Entangled absorption of a single photon with a single spin in diamond

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Quantum entanglement, a key resource for quantum information science, is inherent in a solid. It has been recently shown that entanglement between a single optical photon and a single spin qubit in a solid is generated via spontaneous emission [1]. However, entanglement generation by measurement is rather essential for quantum operations [2]. We here show that the physics behind the entangled emission can be time-reversed to demonstrate entangled absorption mediated by an inherent spin-orbit entanglement [3] in a single nitrogen vacancy center in diamond (Fig. 1) [4]. Optical arbitrary spin state preparation and complete spin state tomography revealed the fidelity of the entangled absorption to be 95% (Fig. 2). With the entangled emission and absorption of a photon, materials can be spontaneously entangled or swap their quantum state based on the quantum teleportation scheme.

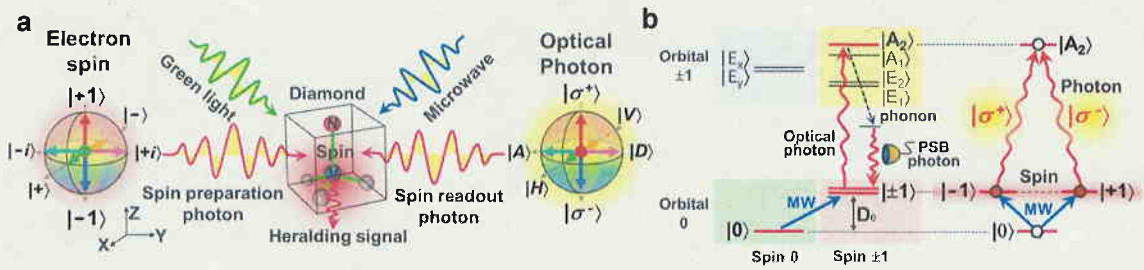

FIG. 1 (a) Scheme for entanglement measurement. Quantum correlation between optically stored electron spin and incoming readout optical photon is measured via resonant absorption, which is heralded by a phonon sideband photon detection. **(b)** Related energy levels of the NV center. Spin triplet sublevels $|\pm1\rangle$ are used as spin qubit bases.

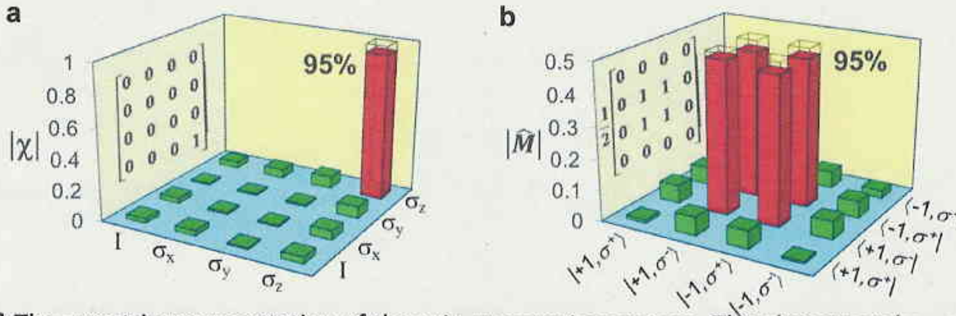

FIG. 2 (a) The χ matrix representation of the spin preparation process. The element at (σ_z, σ_z), which corresponds to the phase flip process originating from the relative phase of the dark state, is used for the estimation of the spin preparation fidelity to be 95%. **(b)** The density operator represenatation of the joint measurement between the electron spin and the photon polarization. The elements at middle 2x2 matrix, which corresponds to the spin-photon entanglement originating from the spin-orbit entanglement in the A_2 state, are used for the estimation of the entanglement detection fidelity to be 95%.

[1] E. Togan et al., *Nature* **466**, 730–734 (2010).
[2] H. Bernien et al., *Nature* **497**, 86 (2013).
[3] H. Kosaka et al., *Nature* **457**, 702–705 (2009).
[4] H. Kosaka and N. Niikura, *Phys. Rev. Lett.*, **114**, 053603 (2015).