Multiplexed quantum correlated photons generated with a tunable delay in a solid-state ensemble

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The quantum repeater [1] is a device that would help to distribute entanglement at high distances. A possible way of implementing this device is to use the DLCZ protocol [2], in order to store entangled excitations in spatially separated media and thus distribute the entanglement. We show here the first implementation of the DLCZ protocol in a rare-earth ion doped crystal, which allowed us to store correlated pairs of photons for 1 ms. As the electric dipole of these material is very weak, the control pulses (write and read pulses) must be applied on resonnance, so that the write photons (Stokes photons) are spontaneously emitted from the excited state of the lambda system. Due to the very large inhomogeneous linewidth of the optical transition, we use a technique initially designed for quantum memories application in order to rephase the atoms after the emission of this Stokes photon: the atomic frequency comb (AFC) technique [3,4]. In this method, the inhomogeneous profile is shaped with a comb-like structure with teeth spacing Δ, so that any photon absorbed on the tailored structure creates a coherence that rephases after a time $1/\Delta$. In the DLCZ experiment, this relates to the fact that the anti-Stokes photon (read photon) is emitted at a very precise instant, when the atomic coherence is rephased. In addition, this protocol allows for the emission of the anti-Stokes photon on demand, as the optical coherence is frozen in a spin transition, like in the spin-wave storage protocol [5].

We implemented this experiment in an isotopically pure $^{151}\mathrm{Eu}^{3+}$:$\mathrm{Y}_2\mathrm{SiO}_5$ crystal, on the visible transition at 580.04 nm. The nuclear quadratic hyperfine splitting of the ground state is used to define the two ground states of the lambda system. By using an AFC time of $1/\Delta = 20\,\mu$s and a spin storage time of 1 ms, we could retrieve photons with a Cauchy-Schwarz violation of $R = 2.88 > 1$, proving the non-classical correlations between the two temporally separated photons. In addition, the photons have a temporal width of 400 ns and are detected on a temporal gate of 10 μs, which means that the temporal multimode capacity of our protocol is of more than 10 modes.

[1] N. Sangouard, C. Simon, H. de Riedmatten and N. Gisin, Rev. Mod. Phys. 83 (2011) 33

[2] L.-M. Duan, M.D. Lukin, J.I. Cirac and P. Zollze, Nature 414 (2001) 413

[3] M. Afzelius, C. Simon, H. de Riedmatten and N. Gisin, Phys. Rev. A 79 (2009) 052329

[4] P. Sekatski, N. Sangouard, N. Gisin, H. de Riedmatten and M. Afzelius, Phys. Rev. A (2011) 053840

[5] P. Jobez, C. Laplane, N. Timoney, N. Gisin, A. Ferrier, P. Goldner and M. Afzelius, Phys. Rev. Lett. 114 (2015) 230502