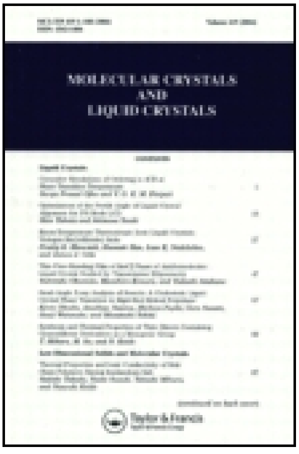

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SPECTRAL AND TIME DOMAIN STUDIES OF ACCUMULATED PHOTON ECHO

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Abstract Multishot or single-shot retrieval of femtosecond echo signal without substantial spectral distortion was experimentally demonstrated for a H_2-octaethylporphine doped polystyrene sample. Upto 10^4 single-shot readout cycles using a femtosecond pulse were observed without substantial echo signal degradation. The echo decay time was determined for this sample to be (50 ± 15) ps.

INTRODUCTION

Persistent hole burning (PHB) media[1,2] has been proposed for ultrahigh-density optical data-storage applications because of their high spectral selectivity and long storage times. Frequency[3,4] and time-domain[5] approaches have been proposed for writing and reading streams of data bits. In the frequency domain, monochromatic light is employed to write and read data sequentially into frequency channels. The upper limit for readout speed of a data bit is determined by the minimum width of a frequency channel or the homogeneous linewidth (FWHM) Γ_H, typically 1 kHz - 1GHz at liquid-helium temperature. In the time-domain, data bits are written and recalled in parallel by a spectrally broad laser pulse. In this case, a read-out speed of a data bit is much higher than in the frequency-domain approach and is limited by the width of the

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inhomogeneous absorption band Γ_I of the storage material, typically of 10 GHz -10 THz.

Utilization of the highest possible readout speed requires femtosecond optical pulses. Femtosecond PHB holography was demonstrated for storage, recall and conjugation of accumulated echo signals. Signals as short as 100 fs were detected using a standard multishot second-harmonic generation technique.[6] To increase the readout speed of femtosecond accumulated photon echo signals, an ultrafast single-shot interferometric crosscorrelation technique was proposed.[7] A data readout speed as fast as 27 Tbits/s was experimentally demonstrated for a H_2-octaethylporphine (OEP) doped polystyrene sample. The observed amplitude correlation time (ACT) of the echo signal was approximately twice as long as the ACT of the readout pulse. ACT broadening could be caused by an distortion of the echo spectrum.[8]

In this work, the PE spectra were measured and analyzed to minimize spectral distortion and to improve the time resolution of the crosscorrelation technique for PE signal from a OEP-doped sample. High intensity pulses, can introduce distortion and degradation of the PE signal. The dependence of PE intensity on the number of the single-shot readout cycles and PE decay time were measured.

EXPERIMENTAL METHOD

A schematic of the experimental arrangement is shown in Figure 1. The optical pulses were generated by a colliding-pulse mode-locked (CPM) laser operating at a repetition rate of 125 MHz, 6-mW average power, with 100 fs pulse duration. The amplifier system was pumped by a Q-switched ND:YAG laser at 20-Hz repetition rate and produced an amplified single pulse with an energy of 3 μJ/pulse.

A OEP- doped polystyrene film at T = 1.4 K (OD = 0.96 at λ = 618 nm) was used as the holographic medium. The signal pulse was stored in the sample after exposure by superimposed reference and signal beams. Average CPM laser power of 1 mW and a 0.8 mm - diameter spot were used. The echo signal was recalled using the multishot CPM pulses with average readout intensity of about 0.04-mW, or by a single amplified pulse of 150 fs duration with an energy of 0.7 μJ. The two spectra from PE and

