On-demand entangled photon sources for quantum networks

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Quantum networks are required to distribute entanglement over longer distances than with peer-to-peer fiber-based quantum communication and to connect remote quantum computers. Semiconductor quantum dots in photonic nanowires are one of the leading candidates for implementing quantum networks since they generate bright entangled photons on-demand with near-unity entanglement fidelity [1], are scalable with deterministically positioned quantum dots [2] and can be controllably tuned to atomic transitions via strain for implementing a quantum repeater node [3]. However, a major challenge remains to use such entangled photon sources in quantum networks – the presence of the exciton fine-structure splitting (FSS) causes the entangled state to oscillate between two Bell states making it difficult to perform entanglement swapping between remote quantum dots.

In this work, we will present two novel methods to remove the FSS. First, we present an all-optical approach to remove the FSS by implementing an emulating rotating half-waveplate with a lithium niobate electro-optic modulator (EOM) [4]. To remove the FSS in this scheme, single photons that are left circularly polarized are shifted to lower energy while single photons that are right circularly polarized are shifted to higher energy. Towards this goal, we show frequency shifting of single photons by up to 350 MHz, with an efficiency for frequency shifting of 90% and optical in/out waveguide coupling efficiency of 86% including transmission loss through the waveguide of the EOM. In the second approach, we demonstrate the use of a novel quadrupole electric field applied to the quantum dot to remove the FSS without sacrificing brightness [5]. Experimental results from the gated nanowire quantum dot shown in Figure 1 is used to controllably tune the FSS by making the exciton wavefunction symmetric.

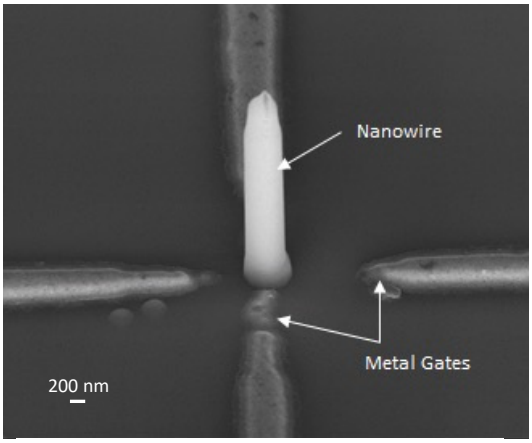

Figure 1 – SEM image of four gates positioned around a nanowire quantum dot to apply a quadrupole electric field to remove the FSS.

References

[1] M. Pennacchietti *et al.*, *Oscillating photonic Bell state from a semiconductor quantum dot for quantum key distribution*. *Commun Phys* **7**, 62 (2024).
[2] P. Laferrière *et al.*, *Unity yield of deterministically positioned quantum dot single photon sources*. *Scientific Reports* **12**, 6376 (2022).
[3] R.A. Maruf *et al.*, *Widely tunable solid-state source of single-photons matching an atomic transition*. arXiv preprint arXiv:2309.06734 (2023).
[4] A. Fognini *et al.*, *Universal fine-structure eraser for quantum dots*, *Optics Express* **26** (19), 24487-24496 (2018).
[5] M. Zeeshan *et al.*, *Quadrupole electric field for erasing the fine structure splitting in a single quantum dot*, *Phys. Rev. Lett.* **122** (22), 227401 (2019).