Fast Polarization Manipulation

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Research Proposal

Under the supervision of

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Contents

1 The Proposal

1.1 Problem Definition and Solution Approach.

The presence of the splitting in the excitonic state is an unwanted effect in QDs that causes a degradation in the degree of entanglement between the two photons in the biexciton-exciton radiative cascade [1]. This is mainly due to the asymmetry of the QD which lifts the degeneracy of the levels. Several methods where investigated to control such as inducing strain and magnetic and electrics fields, but the problem continue to presist. A more straightforward approach is to ignore the causes for the splitting and assume that

1.2 Theoretical formulation (exciton).

$$|\Psi(t)\rangle = \alpha(|H_{XX} \otimes H_X\rangle \cdot e^{\frac{-iE_H t}{\hbar}} + |V_{XX} \otimes V_X\rangle \cdot e^{\frac{-iE_V t}{\hbar}}) \tag{1}$$

1.3 Theoretical formulation (biexciton-exciton)

$$|\Psi(t)\rangle = \alpha(|H_{XX} \otimes H_X\rangle \cdot e^{\frac{-iE_H t}{\hbar}} + |V_{XX} \otimes V_X\rangle \cdot e^{\frac{-iE_V t}{\hbar}}) \tag{2}$$

$$|\Psi(t)\rangle = \alpha(|H_{XX} \otimes H_X\rangle + |V_{XX} \otimes V_X\rangle \cdot e^{\frac{-i(\triangle E t)}{\hbar}}) \tag{3}$$

1.4 Rotation of the exciton's polarization.

1.5 Restoring the entanglement of the photons in the biexciton-exciton radiative cascade.

If we construct two interferometers that allow us to induce phase shift to both the biexciton and exciton polarizations, then we can write the time-dependent phase relations as:

$$\begin{aligned}
\Phi_{H_{XX}}(t,t_{prop}) &= k_{H_{XX}}\cdot(t-t_{prop})+\Phi^0_{H_{XX}}\\
\Phi_{V_{XX}}(t,t_{prop}) &= k_{V_{XX}}\cdot(t-t_{prop})+\Phi^0_{V_{XX}}\\
\Phi_{H_{X}}(t,t_{prop}) &= k_{H_{X}}\cdot(t-t_{prop})+\Phi^0_{H_{X}}\\
\Phi_{V_{X}}(t,t_{prop}) &= k_{V_{X}}\cdot(t-t_{prop})+\Phi^0_{V_{X}}
\end{aligned} \tag{4}$$

Here the K's are the different slopes that introduce the shift to the photons' polarizations, and Φ^0's are the initial phase of the photons at the time of emission. t_{prop} is the propagation times of the photons from the quantum dot to the device. Since it's constant time we can simplify the function by including it in the constant phase Φ^0. By taking the starting time of our system as the biexciton excitation time, we can write the state using the t_x and t_{xx} (where t_{xx} and t_x are the random emission times of the biexciton and exciton respectively), as follows:

$$\begin{aligned}
|\Psi(t)\rangle = \alpha(|H_{XX}\rangle\cdot e^{i*\Phi_{H_{XX}}(t_{XX}-t^{xx}_{start})}\otimes|H_X\rangle\cdot e^{i\Phi_{H_X}(t_X-t^{x}_{start})}+\\
|V_{XX}\rangle\cdot e^{i\Phi_{V_{XX}}(t_{XX}-t^{xx}_{start})}\otimes|V_X\rangle\cdot e^{i\Phi_{V_X}(t_X-t^{x}_{start})}\cdot e^{-i(\triangle Et)/\hbar})
\end{aligned} \tag{5}$$

next, plug it in

$$\Psi(t) = |H_{xx}H_x\rangle + e^{i\Phi}\,|V_{xx}V_x\rangle \tag{6}$$

where $\Phi(t)$:

$$\begin{aligned}
\Phi(t) = (K_{V_{XX}}-K_{H_{XX}}+K_{V_X}-K_{H_X})\cdot t_{xx}+(K_{V_X}-K_{H_X}+\triangle E/\hbar)*t_x+\\
(K_{V_{XX}}-K_{H_{XX}})\cdot -t^{XX}_{Start}+(K_{V_X}-K_{H_X})\cdot -t^{X}_{Start}+\\
(\Phi^0_{V_{XX}}-\Phi^0_{H_{XX}}+\Phi^0_{V_X}-\Phi^0_{H_X}).
\end{aligned} \tag{7}$$

Conditions:

$$K_{V_X} - K_{H_X} = -\triangle E/\overline{h} \tag{8}$$

$$(K_{V_{XX}} - K_{H_{XX}}) = -(K_{V_X} - K_{H_X}) \tag{9}$$

1.6 Additional proposed advances

1.6.1 Combining the radiative cascade into the knitting machine.

1.6.2 Using the experimental system for feed-forward operations in 1D cluster states.

References

[1] R. Winik et al. "On-demand source of maximally entangled photon pairs using the biexciton-exciton radiative cascade". In: *Phys. Rev. B* 95 (23 June 2017).

