Arbitrary shaping of light pulses at the single-photon level.

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Quantum interconnects between light and matter are essential for future applications of quantum information science. For example, they are important ingredients of long-distance quantum networks, in which remote quantum nodes are connected by light pulses carrying quantum information. A technologically appealing system for the realization of such quantum interconnects is provided by an optically dense room-temperature atomic ensembles where quantum pulses of light are manipulated using electromagnetically induced transparency (EIT).

Despite the remarkable experimental progress demonstrated recently using single atoms in optical cavities as quantum nodes and node-connecting single photons [1], several requirements remain unfulfilled in order to implement a truly practical quantum network. One of them is the capability to easily restore the quality of an input signal so that degradations in signal quality do not propagate through the network [2]. For photon-linked quantum networks, in particular, it is necessary to preserve the temporal envelope of a light pulse containing a single information-carrying photon. We therefore aim to develop a practical device which allows one to control the temporal envelope of a light pulse on the fly.

Towards this goal, we have set up an EIT-based light storage experiment using a ^{87}Rb vapour cell. The classical signal field is obtained from a diode laser and attenuated to the single-photon level. The control field comes from an additional diode laser phase locked to the signal in order to ensure a two-photon resonance. We use linear orthogonal polarizations for the two lasers, and the time-dependent field intensities are controlled using acousto-optical modulators.

In order to prove that our system is able to control light pulses at the single-photon level, we have implemented a stack of filtering stages for the control-field photons. Filtering is particularly important because typically one signal photon has to be distinguished from 10^{11} control photons. In our experiment, the filtering is provided by polarization optics and two temperature-controlled silica etalons. Overall we have achieved 131 dB control-field suppression while only having 10 dB signal losses. This results in an effective control suppression of 121 dB which is almost two orders of magnitude better than results reported in recent experiments [3, 4]. Additional measures have also been taken to minimize control-field induced noise photons produced at the signal frequency.

We have then performed EIT storage experiments at the single-photon level and recorded the results over many experimental runs using a single-photon counting module. The resulting histogram of click-events contains information regarding the storage process, but also events associated to control-field induced noise photons (*storage histogram*). Additionally, we have repeated the storage sequence but only with the control field present, thereby obtaining a histogram of clicks associated exclusively to the noise photons (*noise histogram*). Subtracting both sets of experimental measurements yields the histogram of counts provided only by the storage and retrieval of the signal field (*noise-free storage histogram*). Finally, we have determined the ratio between the total number of counts in the *noise-free storage histogram* during the time-interval associated to the retrieval, and the total number of counts in the *noise histogram* during the same time-interval. This yields our *measured* signal-to-noise-ratio (an adequate measure of the performance of the device at the single-photon level) of 1.5. This is to the best of our knowledge the first time that such high *measured* signal-to-noise-ratio has been achieved in a vapour experiment.

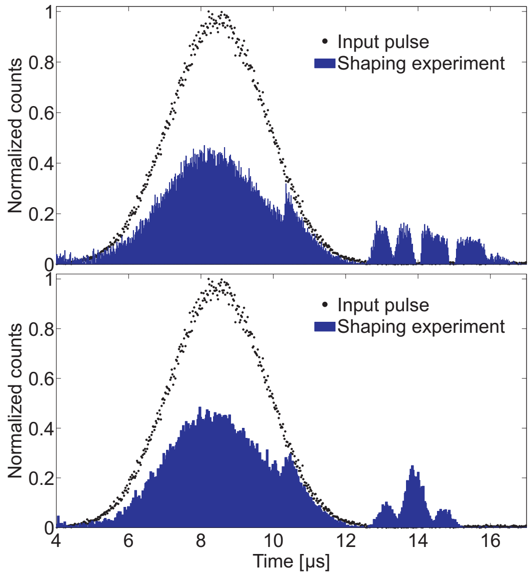

Figure 1: *Noise-free storage histograms* with arbitrarily - shaped retrieval for input pulses containing on average one single-photon (see text for details).

Moreover, we have stored single-photon level light pulses with a given temporal envelope in the medium and engineered their retrieval with an arbitrary shape (see Fig. 1). This is achieved by means of dynamically manipulating the intensity of the control field during read-out, thus coherently modulating the group velocity of the propagating light pulse. The latter experiment opens up realistic avenues for the optically controlled manipulation of the temporal wave-function of true single-photon fields.

References

[1] S. Ritter *at al.*, Nature (in press)

[2] D. A. B. Miller, Nature Photonics, **4**, 3 (2010)

[3] D. Hoeckel *et al.*, Phys. Rev. Lett., **105**, 153605 (2010).

[4] K. F. Reim *et al.*, Phys. Rev. Lett., **107**, 052603 (2011).