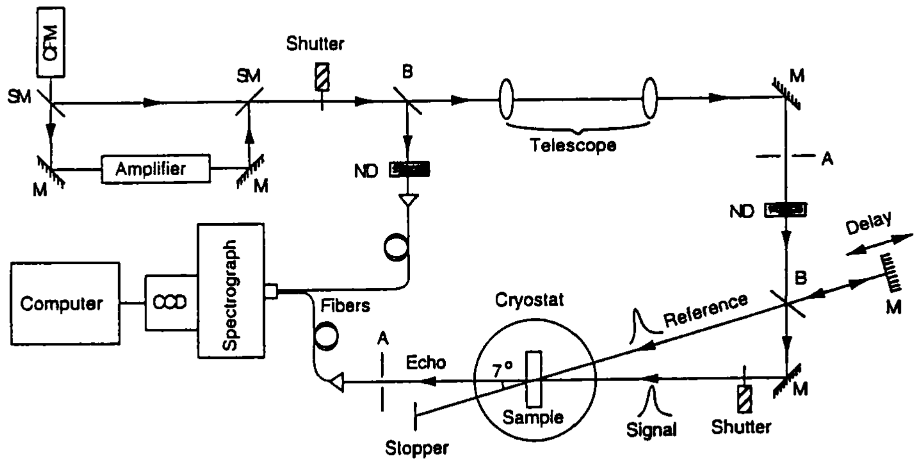

FIGURE 1 Experimental arrangement for hole-burning holography using CPM laser pulses: SM's, transfer mirrors; M's, mirrors, ND's, neutral density filters; B's, beam splitters; A's, aperture.

readout pulses were recorded simultaneously by a spectrograph and a CCD sensor (Photometrics Ltd., Model LC 200). The spectrum of transmitted pulses was measured using the signal beam (reference beam was blocked).

EXPERIMENTAL RESULTS

Hologram Writing

The dependence of PE spectral intensity on writing exposure is shown in Figure 2. At low exposure level, PE intensity depends on exposure almost linearly, and saturates at the level of 6 J/cm^2. This behavior is related to the saturation of the narrow hole shape at high exposures in hole-burning materials,[9] which causes hole broadening, a decrease of spectral grating contrast, and shortening of the PE decay time.[10] To minimize such effects, a low exposure level of 1 J/cm^2 was used in the experiments, corresponding to an exposure time of about 5s for the CPM laser pulse energy of the order of 40 pJ with 6×10^8 writing pulse sequences.

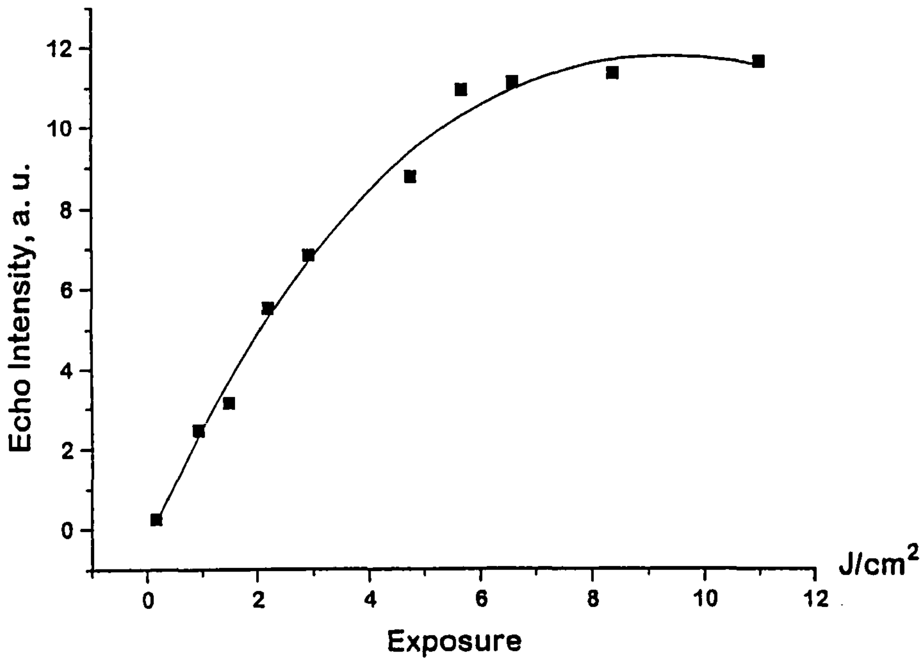

FIGURE 2 The dependence of the normalized multishot echo intensity from exposure.

