Indistinguishable photons from the quantum dot biexciton cascade through lifetime engineering with a tunable microcavity

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A crucial property of photons for quantum technologies is indistinguishability, which enables quantum interference by the Hong-Ou-Mandel (HOM) effect. Similarly, entanglement between photons gives rise to a wide range of non-classical effects. Both these properties are important resources for e.g. quantum sensing with light [1], quantum communication [2], and all-optical linear quantum computing [3]. The biexciton (XX) – exciton (X^0) – ground-state (GS) cascade in self-assembled semiconductor quantum dots (QDs) produces polarization-entangled photon pairs on eliminating the fine-structure splitting [4] (Figure 1a). However, the cascaded emission of this ladder system leads to timing jitter in photon emission, which translates to a reduced indistinguishability of photons from both transitions [5]. This problem can be solved in principle by creating an imbalance in the lifetimes of the two transitions So far, this theory has been experimentally tested using small intrinsic dot-to-dot variations in lifetime ratio [5]. Here, we engineer highly imbalanced lifetime ratios in-situ, using selective Purcell enhancement from a tunable microcavity.

Our Fabry-Perot open-microcavity [6] (Figure 1b) allows us to selectively enhance either the XX – X^0 transition or the X^0 – GS transition, modifying the lifetime ratio in one or the other direction. Enhancing the XX – X^0 transition leads to a strong increase in indistinguishability for both photons in the cascade (Figure 1c). Conversely, enhancing the X^0 – GS transition decreases the indistinguishability drastically. These results demonstrate that photons from the biexciton-cascade can be prepared with both excellent entanglement and purity, a requirement for many applications in quantum technologies.

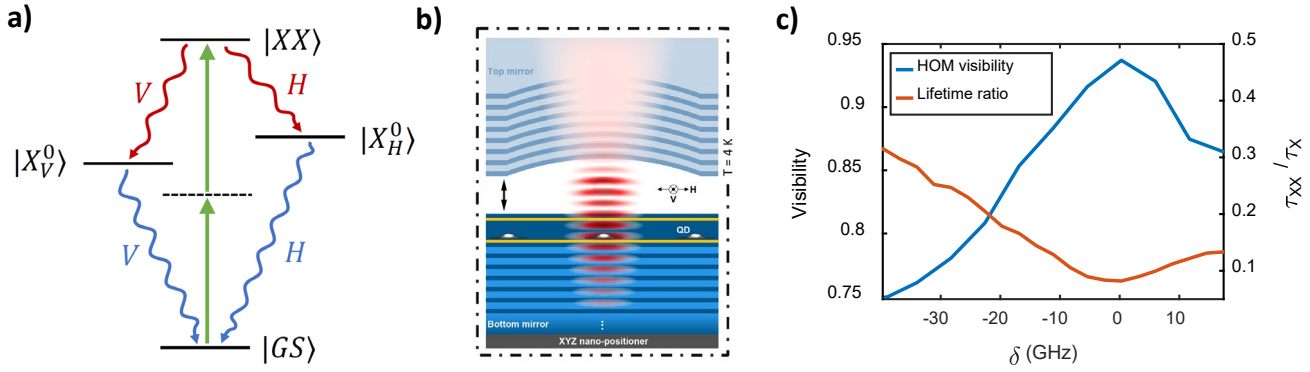

Figure 1 **a**: Energy levels of the biexciton ladder. The two exciton energies are split by the fine-structure splitting of about 2.6 GHz. The two emission pathways have orthogonal, linear polarizations (H and V). In the experiments, the biexciton was excited with a 2-photon process (green). **b**: Tunable open microcavity allows for the selective Purcell-enhancement of one of the two transitions of the biexciton cascade. **c**: Cavity detuning δ from XX – X^0 transition vs. photon indistinguishability and lifetime ratio. Shortening the lifetime of the biexciton compared to the exciton reduces timing-jitter in the emission of the photons. This in turn increases the indistinguishability of the emitted photons, quantified by the HOM visibility. Values of the HOM visibility are corrected for finite $g^{(2)}$. Data shown for photons from the XX – X^0 transition.

References

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