On-demand semiconductor source of entangled photons which simultaneously has high fidelity, efficiency and indistinguishability

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Abstract

By coherent two-photon excitation of a single InGaAs quantum dot coupled to a circular Bragg grating bullseye cavity with broadband high Purcell factor up to 11.3, we generate entangled photon pairs with a state fidelity of 0.90(1), pair generation rate of 0.59(1), pair extraction efficiency of 0.62(1), and photon indistinguishability up to 0.93(1) simultaneously. Our work will open up many applications in high-efficiency multi-photon experiments and solid-state quantum repeaters.

An outstanding goal in quantum optics and scalable photonic quantum technology is to develop a source that each time emits one and only one entangled photon pair with simultaneously high entanglement fidelity, extraction efficiency, and photon indistinguishability. The past decades have witnessed great success of spontaneous parametric down-conversion (SPDC) photons, for example, allowing for demonstrating 12-photon entanglement and scattershot boson sampling [1]. However, an intrinsic problem for the SPDC is that the photon pairs are generated probabilistically, and inevitably accompanied with undesirable multi-pair emissions.

An alternative route to generate entangled photons is through radiative cascades in single quantum emitters such as quantum dots which can have a near-unity quantum efficiency, therefore inherently solving the problem in SPDC. Here, we report a on-demand entangled-photon source which simultaneously has high fidelity, efficiency and indistinguishability.

Our scheme to generate entangled photons is via XX-X cascade radiative decay in an neutral InGaAs quantum dot. The polarization of emitted photons is determined by the spin of the intermediate exciton states. To enhance the intensity of the entangled photon pairs, we embedded the quantum dot into a broadband circular Bragg grating cavity, which features a small effective mode volume and a relatively low Q factor ($\sim$150). By pulsed two-photon resonant excitation, we have realized a deterministic entangled photon pair source with simultaneously an entanglement fidelity of 90%, pair generation rate of 59%, pair extraction efficiency of 62%, and photon indistinguishability of 90% (93%) without (with) temporal filtering. Our work can be extended to the realization of entanglement swapping [2] between remote entangled photons from quantum dots embedded in CBG bullseye cavities, a step toward solid-state quantum repeaters [3].

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