Single-Photon-Level Quantum Image Memory Based on Cold Atomic Ensembles

Dong-Sheng Ding*, Zhi-Yuan Zhou, Bao-Sen Shi†, and Guang-Can Guo

Key Laboratory of Quantum Information, University of Science and Technology of China, Hefei 230026, China

Abstract. In this work, we report on the first experimental realization of storing a true single photon carrying an orbital angular momentum in a cold atomic ensemble. We prepare a non-classical photon pair via spontaneous four-wave-mixing in a cold atomic ensemble. One photon of each pair is used as a trigger and the other is stored in the experiment. After transmitting through a spiral phase plate, the photon to be stored carries a spatial structure. It is input to the second atomic ensemble and is stored there via electromagnetically induced transparency and retrieved later after a given storage time. We experimentally prove that the non-classical correlation between the trigger photon and the retrieved photon is still kept, the structures of the input and the retrieved photons show very good similarity. The demonstrated capability of storing a spatial structure at single-photon-level opens the possibility to the realization of a high-dimensional quantum memory.

Keywords: OAM, EIT, Quantum memory.

A light with an orbital angular momentum (OAM) has many exciting applications, including optical communications, trapping of particles and astrophysics. In quantum information and quantum optics fields, a light with an OAM has been used to encode the information in a high-dimensional state, by which the network's information-carrying capacity can be significantly increased. Besides, higher-dimensional states enable more efficient quantum-information processing, and large-alphabet quantum key distribution affords an increased flux of information, etc. Establishing a quantum network involves the coherent interaction between a light and a matter. There are some experiments based on such a light-matter interface, for example, establishing the entanglement of OAM between a photon and a collective atomic spin excitation. Recently, storing a light with an OAM or a spatial structure via electromagnetically induced transparency (EIT) in an atomic ensemble or in a cryogenically cooled doped crystal, or via gradient echo technique in an atomic ensemble, or using atomic frequency comb technique in solids doped with rare-earth-metal ions has been realized, but these important works involve bright lights. Very recently, there were some works related to the storage of a light carrying an OAM or a spatial structure near single-photon-level, but the light is strongly attenuated laser, not a true single photon. So far, there is no any report on the storage of an image at the true single photon level. The reversible transfer of a quantum state between a true single photon and a matter is an essential requirement in quantum information science. It is a crucial resource for the implementation of quantum repeater, a potential solution to overcome the limited distance of quantum communication schemes due to losses in optical fibers. Here, we report on the first experimental realization of a multimode optical memory at the true single-photon-level via EIT in a cold atomic ensemble. In our experiment, we prepare a non-classical photon pair via spontaneous four-wave-mixing (SFWM) via a double lambda configuration in a cold Rb^{85} atomic ensemble. One photon of each pair is used as a trigger and the other is stored in the experiment. The photon to be stored carries an OAM 1 per photon in units of $\hbar$, is mapped into and stored in another cold atomic ensemble via EIT firstly, then is retrieved after a programmed storage time. We experimentally prove that the non-classical correlation between the trigger photon and the retrieved

*dds@mail.ustc.edu.cn
†drshi@ustc.edu.cn

photon is still kept, the spatial structure of the photon is preserved very well during this storage process. We believe that our results could lay the basis for establishing a high-dimensional quantum network in the future.

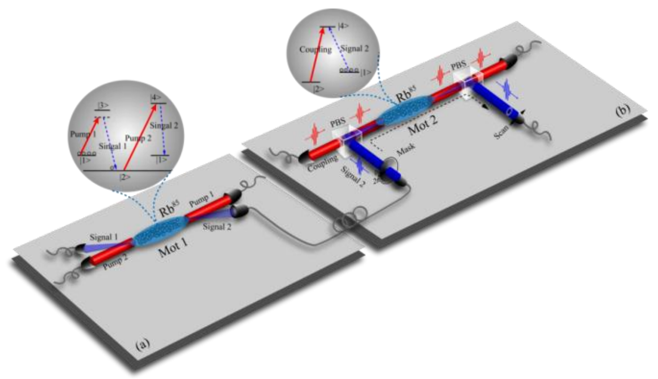

Fig. 1 (Color online.) (a) was the simplified diagram of generating a single photon by using SFWM configuration. (b) was the storage diagram. PBS: Glan-Taylor polarization beam splitter with the extinction ratio of 10^5:1.

