Partial Storage and Retrieval of a Light Pulse in a Cs Atomic Vapor with Λ-Type EIT

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We are able to store and retrieve part of a Gaussian light pulse in Cs atomic vapors with a Λ-type electromagnetically induced transparency (EIT) scheme. After storing part of the probe light pulse by switching off a controlling field while the probe pulse was propagating through the vapor cell, we were able to retrieve the pulse when the controlling field was turned on after some dark interval. By changing the coupling off time by a constant quantity, we were able to reproduce the whole pulse shape, and by changing the dark interval, we were able to measure the decay time of atomic coherence, which is the timekeeper of information.

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I. INTRODUCTION

With the rapid development of quantum optics, various kinds of novel phenomena have been discovered, such as electromagnetically induced transparency (EIT) [1,2], coherent population trapping (CPT) [3, 4], superluminal propagation [4], light storage [5,6], and so on. For quantum information technology, information should be easily stored and retrieved. Atomic media are not only very good candidates for information storage but also for information operation. Chien Liu et al. [7] were able to store and retrieve information of light in a Bose-Einstein condensation of Na atoms, and at the nearly same time, D. F. Phillips et al. [8] succeeded with light storage in a degenerate two-level system of Rb vapor atoms. Very recently Akulshin et al. [9] reported light storage by using electromagnetically induced absorption. Most of the experiments were done in degenerate two-level atomic vapor systems. They used one laser source to prepare two light fields, a control field and a probe field; however, in these methods, independent dynamic controls, such as controls of the intensity, the frequency, the polarizations of the lasers, or the dark time, were limited. In addition to these experimental works, many theoretical works [10, 11] about light storage for developing quantum information technology have been done. Fleischhauer and Lukin [12] used dark-state polaritons to interpret the process of light storage [13]. Recently, we reported the theoretical results for partial storage and retrieval in a degenerate two-level system [14].

In this paper, we will report a partial light storage experiment involving Cs atoms at room temperature. In order to investigate the interaction between atoms and light in detail, we used the fact that our system was not slow enough to store a full pulse. We found that the retrieved signal was distorted in contrast with the original part. We also studied the relationship between the signal’s intensity and the interval of the dark time. The fitting result shows that the coherent storage of the signal’s information is attenuated due to the decay of the lower coupling state, so it can be used as a method to measure the decay rate of atomic coherence.

II. EXPERIMENTAL SETUP

Figure 1 shows our experimental setup. Λ-type energy levels in the Cs D2 line have been adopted for light storage based on electromagnetically induced transparency (EIT). A controlling field is used for coupling the transition between the \( F = 3 \) state in the ground level and the \( F = 4 \) state in the excited state, and a probe field is used for coupling the transition between the \( F = 4 \) state in the ground level and \( F = 4 \) state in the excited state, where the excited state is coupled commonly by two fields to make the so-called Λ-type configuration. Both the controlling and the probe fields are coherent with each other because the controlling laser is generated by injection-
Fig. 1. Experimental setup.

Fig. 2. Probe pulse shape and switching time of the controlling laser.

locking the probe field which is frequency-shifted by an electro-optic modulator (EOM), where the modulation frequency is exactly the same as the hyperfine splitting of the ground states [15]. The frequencies of two laser systems were monitored by using saturated absorption spectrometers.

An acousto-optic modulator (AOM) derived by using an arbitrary function generator generates a probe pulse, which has a Gaussian shape. A polarizing beam splitter overlaps the controlling laser and the probe pulse. The two fields are controlled by a second AOM. When the second AOM is turned off, the remaining part of the probe pulse is also turned off. Figure 2 shows the shape of the probe pulse and the switching timing of the controlling laser.

