Engineering photon-photon interactions within rubidium-filled waveguides for high-bandwidth quantum memories

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Hollow-core photonic-crystal fibres (HC-PCF) provide efficient and strong atom-light interaction that can be utilised to produce strong multi-photon transitions for use in quantum logic gates (cross-Kerr nonlinearities) or quantum memories. We present a broad study of photon-photon interactions mediated via a two-photon transition in a rubidium vapor which is excited within hollow-core fibers of different core diameters, d, [1]. Limited light-atom interaction times lead to transit-time broadening, increasing the spectral line-width proportional to $1/d$, (Fig. 1(a)). As a result, the interaction strength increases proportional to the optical mode diameter, $1/d$, rather than that typically expected from an increasing field intensity, $1/d^2$. This allows accurate estimation of the expected photon-photon interaction strength for a given waveguide geometry, allowing waveguide designs to target specific photon-photon interaction strengths. We utilise this understanding to perform off-resonance cascaded absorption (ORCA) [2] (Fig. 1(b,c)). Preliminary results show a 10% memory efficiency, a bandwidth of hundreds of MHz to GHz, and a 30ns coherent storage time which we expect to increase to 90ns.

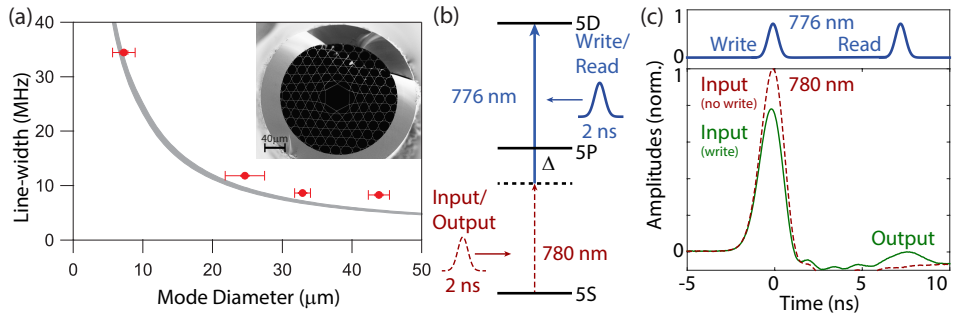

Figure 1. (a) Two-photon transition linewidth observed within hollow-core fibre (inset) of different core diameters. (b) ORCA scheme using two pulsed counter-propagating optical fields. (c) 780nm optical fields, showing transmission without the write pulse (dashed), and storage and retrieval (solid) with both write and read pulses on.

[1] C. Perrella, *et al.*, Engineering Photon-Photon Interactions within Rubidium-Filled Waveguides, Physical Review Applied, **9**, 044001 (2018).
[2] K. T. Kaczmarek, *et al.*, High-speed noise-free optical quantum memory, Physical Review A, **97**, 042316 (2018).