A three folded faster quantum knitting machine for deterministic generation of cluster states of many entangled photons.

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Cluster states of photons are important resources for implementations of quantum computation and communication [1]. In a theoretical proposal Lindner and Rudolph suggested to use a confined electronic spin in a semiconductor quantum dot as a "needle" in a quantum knitting, repetitive process, which entangles sequentially emitted photons, thereby producing the fabric of cluster entangled photons [2].

Recently we have taken a major step toward implementations of photonic cluster states using the quantum dot confined dark exciton as the matter spin qubit ("needle") which entangles the polarizations of the emitted photons in a deterministic way [3]. The dark exciton is an electron-hole pair that exhibits a very long lifetime and coherent time. By optically exciting the dark exciton periodically, using timed laser pulses we deterministically generate each period a photon and, notably, also entangle its polarization state with the polarization state of the photons that have already been emitted previously.

In Ref 3 each period was timed to ¾ of the dark exciton precession time of about 3 nsec. Here we report on a 3 folded faster repetition rate by timing the excitation to only ¼ of the dark exciton precession rate. Our new demonstration was made possible by an improvement that we introduced to our measurement setup. We replaced the avalanche silicon photodetectors (APDs) by superconducting photodetectors (SSPDs). While the APDs have temporal resolution of about 400 ps, limited by the detectors' rise time, the SSPDs have temporal resolution of about 70 ps, currently limited by their electronics.

The higher repetition rate is an important improvement because it demonstrates considerably higher entangled photon production rate. In addition, it results also in a more robust entanglement within the cluster state. This is because during a ¼ of the precession the dark exciton loses coherence less than it does during ¾ of a precession.

The robustness of the cluster state entanglement is characterized by its localizable entanglement characteristic decay length. While in Ref 3 the decay length was ~3 photons, here, the length exceeds 5 photons. The increase in the degree of entanglement between sequential photons is increased as well. While in Ref. 3 the negativity in the two photons density matrix amounted to 0.20, here it exceeded 0.3.

[1] H. J. Briegel Science 354 (6311), 416-417 (2016)
[2] N. H. Lindner, T. Rudolph, Phys. Rev. Lett. 103, 113602, (2009)
[3] I. Schwartz, et al, Science 354(6311): 434-437 (2016)