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Enhanced Spin Depolarization and Storage Time in a Rb Vapor *

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The experiment of measuring the spin depolarized time and light storage time in a Rb vapor under different conditions is performed. Typically, these measurements are accomplished in three different containers: atoms in a bare glass cell, atoms in a buffer gas cell, and atoms in a tetracontane ($C_{40}H_{82}$) coating cell. The increasing depolarization and storage times are observed in both the buffer gas cell and the tetracontane coating cell. In the latter case, a storage time greater than 400 μs is obtained.

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Using light to manipulate the spin states in atomic ensembles lies at the heart of many quantum optics effects.[1] Recently, mapping a polarization state of light onto an atomic spin state via electromagnetically induced transparency (EIT)[2] has been proposed[3−6] and demonstrated.[7−9] Storage and recovery of light information in an atomic ensemble is an interesting topic in the field of quantum information because photons are excellent long distance carriers of information, and quantum gates can be realized with atoms.[1,10,11] Light storage is implemented by the technique of ultraslow light group velocity and EIT effect,[12−14] which are both caused by the resonant or near resonant interaction between light and a Λ-type atom (Fig. 1(a)). Typically, we use a control light to make an opaque medium become transparent near atomic resonance. An orthogonal polarized weak optical field (the "signal filed") can then propagate without much absorption but with a substantially reduced group velocity. At the same time a mixture of signal light field and collective atomic excitation of spin transitions, which are known as dark-state polariton, can be generated. As we smoothly turn off the control field, the signal field is converted to a purely atomic spin-wave polariton and the quantum state of the signal field is then transferred to the atoms. By turning on the control field again after a time interval, the stored signal field can be released out.

The storage of arbitrary polarized lights with a good fidelity in the atomic ensembles has also been demonstrated recently.[15] This leads to a possible way to use current technology to photonic quantum memory or quantum repeater. However, such light storage process requires high quality state preparation and minimal depolarization and decoherence of the spin state of the atomic ensemble. Depolarization and decoherence are generally caused by the collisions of the target atoms with the cell walls or with other atoms and by external fields such as the leakage of the Earth's magnetic field.[16]

In warm atomic vapor cells, spin state lifetimes are often limited by the atom-wall collisions, which thermalize internal atomic states and destroy spin coherence. To avoid such spin state deterioration, filling the cell with noble buffer gas or coating the cell with paraffin material is usually used. The buffer gas keeps the atoms away from the walls of the cell such that the spin depolarization and decoherence are suppressed. Coating the walls of the cell with a paraffin derivative allows atoms to undergo many wall-collisions without losing their spin coherence and increases spin lifetimes. In the previous papers, many concerns have been taken for the novel coating methods which can significantly improve the depolarization time and reduce the group velocity.[17,18] Paraffin-coated alkali vapor cells have been successfully used to demonstrate spin squeezing, entanglement of atomic ensembles and quantum memory for continuous quantum variables, and are also used for high-precision atomic clocks and magnetometers.

In this Letter, we report a comparison study to measure the spin depolarized time and light storage time in a Rb vapor at different conditions, i.e., atoms in a bare glass cell, atoms in a buffer gas cell, and atoms in a tetracontane coating cell. We find that the depolarization and storage times are increased in the buffer gas cell and tetracontane coating cell. The experimental results also show that coating the cell has a significant impact on the light storage time.

Three different Rb cells are assembled as follows. First, a thoroughly cleaned and dried glass cell system is constructed. The cell system composes of two main parts, a cylindrical glass cell, which is named as the working cell, and a rubidium source chamber.

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The glass cell system is connected to a vacuum system through a vacuum valve and is pumped to a vacuum pressure at about 10^{-7} torr. Then the vacuum valve is closed, and a pure rubidium 87 isotope ampoule in the source chamber is broken by an iron hammer and a magnet. Rubidium is transferred to the cylindrical working cell by using a heat gun. The bare rubidium cell is directly made by sealing the working cell from the vacuum at this stage. While the buffer gas cell is made by injecting the 5 torr Nitrogen into the working cell before sealing.