At time t = 0 in Figure 2, the two fields are off for storage, and after some time, called the dark interval, only the controlling field is on for retrieval. Two coherent fields are passing through a Cs vapor cell with no buffer gas at room temperature. Two layers of μ metal sheets blocked the effect of the Earth’s magnetic on the Cs atoms. Another polarizing beam splitter is used to detect only the transmitted probe pulse and the retrieved pulse with the stored information.

III. EXPERIMENTAL RESULTS

Figure 3 shows a delayed pulse compared to the reference pulse propagating in the air, where the intensity of the controlling beam is 1 mW/cm². Because the maximum delay is measured to be ∼2.2 μsec in a 5-cm-long cell, the group velocity is approximately 23,300 m/sec,
which is 1/13,000 times slower than the speed of light in a vacuum. This delay is not enough to store a total pulse shape with pulse width of about 5.9 µsec in the cell. We should have a delay a larger than the pulse width to store and retrieve a complete pulse. However, we found that this much delay is better for investigating the detailed physical background for the storage and retrieval processes. Thus, when we turn off the controlling field, the controlling field separates the probe field into two parts in the temporal consequence; the front part will propagate very slowly in the cell due to the very high group refractive index created by electromagnetically induced transparency (EIT) while the back part will vanish due to the absorption and fast decay between the upper level and the lower level because there is no controlling field after switching off. In the cell, the controlling field travels at a phase velocity much faster than the probe field does. Consequently, as Figure 4 shows, only the temporal information of the left back part of the probe pulse, which is represented by $\Delta t$, will be mapped into the spatial atomic coherence between lower states. This is the storage process.

When we applied temporal sequences with a dark interval of 0.2 msec to the AOM shown in Figure 2, we were able to get the typical signal shown in Figure 5. At $t = 0$, all fields were supposed to be shut down. The front part of the probe pulse was transmitted and detected; then, after the dark interval, the retrieved signal was detected when the controlling field was turned on. Because the controlling field propagated with a phase velocity in the atomic medium, the spatially distributed atoms having information interacted with the control field at almost the same time; however, the retrieved pulse propagated with a very slow group velocity. We should point out that the tail of the retrieved pulse is not exactly the same as the tail of the probe pulse, but is related to the atomic coherence decay [9], which is an exponential decay. Furthermore, we were able to obtain a sequence of retrieved pulses by changing the switching time with a fixed dark interval of 0.2 msec. The input pulse is divided sequentially, stored, and then retrieved. In Figure 6, all output signals are collected together, and the pro-
file of the retrieved pulses’ peaks is normalized and then fitted as a Gaussian function (the solid line in Figure 6). This can be used to describe the shape of the entire output probe field if the whole probe pulse is stored in the cell. It is notable that the retrieved pulse is broadened slightly. This slight reshaping appeared in Figure 3 and may be due to contributions of Fourier frequency components out of the EIT bandwidth in the input probe pulse. This result was expected in the theoretical calculation [14].

In order to study the storing time of information in an atomic coherence state, we fixed the switching off time at 0.1 ms from the peak of the probe pulse and changed the dark interval. We were able to get the retrieved signal up to about 3 msec. Output pulses were fitted into an exponential function as shown in Figure 7. For Cs atoms, lifetime storing information was obtained up to 0.41 ms. This lifetime may not depend on the switching-off time because different values of atomic coherence when the information is stored will have the same decay constant, but may depend on the atomic density, the temperature, or the buffer gas, which will be interesting to investigate quantitatively.

IV. CONCLUSION

Here, we reported a partial light storage experiment at room temperature in Cs atoms. The velocity of the probe field could be greatly slowed under an EIT condition. When the controlling field was turned off, the probe field was partially stored due to the short cell or the group velocity not being slow enough. After some dark interval, we were able to get the retrieved signal. We found the pulse shape of the output signal to be distorted by combining each signal together, which was also found in our simulations. That probably means each Fourier component of the original pulse does not contribute the same to the retrieved pulse. Lastly, the storing time was obtained by measuring the decay time of atomic coherence.

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REFERENCES