<u>PE Spectra</u>

To determine spectral distortion from the OEP-doped sample, PE spectra for holograms written by CPM laser at two wavelengths, 620 nm, or 616 nm, were studied. Figs. 3a and b show the spectra of the PE (solid) and readout pulses (dashed line) for the CPM multishot readout mode. For laser wavelength of 620 nm, the PE spectrum consists of two bands. The most intense band at 622 nm is more than twice as narrow (FWHM ≈ 2.5 nm) as the readout pulse spectrum. As a result, the ACT of the PE signal became twice as long. The PE spectrum changes (see Fig. 3b) when writing and readout were performed at 616 nm. The spectrum (FWHM ≈ 4 nm) became smooth and only about

10 % narrower than the readout pulses spectrum. Figs. 3c and 3d show the spectra of the PE and readout pulses (solid and dashed lines, respectively) for single-shot readouts.

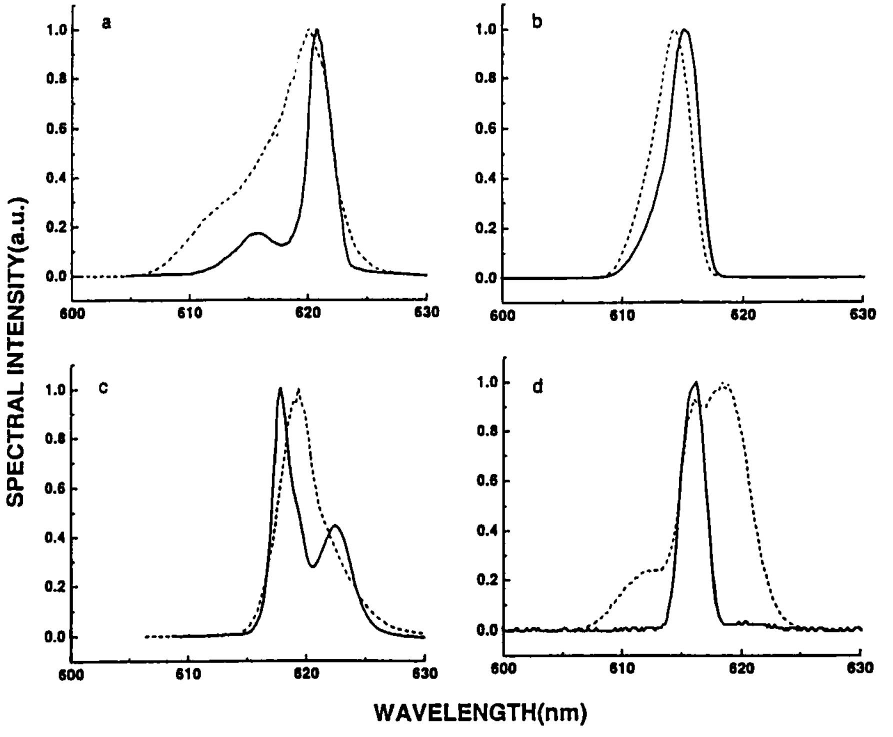

FIGURE 3 Spectra of the echo and readout pulses (solid and dashed lines, respectively). (a) and (b) for readout multishot CPM pulses, and (c) and (d) for readout single.

These spectra show the basic features of the multishot PE spectra.