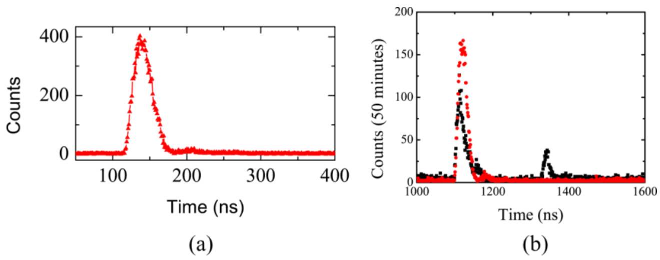

Fig. 2 (Color online) (a) cross-correlation function gs1,s2(τ) between signal 1 and signal 2 photons. (b) The input signal 2 (red) was scaled by 0.5, the black curve corresponded the leaked and the retrieved signal 2. The time-correlated function measured within 30 minutes in this experiment was shown in Fig. 2 (a), where the $g_{s1,s2}(\tau)$ was about 200, much larger than 2, which clearly demonstrated the non-classical correlation between photons.

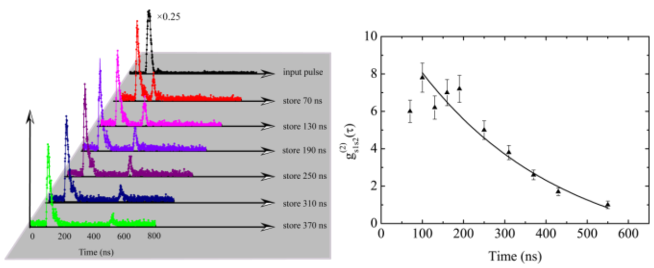

Fig. 3 (Color online) Left was the experimental results of the retrieved signal 2 against the storage time. Right was the cross-correlation function between the retrieved signal 2 and the signal 1 photons vs the storage time.

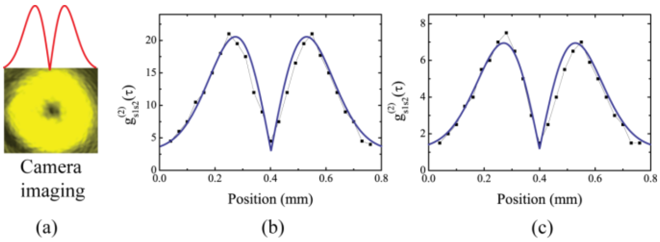

Fig. 4 (Color online) (a) Image of a beam passing through the spiral phase plate. (b) the cross-correlation between the retrieved signal 2 and the signal 1 photons, obtained by scanning the transverse position of the input signal 2. (c) the cross-correlation function between the retrieved signal 2 and the signal 1 photons. The solid lines were the theoretical fitted curves. According to the data shown in 4(b) and 4(c), we calculated the visibility, which was of 0.9 for input signal and of 0.88 for the retrieved signal respectively. The calculated similarity of the retrieved image was 0.996.

In our work, we gave an experimental verification of the ability of storing a true single photon carrying a spatial structure for the first time. Our work made an important step toward realizing a high-dimensional quantum memory using an atomic ensemble. Along with the recent important progresses made in the areas of infrared-to-visible wavelength conversion and long-distance fiber transmission of a photon encoded in a high-dimensional state, or with the significant progresses made in the area of the quantum key distribution between the ground and air, our results may lay the basis for establishing a high-dimensional quantum network in the future.

References

Dong-Sheng Ding, Zhi-Yuan Zhou, Bao-Sen Shi, Guang-Can Guo. Single-Photon-Level Quantum Image Memory Based on Cold Atomic Ensembles. arXiv:1305.2675