QLAD - A noise-free quantum memory for broadband light

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Abstract: We have developed a novel protocol for broadband, noise-free light-matter interactions using off-resonant two-photon absorption. We have then used this quantum ladder (QLAD) protocol to store and retrieve 1.5 GHz bandwidth heralded single photons.

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1. Main Text

Broadband light-matter interfaces are a key enabler technology for the manipulation [1] and storage of single photons [2]. Especially light storage, using quantum memories, is a very promising solution to the problem of large-scale photonic quantum information processing. This is because quantum memories can be used for temporal multiplexing of probabilistic operations, allowing repeat-until-success strategies to be exploited [3]. For this application in particular, the requirements for such a memory are broad acceptance bandwidth, on-demand storage and retrieval, and high end-to-end efficiency, even at the expense of memory lifetime.

There have been several attempts in the recent past to interface quantum memories with single photons, e.g. from Spontaneous Parametric Downconversion (SPDC) [2,4]. Unfortunately, most quantum memory protocols to-date have suffered from the presence of unwanted noise processes, which contaminated their output, modifying the statistics of the retrieved light [4].

Fig. 1. (a) Scheme of the QLAD protocol: blue - signal field, red - control field, purple - generated coherence (orbital wave). (b) Numerical simulation of the behaviour of the signal field in the QLAD protocol (dashed lines signify the control field). (c) Numerical simulation of the behaviour of the orbital wave in the QLAD protocol.

Here, we present a novel platform for noise-free broadband light-matter interactions using off-resonant two-photon absorption (Fig. 1). A strong driving field (control) mediates the reversible transformation of a weak signal field (potentially a single photon) into an atomic coherence (orbital wave).

This quantum ladder (QLAD) platform can in principle be used for both storage and manipulation of single photons. QLAD requires no initial preparation of the atomic ensemble and, unlike lambda-type systems, possesses no fundamental limit on the bandwidth of the interaction.

Fig. 2. Storage and retrieval of weak coherent states after 3 ns using the QLAD protocol.

We have successfully applied the QLAD protocol to quantum memories experimentally using warm Cesium vapours, demonstrating noise-free storage and retrieval of single heralded photons from a ppKTP waveguided SPDC source. We have retrieved heralded single photons of 1.5 GHz bandwidth after 4 ns of storage time with an internal efficiency of 5%, and a high end-to-end efficiency of 1%.

Furthermore, we have measured the heralded autocorrelation $g(2)$ of the memory output to be 0.39 ± 0.05 - significantly below the classical limit of 1 - and measured a cross-correlation $g(1,1)$ of 12.6 ± 0.3 , demonstrating not only the preservation of the single-photon character of the input, but also the successful storage of quantum correlations.

In summary, we have developed a novel protocol for broadband, noise-free light-matter interactions using off-resonant two-photon absorption, called QLAD. We have then used QLAD to store and retrieve 1.5 GHz bandwidth heralded single photons after 4 ns, preserving their single photon character and quantum correlations.

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