Long-lived conjugate optical echo in a crystal

N. N. Akhmediev, B. S. Borisov, V. A. Zuĭkov, V. V. Samartsev,
M. F. Stel'makh, A. A. Fomichev, and M. A. Yakshin

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A long-lived conjugate optical echo has been observed in the $LaF_3:Pr^{3+}$ crystal. The maximum delay at which the optical-echo signal could be detected in these experiments was 5 s.

The experiments of Refs. 1 and 2 laid the foundation for the use of the signal of the stimulated optical echo in optical memories and data processing systems with prolonged storage.[3–5] It is known that this signal may appear as a result of a resonant effect on the substance of at least three temporally separated laser pulses. After three pulses, a coherently excited[6] resonant medium emits three echo signals in addition to the stimulated echo. There is accordingly the important problem of filtering out the avalanche of "unnecessary" coherent responses from the useful signal (the stimulated optical echo). This problem can be solved by a conjugation technique,[7] through the use of a spatial variation in the generation of echo signals.

In this letter we are reporting a search for and an experimental study of the long-lived conjugate stimulated optical echo in the $LaF_3:Pr^{3+}$ crystal with a "memory" time far longer than the lifetime of the excited optical state.

The resonant excitation of the Pr^{3+} ions (with a concentration of 0.5 at.%) in the LaF_3 matrix is carried out in the present experiments on the energy transition[8] $^3H_4$–$^3P_0$, at the wavelength 4777 Å. The time scale of the irreversible transverse relaxation at this impurity concentration corresponds to several hundred nanoseconds.

Figure 1A is a block diagram of the experimental apparatus. The output pulse from dye laser 1 (with a minimum power of 10^3 W in the pulse) is focused by lens 3 along the direction $\mathbf{K}_1$ onto the test crystal, 4, which is 0.1 cm thick and which is positioned in an optical cryostat at a temperature of 1.6–4.2 K. Part of the laser output pulse is tapped by a beam splitter 5 and directed into optical delay line 2 (DL1). At the given instant, this delay line forms a second exciting pulse. At the output from the DL1, mirror 6 and lens 3 direct this pulse to the sample (4), at some angle with respect to the first pulse. The direction in which the second pulse is applied is shown by wave vector $\mathbf{K}_2$ in Fig. 1A. The third exciting pulse is formed in the direction $-\mathbf{K}_2$ by optical delay line DL2. In the simplest case (which we will call the "two-pulse case"), in which the time interval between the second and third pulses is essentially zero, this delay line is replaced by a standard total-reflection mirror 7, which forms a standing wave. The signal of the two-pulse conjugate echo is emitted in the direction $-\mathbf{K}_1$ at a time equal to twice the time interval between the pulses. The signal of the conjugate stimulated optical echo is formed at a time $t_c = 2\tau + T$ after the first pulse, where τ is the time interval between the first two pulses, and T is the time interval between the second and third pulses. The echo signal is sent to a photomultiplier (18-ÉLU-FM) by means of a beam splitter 9 and lens 10 through an iris diaphragm 11

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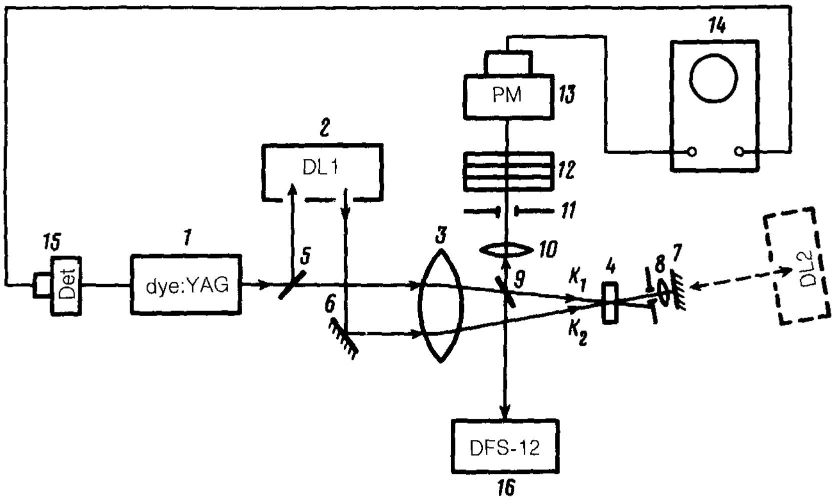