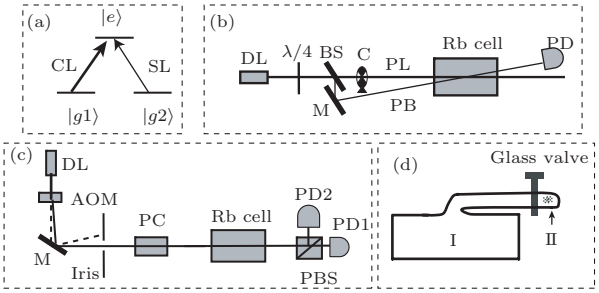


Fig. 1. Schematic of the atomic energy level and experimental setup. (a) A Λ-type atom for EIT effect. (b) Experimental configuration to measure the spin depolarized time. (c). Experimental configuration to measure the light storage time. (d) The schematic structure of tetracantone coating cell. Regions I and II are the working cell and Rb storage cell, respectively. $|e\rangle$, excited state; $|g1\rangle$ and $|g2\rangle$, ground states; CL, control light; SL, signal light; DL, diode laser; PL, pump light; PB, probe beam; BS, beam splitter; M, mirror; PD, photo detector; C, optical chopper; PC, Pockel's cell; PBS, polarized beam splitter.

The coating cell assembled is more complex than the above two cells. First, we have a similar glass cell system, while the working cell is now connected to a long glass tube with a glass valve on it. We drop some tetracontane into the working cell and pump the whole glass cell system to about 10^{-7} torr. Then the glass valve is closed. We warm up the working cell region until all the tetracontane is melted. Keep this status for several hours such that the inner wall of the working cell is well coated by tetracontane. When this step is finished, the working cell is cooled down to room temperature and back to vacuum again by gradually switching on the glass valve. After this stage, the glass and vacuum valves are closed. By repeating the bare cell assembling process we produce the coating cell with Rb stored in a storage cell (Fig. 1(d)).

In all our experiments, we maintain the Rb cell temperature of 70–80°C, corresponding to an atomic density of about 10^{11}–$10^{12}/\mathrm{cm}^3$. For the coating cell, we keep the working cell temperature slightly higher (80–90°C) than that of the storage cell in order to avoid Rb being stack and attached on the working cell windows. Therefore, we first warm up the working cell to a target temperature, then open the glass valve and warm up the storage cell to a temperature slightly lower than the working cell target temperature. Reverse the above processes to recycle the Rb to the storage cell again when the experiment is finished.

The first experiment we perform is to measure the depolarized time. Figure 1(b) shows the experimental setup. An extended cavity diode laser with 300 kHz bandwidth is used as the light source. After passing through a quarter wave plate, an original linearly polarized light is converted to the circular one. Then the laser beam is split into two parts with the same circular polarization. The main beam carrying most of the laser power severs as a pump light and polarizes the Rb atoms in its path. The weaker probe beam, which is not strong enough to noticeably affect the polarization of the cell, is absorbed by unpolarized atoms in its path. By polarizing the atom with the pump beam and then measuring the polarization over time with the probe beam, spin depolarized time can be determined. The laser frequency is adjusted to the D1 transition of ^{87}Rb ($\lambda = 794.987$ nm), i.e., $5S_{1/2}$, $F = 2 \to 5P_{1/2}$, $F = 1$, which is checked by observing the fluorescence or absorption spectrum. The laser beam diameter is about 5 mm with an output power of 8 mW.

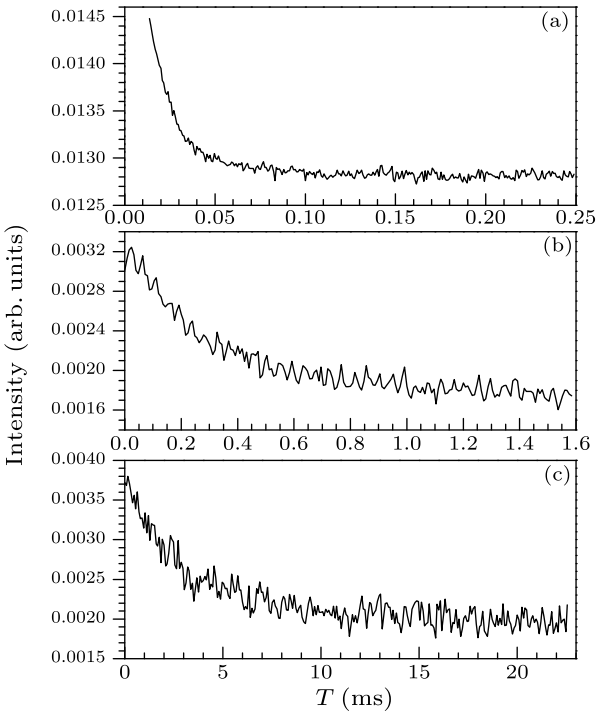


Fig. 2. Experimental results of measuring spin depolarized time T_1. (a) Bare rubidium cell, $T_1 = 10\,\mu$s. (b) Buffer gas filling cell, $T_1 = 300\,\mu$s. (c) Tetracantone coating cell, $T_1 = 3.21$ ms.

