Quantum Memory in an Optical Dipole Trap

Chih-Sung Chuu, Ph.D, University of Heidelberg

Application Note

Introduction

In the protocol of quantum repeater, the transmission channel is divided into several segments which have lengths comparable to the channel attenuation length. Entanglement is first generated and purified for short distances, and then extended to a longer distance by entanglement swapping. As the entanglement is distributed over the transmission channel, one can carry out quantum teleportation or quantum cryptography. However, the nature of entanglement creation, purification, and connection are all probabilistic. As a result, it requires storing the successfully entangled segment state in a place, or a quantum memory, while waiting for the others to be generated. A quantum memory with long storage time is thus very critical to achieve a scalable quantum communication network.

Experimental Set-Up

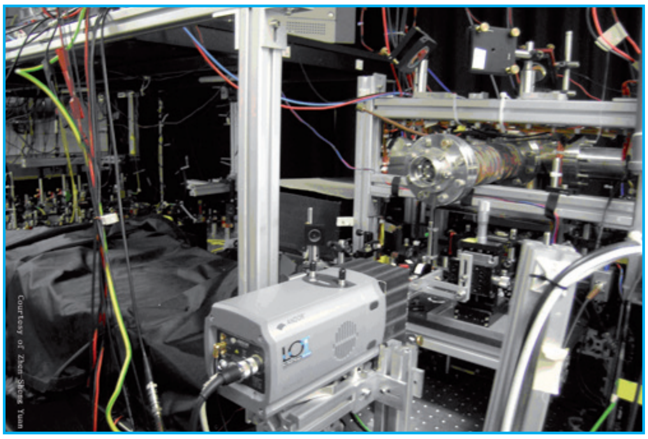

Fig. 1 Experimental setup.

In our experiment, we employ atoms in an optical dipole trap as a quantum memory [1]. The optical trapping avoids the ground state broadening caused by magnetic fields and thus provides coherent storage for quantum states. In addition, we also make use of the clock transition which is first-order insensitive to the magnetic inhomogeneity induced by any magnetic field.

Our experiment begins with a standard magneto-optical trap (MOT). During 2 seconds of loading, about 5 millions of ^{87}Rb atoms with a temperature of 100 μK, are loaded from the background vapor. The MOT configuration is changed to a temporarily dark MOT, followed by molasses cooling, to maximize the transfer of atoms into the optical trap. In the dark MOT phase, the frequency of the cooling light is shifted to the red of the transition, while the repumping intensity is ramped down by a factor of 200.

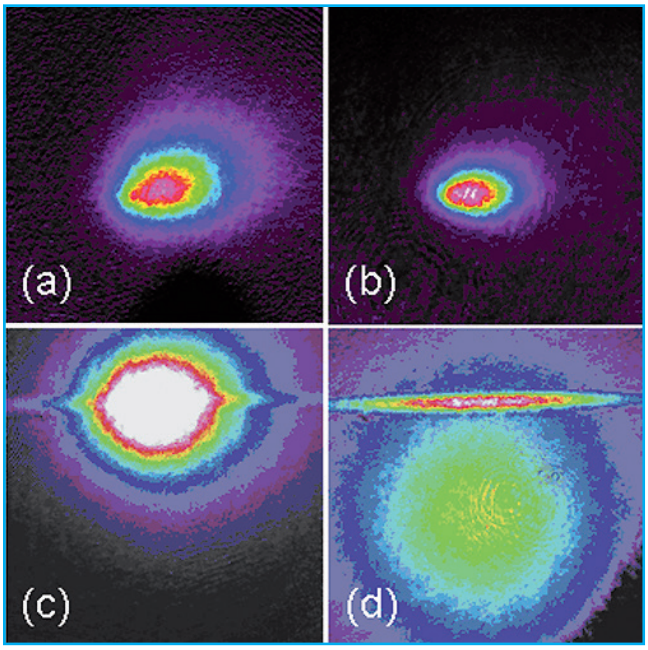

Fig. 2 Absorption images of the atoms (a) in the magneto-optical trap (MOT), (b) in the dark MOT, (c) in the optical trap surrounded by the untrapped atoms, and (d) in the optical trap with untrapped atoms falling under the gravity.

After the dark MOT, the MOT quadrupole field is switched off and molasses cooling is applied for 5 ms, resulting in a peak atomic density of 3 10^{10} cm^{-3} and a temperature of about 20 μK.

The optical trap is formed by a tightly focused laser beam at the wavelength of 1030 nm with a $1/e^2$ radius of 36 μm. The beam is left on during the whole experimental cycles at a power of 7 W, leading to radial and axial trapping frequencies of 2π 2 kHz and 2π 10 Hz, respectively, and a trap depth of 500 μK. For typical operating conditions, 200.000 atoms are transferred into the optical trap. Untrapped atoms are allowed to free fall under gravity for 30 ms. The temperature of the atoms after the transfer increases to 45 μK, possibly due to the heating associated with the optical pumping. The radial and axial rms radius of the trapped atomic cloud are measured to be 5.5 μm and 0.85 mm, respectively, which infers a peak atomic density of 10^{12} cm^{-3} in the optical trap. Fig.2 shows a series of absorption images of the loading process. These images are taken by a cooled CCD camera (*iKon-M* DU934N-BR-DD, Andor Technology) as shown in Fig.1.

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Results

The quantum storage is demonstrated by storing a collective atomic state in the atoms and retrieved it at a later time. The generation of the collective atomic state is accomplished by shining a weak Raman laser pulse onto the atoms, and is verified by detecting a forward scattered photon due to a single atomic excitation followed by spontaneous emission. Since every atom has the same probability of contributing to the detected photon, a collective superposition state (or spin wave) is created and then stored in the atomic ensemble. To verify the storage, the collective state is first coherently converted into another photon at a later time by a strong resonant laser pulse. The non-classical number correlation of these two photons is then verified by the measurement of normalized second-order correlation function.

Reference:

[1] Chih-Sung Chuu, Thorsten Strassel, Bo Zhao, Markus Koch, Yu-Ao Chen, Shuai Chen, Zhen-Sheng Yuan, Jörg Schmiedmayer, and Jian-Wei Pan, Physical Review Letters 101, 120501 (2008).

Contact:

Quantum Optics and Quantum Information Group
Prof. Jian-Wei Pan
Institute of Physics

University of Heidelberg

www.quantummemory.org