Versatile and Optically Controlled Spin-Multiphoton Entanglement with a Quantum Dot-Cavity Device

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Measurement-based quantum computing offers a promising route towards scalable, universal photonic quantum computation and quantum technologies. [1] This approach relies upon the controlled generation of photonic graph states, where many photons are mutually entangled. A single electron confined in a semiconductor InGaAs quantum dot (QD) embedded in a micropillar cavity (Fig.1a) has been proposed [2] and proven [3] to be a useful platform for the generation of linear photonic cluster states. This method exploits the spin-photon entanglement enabled by the optical selection rules that connect the spin state of an electron in the ground state to the polarization of the emitted photon. However, spin coherence time poses limits to the number of photons in the cluster state. In this work, we implement spin-echo [4] sequences to mitigate the spin decoherence and increase the number of entangled particles. We also propose and demonstrate an optical protocol allowing to generate various entangled states comprising a single spin and three photons.

Four optical pulses are used to generate single photons. The first photon is measured to initialize the sequence with either spin up or down states. The following pulses are then synchronized with the spin precession induced by a static magnetic field. Additionally, we use fast (4 ps) red-detuned laser pulses (SRPs) to induce optical spin rotation and produce various spin-photon entangled states, such as cluster and Greenberg-Horne-Zeilinger (GHZ) states. The SRPs both limit spin decoherence between consecutive photon emissions and, by rotating the spin around the optical axis, prevent the need for additional precession, and therefore further decoherence, to create the desired state. We experimentally implement multiple sequences of excitation (Fig.1b-c) each resulting in a specific output state. Finally, we disentangle the photonic chain from the spin by measuring the last photon in the circular polarization basis and we perform quantum state tomography on the remaining photon pair in order to reconstruct their polarization state (Fig.1b-c). Doing so, we measure fidelity to the target state ranging from 0.75 ± 0.05 to 0.87± 0.03. Additionally, by only scanning the intensity of the SRPs for a given excitation sequence, we demonstrate the ability to continuously modify the output state, as depicted in Fig.1d. The versatility of our scheme for controlled spin rotation and generation of various spin-multi photon entangled states, brings up new tools for further scalable and multidimensional entangled states.

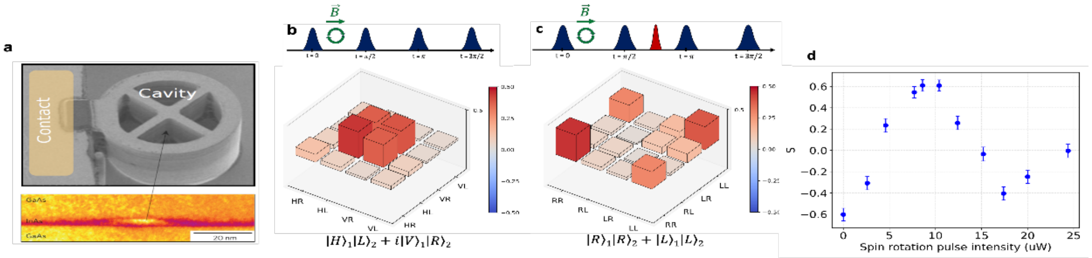

Fig. 1. a Scanning electron microscopy image of the electrically-connected micropillar and transmission electron microscopy image of a single InGaAs QD embedded in GaAs. b-c [Top] Excitation sequences used to generate different spin-photon entangled states. Blue indicates laser excitation that leads to photon emission, red represents SRP. [Bottom] Corresponding measured polarization density matrices of two successive photons when the last photon is measured in the circularly right-polarized state. Histogram bars indicate the absolute values of the density matrix elements. d Measured 4-partite stabilizer S as a function of the SRP intensity. S ranges from negative to positive values indicating modification of the spin-photon state.

References

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