Figure 2 shows the experimental results of (a) a bare rubidium cell, (b) a buffer gas filling cell, and (c) the tetracantone coating cell, respectively. We fit the experimental results with the exponential decay and obtain the lifetime as 10 μs for the bare cell, 300 μs for the buffer gas cell and 3.2 ms for the coating cell.

The experimental results show that coating the glass wall has a significant impact on the depolarized time, which reveals that the collision of atoms with the cell wall is an important factor relative to the depolarized time.

The second experiment we perform is the light storage experiment. Figure 1(c) shows the experimental setup. A linear polarized laser beam is rapidly switched by an acoustic-optical modulator (AOM) and iris. A fast Pockel's cell slightly rotates the linearly polarized laser light to create a weak pulse, which is the signal field. The polarization of the weak pulse is perpendicular to that of the remaining light, which serves as the control field. Both the signal and control light are then sent into the Rb cell to accomplish the light storage experiment. A linear polarized light is used to keep the experiment simple. Other polarized lights, especially circular light, are found to have no effect the light storage time. A PBS and two photodiodes (PD) comprise the detection system. For the light storage experiment, the time sequence of the control and signal fields is the same as in Refs. [7,8,15].

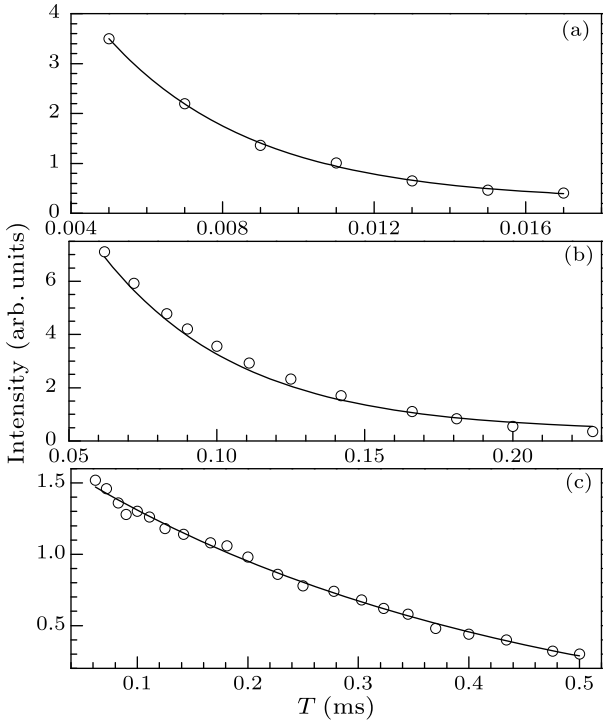


Fig. 3. Experimental results of measuring light storage time T_s. (a) Bare rubidium cell, $T_s = 3.89\,\mu s$. (b) Buffer gas filling cell, $T_s = 46.6\,\mu s$. (c) Tetracantone coating cell, $T_s = 398.6\,\mu s$.

In order to complete the light storage experiment, one should first check the EIT effect. We carefully adjust the laser frequency until EIT occurs. This can be checked when the signal light is totally absorbed by blocking the control light. Figure 3 shows the light storage experimental results in three different cells, where (a) is bare cell, (b) is buffer gas filling cell and (c) is the tetracontane coating cell. The solid lines are the exponential decay fit to the experimental data and the fitting results give the storage time as about 3.89 μs for bare cell, 46.6 μs for the buffer gas cell and 398 μs for the coating cell, respectively. Corresponding to the depolarized time measurement results, the storage time is decreased by almost one order. This is mainly because the light storage time is not only governed by the depolarization time, but also by the decoherence time. Indeed decoherence time plays an important role in the light storage experiment since the retrieval signal is coherently added when the control light is switched on again. Unlike the depolarized time, the signal exists as long as atoms are still on the target energy level, we do not have any light storage signal if these atoms lose the phase coherence.

In summary, we have performed the experiment to measure the spin depolarized time and light storage time in three different Rb vapor cells, and found that depolarized and storage times are increased both in the buffer gas cell and the Tetracantone coating cell. In the latter case, we obtain a storage time greater than 400 μs.

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