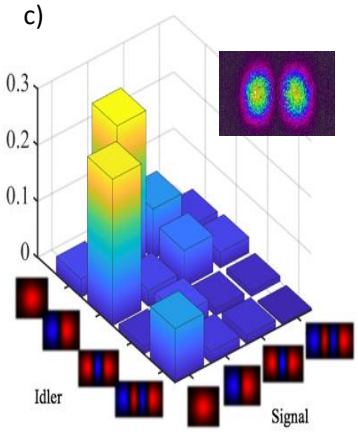


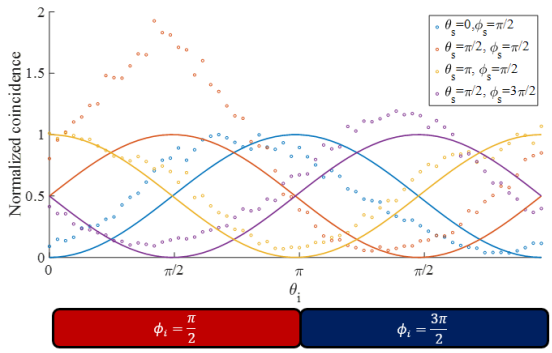
Fig.2 – We designed and fabricated an HG_{10} shaped NPC (Fig. 2b) using electric field poling. Coincidence measurements were taken using the set-up depicted in (Fig 2.a). The highest coincidence counts are obtained for only two cases, when one of the two beams is an HG_{01} beam and the other one is an HG_{00} beam, as expected from the Bell state design (Fig 2.c). Inset shows SH.

Normalized state coefficients

c)



Results



To further characterize the generated quantum state, we performed a Bell-type inequality experiment. By projecting the generated state on different points on the Bloch sphere, characterized by $|\psi_{i,s}\rangle = cos\,(\theta_{i,s}/2)|HG_{00}\rangle + e^{i\phi_{i,s}} sin(\theta_{i,s}/2)|HG_{10}\rangle$, We calculated the Clause-Horne-Shimony-Holt (CHSH) S parameter, and violated the CHSH inequality with $S = 2.38 \pm 0.18$ [3].

Conclusions and future work

- The state generation is compact, requiring only the laser and the nonlinear crystal - crucial for on-chip applications
- The crystal shape is not bound to the paraxial Helmholtz equation. any desired pattern can be engineered including structures with modulation pattern that varies along the propagation axis.

References

[1] Y. Zhang, et. al, Optica 8, 372 (2021).

[2] Lee, Wai-Hon - Binary computer-generated holograms, Applied Optics Volume 18 issue 21 1979.

[3] B. Jack, et. al., Phys. Rev. A - At. Mol. Opt. Phys. 81, 1–5 (2010).