Entanglement Between a Dark Exciton and a Single Photon

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The building block for quantum information processing is a reliable two-level system - a 'qubit.' A candidate qubit must have a long lifetime and a long coherence time, in which its quantum state is not randomized by stochastic interactions with its environment. In addition, for networking, it is required to efficiently generate entanglement between stationary matter qubits such as spins in matter and propagating qubits such as photons[1-2]. Previously [3], we demonstrated that the spin of quantum dot-(QD) confined dark excitons (DE) has great potential as a matter qubit. The DE, which is formed from an electron-heavy-hole pair with parallel spins is optically inactive. Therefore, its lifetime is very long, 3-4 orders of magnitude longer than that of the optically-active bright exciton (BE). The DE is neutral, thus, unlike charge-carriers it is protected from dephasing by electrostatic fluctuations in its vicinity. In addition, the short range electron-hole exchange interaction removes the degeneracy between its two eigenstates even in the absence of an external magnetic field. Thus, the DE spin is protected also from dephasing induced by local fluctuations in the nuclear magnetic field. This is markedly different than charge-carrier spins, which are Kramers' degenerate.

Here we report on the first observation of quantum entanglement between the DE spin and the polarization of a propagating optical photon. Our demonstration of entanglement relies on the use of polarization sensitive single-photon detection, which allows us to project the photon into a superposition of two cross circular polarization states. The detection is temporally correlated with the detection of a polarized biexciton photon which heralds the generation of the DE in a well-defined coherent superposition of its two non-degenerate eigenstates. The DE spin then coherently precesses in time [3] in a relatively slow rate of ~3 nsec per period [3], since the short range exchange interaction amounts to 1.5 μeV only [3].

The scheme that we implement can generate nearly deterministic entangled DE spin–photon pairs at a rate determined by the high spontaneous recombination rate of the allowed transition from the biexciton state to the DE. The method provides a direct way for measuring the DE dephasing rate. Using pulsed, rather than cw excitation (Fig. 1), we straightforwardly obtained a lower limit of ~100nsec, for the coherence time of the DE.

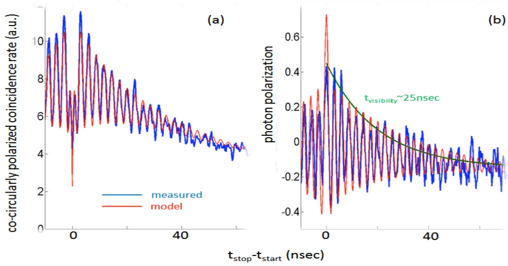

Fig. 1 a) Measured (blue) and calculated time resolved co circularly polarized autocorrelations of the biexciton spectral line which heralds the dark exciton, under resonant co-circularly polarized cw biexciton excitation. (b) Polarization degree of the emitted photon as a function of time after the DE is heralded. The polarization periodicity of ~3 nsec, demonstrates the entanglement between the emitted biexciton photon and the precessing spin of the DE in the QD. The polarization degree was obtained by subtracting from the measured signal in a) a similar measurement but for cross-circularly polarized photons. The degree of polarization is defined as $P=(I_{co}-I_{cross}) / (I_{co}+I_{cross})$ where I_{co} (I_{cross}) is the coincidence rate for co (cross) circularly polarized photons.

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[3] E.Poem, et al., Nature Physics **6**, 993-997, (2010