Simultaneous Trapping of Two Optical Pulses in an Atomic Ensemble as Stationary Light Pulses

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The stationary light pulse (SLP) refers to a zero-group-velocity optical pulse in an atomic ensemble prepared by two counter-propagating driving fields. Despite the uniqueness of an optical pulse trapped within an atomic medium without a cavity, observations of SLP so far have been limited to trapping a single optical pulse due to the stringent SLP phase-matching condition, and this has severely hindered the development of SLP-based applications. Here, we first show theoretically that the SLP process in fact supports two phase-matching conditions and we then utilize the result to experimentally demonstrate simultaneous SLP trapping of two optical pulses for the duration from 0.8 μs to 2.0 μs. The characteristic dissipation time, obtained by the release efficiency measurement, is 1.22 μs, which corresponds to an effective Q-factor of $2.9 \times 10^9$ [1]. As our SLP system reports a large effective N-atom cooperativity of $8 \times 10^6$, our work is expected to bring forth interesting SLP-based applications, such as, efficient photon-photon interaction, spatially multi-mode coherent quantum memory, creation of exotic photonic gas states, etc.

Figure 1(a) shows the experimental results of the simultaneous electromagnetically induced transparency (EIT) storage of 2 μs only and those followed by the simultaneous SLP trapping process of 1 μs. The prepared cold atom is dressed with forward control (FWC) beam and, at the time of 1.6 μs, probe 1 and 2 are injected into the atomic medium with specific angles satisfying the simultaneous SLP phase-matching conditions. When FWC is turned off for 2 μs, probe 1 and 2 are simultaneously mapped to the collective atomic spin states by the EIT storage process. Then, when FWC is turned back on at the time of 5.6 μs, the two probe pulses are retrieved as propagating optical pulses from the collective atomic spin states. In contrast, if both FWC and backward control (BWC) beam are turned on simultaneously at 5.6 μs, the retrieved optical pulses are immediately trapped within the atomic medium as SLPs, and, when BWC is later turned off, SLPs are converted into propagating optical pulses. The suppressed emission during the time both FWC and BWC are simultaneously turned on and the subsequent emission of the optical pulses when BWC is turned off clearly indicate the formation of simultaneous SLPs for probe 1 and 2 for the duration of 1 μs [2].

Figure 1(b) shows the release efficiency measurements of probe 1 and 2, as a function of the simultaneous SLP trapping time. The release efficiency of probe 1 and 2 exhibit the same exponential energy dissipation with the characteristic time of 1.22 μs. Since they are trapped in the atomic ensemble while retaining their electromagnetic field nature, the simultaneous SLP trapping process can be understood with the analogy of an optical cavity system. In this manner, the characteristic dissipation time of 1.22 μs corresponds to the optical cavity system with an effective Q-factor of $2.9 \times 10^9$. The high effective Q-factor demonstrated in this work also implies that there is a strong atom-photon coupling, which can be estimated by N-atom cooperativity, $C_N$, as the photons are effectively trapped within the atomic ensemble, similarly to a cavity quantum electrodynamics (QED) system. The relevant experimental parameters lead to the N-atom cooperativity of our SLP system as $C_N \sim 8 \times 10^6$, which is larger by an order of magnitude than those reported in recent cavity QED experiments [3].

FIG. 1. (a) The simultaneous EIT storage process and those followed by the simultaneous SLP trapping process. (b) The release efficiency for the simultaneous SLP trapping time.

References
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