Deterministic generation of a large-scale photonic GHZ state

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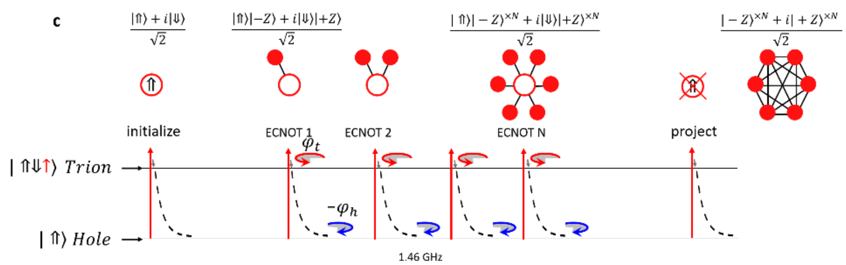
One of the emerging approaches towards building a general-purpose photonic quantum information and communication processors are fusion-based generation of multi-entangled photon quantum states [1]. In the heart of this approach is a ballistic construction of large cluster states in a scalable manner, by fusing many small N-photon entangled resource states [1,2]. The multi-photon cluster state can then be used for measurement-based quantum calculation and communication [3]. A key element and an essential resource for this approach is a photonic source of at least three-photon Greenberger-Horne-Zeilinger (3-GHZ) state [1,2].

Here, we generate deterministically a large-scale GHZ-state, capable of emitting strings of 13 polarization entangled and indistinguishable photons in a GHZ state [4], rather than in a cluster state [5-7].

To achieve this goal, we use periodic laser excitation of a semiconductor quantum-dot-confined heavy hole spin, precessing in a magnetic field in Voigt configuration. The exciting resonantly-tuned π-pulse, deterministically generates a positive trion, in which there are two paired heavy-holes forming a spin-singlet in their respective ground energy level and an unpaired electron. During the radiative lifetime of the trion, its electron also precesses in the magnetic field. However, since the electron g-factor is about three times larger in magnitude than that of the hole and it has opposite sign, the electron precesses about 3 times faster than the hole in opposite direction.



Schematics of the multiphoton GHZ state deterministic generation, showing spin initialization, N- entangled photons generation, and spin projection. The resulting state in each stage is marked above. A train of laser pulses (red arrows) excite the hole to the trion which radiatively decays to the hole by emitting a single photon entangled to the spin. The entangling cycle (ECNOT gate) is repeated N times resulting in an N-photon GHZ state. The oppositely precessing spins are marked by red and blue arrows. The excitation rate is set so that the acquired phase in each cycle is canceled out.

The rectilinear polarization of the laser pulse translates the coherent superposition of the heavy hole spin eigenstates before the pulse, to that of the trion's electron spin after the pulse. Under these conditions, the system performs a natural spin echo in which the phase accumulated by the precessing electron during the recombination, can be cancelled out by the precession of the hole. This is done by timing the hole precession using the next exciting pulse. Thus, by optimizing the magnetic field (about 0.05 Tesla) and using excitation repetition rate of 1.45 GHz, we were able to demonstrate deterministic generation of an N-photon GHZ state in which the robustness of the entanglement is characterized by an exponential decay length of 13 photons.

We foresee that this method to produce high-rate long photonic GHZ-states will significantly reduce the overhead requirements for measurement-based quantum computation and communication.

References

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