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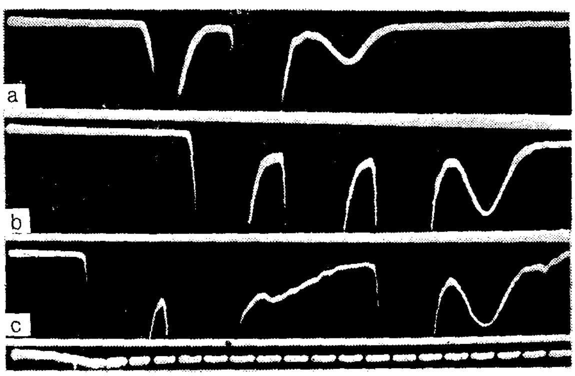

B

FIG. 1. A: Block diagram of the experimental apparatus. 1 (dye:YAG)—Exciting dye laser, including a pumping YAG laser with a repetition frequency of 12.5 Hz and a liquid laser; 2 (DL1)—optical delay line; 3—lens; 4—test sample; 5—beam splitter; 6,7—total-reflection mirrors; 8—lens; 9—half-silvered mirror; 10—lens; 11—iris diaphragm; 12—set of calibrated optical filters; 13 (PM)—photomultiplier; 14—high-speed oscilloscope; 15—photodiode; DL2—optical delay line 2; 16 (DFS-12)—spectrograph. B: oscilloscope traces of the signals of the two-pulses (a) and three-pulse (b and c) conjugate optical echos in the LaF_3:Pr^{3+} crystal. The echo signal is the first from the right. The other signals are the attenuated exciting pulses. The time interval τ is 50 ns on all of the traces. The interval T on trace b is 50 ns, and that on trace c is 75 ns. The sweep time is 250 ns, and the time marker is 10 ns. The pulse length is 10 ns.

and a set of calibrated optical filters 12. The diaphragm and the lens are used to substantially reduce the background from the scattered light of the exciting pulses. The filters 12 make it possible to measure the echo signal in the region of a linear sensitivity of the photodetector. The echo signal is observed and studied with the help of a stroboscopic oscilloscope 14 (I2-7). The wavelength is measured with a DFS-12 spectrometer.

Figure 1B shows oscilloscope traces illustrating the signals of the conjugate two-pulse echo observed in this crystal (trace *a*, corresponding to $T = 0$) and of the conjugate stimulated optical echo (traces b and c, corresponding to different values of the time interval T). In an effort to observe the long-lived stimulated optical echo at the given time interval between the first two pulses ($\tau = 50$ ns), we increased the time interval T to values greater than the lifetime of the upper optical state, $\sim 50\,\mu s$. Figure 2 shows oscilloscope traces illustrating the conjugate long-lived optical echo in these crystals; the echo signal is the first from the right. The maximum value of the interval T (corresponding to the information storage time), at which it is still possible to detect the signal of the conjugate long-lived optical echo in these crystals, is 5 s. This is not the longest memory time which can be observed in these crystals.[1,2]

Such a prolonged optical "memory" is known[3–5,9,10] to stem from a transfer, during the time interval T, of information on the "lattice" of the nonequilibrium population difference after the first two pulses from optical sublevels to hyperfine sublevels of the ground ($^3H_4$) state. An important point is that an energy transition between a pair of hyperfine sublevels is forbidden. All possible uncontrolled inclusions (primarily neodymium ions), which cause transitions between hyperfine sublevels, lead to a substantial shortening of the optical memory.

We might also note that even if resonance conditions are exactly maintained during the excitation of the long-lived echo in the $^3H_4$–$^3P_0$ transition, this crystal emitted some of the absorbed energy on the transition $^1D_2$–$^3H_4$; this circumstance was seen as the existence of a yellow glow of the crystal at the wavelength 5925 Å, along with the emission of the echo signal at the wavelength 4777 Å. The presence of this glow required a frequency selection of the echo signals.

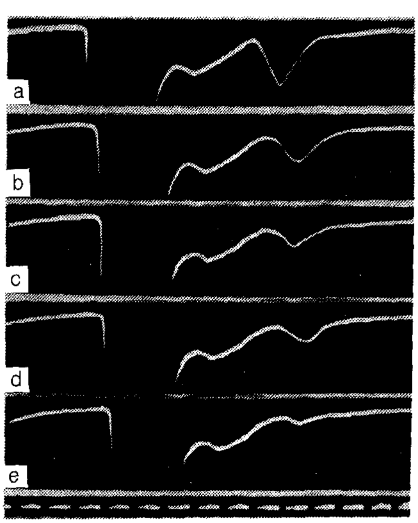

FIG. 2. Oscilloscope traces illustrating the observation of a conjugate long-lived optical echo (the first from the right) in the $LaF_3:Pr^{3+}$ crystal. The first signal from the left is the attenuated third pulse, of length 10 ns. The time interval τ is 50 ns for all of the traces. The time interval T has the following values: a—0.5 s; b—1 s; c—1.5 s; d—2 s; e—3 s. The sweep time is 250 ns, and the time marker is 10 ns.

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