[2] A. Fognini et al. "Universal fine-structure eraser for quantum dots". In: *Opt. Express* 26.19 (Sept. 2018), pp. 24487–24496.

[3] Simone Varo, Gediminas Juska, and Emanuele Pelucchi. "An intuitive protocol for polarization-entanglement restoral of quantum dot photon sources with non-vanishing fine-structure splitting". In: *Scientific Reports 2022 12:1* 12 (Mar. 2022), pp. 1–8.

[4] Marc A. Kastner. "Artificial Atoms". In: *Physics Today* 46.1 (Jan. 1993), pp. 24–31. DOI: 10.1063/1.881393.

[5] E. Dekel et al. "Carrier-carrier correlations in an optically excited single semiconductor quantum dot". In: *Phys. Rev. B* 61 (16 Apr. 2000), pp. 11009–11020. DOI: 10.1103/PhysRevB.61.11009.

[6] P. Michler, A Imamoğlu, and M. Mason. "Quantum correlation among photons from a single quantum dot at room temperature". In: *Nature* (2000), pp. 968–970.

[7] P. Michler et al. "A Quantum Dot Single-Photon Turnstile Device". In: *Science* 290.5500 (2000), pp. 2282–2285. DOI: 10.1126/science.290.5500.2282.

[8] Zhiliang Yuan et al. "Electrically Driven Single-Photon Source". In: *Science* 295.5552 (2002), pp. 102–105. DOI: 10.1126/science.1066790.

[9] N Akopian et al. In: *Physical Review Letters* 96 (Apr. 2006). DOI: 10.1103/PhysRevLett.96.130501.

[10] R Hafenbrak et al. "Triggered polarization-entangled photon pairs from a single quantum dot up to 30 K". In: *New Journal of Physics* 9.9 (Sept. 2007), p. 315. DOI: 10.1088/1367-2630/9/9/315.

[11] "Downconversion quantum interface for a single quantum dot spin and 1550-nm single-photon channel". In: *Optics Express, Vol. 20, Issue 25, pp. 27510-27519* 20 (25 Dec. 2012), pp. 27510–27519. ISSN: 1094-4087. DOI: 10.1364/OE.20.027510.

[12] J. R. Schaibley et al. "Demonstration of Quantum Entanglement between a Single Electron Spin Confined to an InAs Quantum Dot and a Photon". In: *Phys. Rev. Lett.* 110 (16 Apr. 2013), p. 167401. DOI: 10.1103/PhysRevLett.110.167401.

[13] W. B. Gao et al. "Observation of entanglement between a quantum dot spin and a single photon". In: *Nature 2012 491:7424* 491 (7424 Nov. 2012), pp. 426–430. ISSN: 1476-4687. DOI: 10.1038/nature11573.

[14] Daniel Loss and David P. DiVincenzo. "Quantum computation with quantum dots". In: *Phys. Rev. A* 57 (1 Jan. 1998), pp. 120–126. DOI: 10.1103/PhysRevA.57.120.

[15] L. M. Duan et al. "Long-distance quantum communication with atomic ensembles and linear optics". In: *Nature 2001 414:6862* 414 (6862 Nov. 2001), pp. 413–418. DOI: 10.1038/35106500.

[16] J. McFarlane et al. “Gigahertz bandwidth electrical control over a dark exciton-based memory bit in a single quantum dot”. In: *Applied Physics Letters* 94.9 (2009), p. 093113. DOI: 10.1063/1.3086461.

[17] I. Schwartz et al. “Deterministic Writing and Control of the Dark Exciton Spin Using Single Short Optical Pulses”. In: *Physical Review X* (Jan. 2015). DOI: 10.1103/physrevx.5.011009.

[18] Marek Korkusinski and Pawel Hawrylak. “Atomistic theory of emission from dark excitons in self-assembled quantum dots”. In: *Phys. Rev. B* (Mar. 2013). DOI: 10.1103/PhysRevB.87.115310.

[19] M. Zieliński. *Valence band offset, strain and shape effects on confined states in self-assembled InAs/InP and InAs/GaAs quantum dots*. 2013. DOI: 10.48550/ARXIV.1303.4417.

Appendices

Appendix I

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Appendix 2

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