PE Decay

The capacity of time-domain storage depends on the accumulated PE decay time, τ_{PE} . This time was determined using the multishot readout mode. The echo intensity was measured at the maximum of the echo spectrum and normalized to the intensity of the laser pulses for different delay times between the data and reference pulses.

Experimental data are shown in Fig.4. The echo signal decays exponentially with the time constant $\tau_{PE} = 50 \pm 15$ ps.

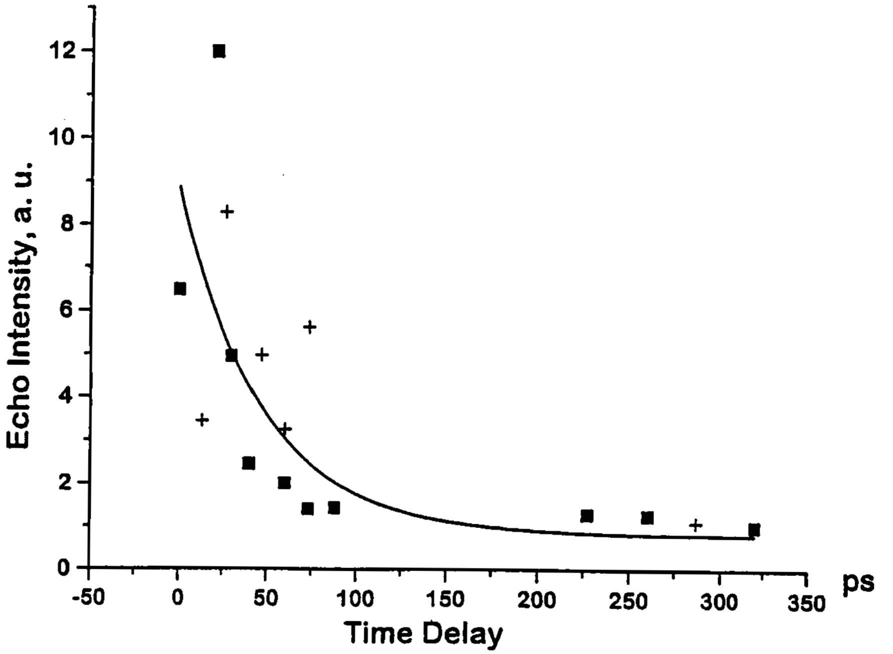

FIGURE 4 The normalized multishot echo intensity decay curve versus the time delay τ.

The accumulated echo in PHB media is a 3 pulse stimulated PE. Its decay is typically expressed as $I(t_{12}) = I(0)\exp(-4t_{12}/T_2^{3PE})$, where t_{12} is the delay time between the data and reference pulse, and T_2^{3PE} is the dephasing time.[11] For persistent hole-burning materials with long storage lifetime, the delay between reference and readout pulses, $t_{23} \sim 1$-10 s, and T_2^{3PE} includes optical dephasing and spectral diffusion effects over time $(t_{12} + t_{23})$.[12] We may compare T_2^{3PE} to the dephasing time determined from persistent hole-burning experiments which have the same time scale on the order of seconds, $T_2^H = 2(\pi\delta_v)^{-1}$, where $\delta_v = 2\Gamma_H$ is the holewidth (FWHM). For OEP-PS at temperature of 1.4 K, $\delta_v = 900$ MHz,[13] what gives $T_2^H = 710$ ps. Therefore, on the basis of hole-burning data a decay time of 177 ps is expected for this material, more than 3× longer than measured. This discrepancy is most likely related to a high peak intensity of femtosecond pulses used in PE experiments (≈ 10^8 W/cm^2), which is much higher than for CW lasers typically used for narrow band hole-burning (≈ 0.01 - 1 W/cm^2). This effect may cause an excessive dephasing. Phonon-induced[14] or instantaneous[15] spectral diffusion, or nonequilibrium optical heating[16] may be responsible for this difference.

Single-shot PE Readout Mode

The PE intensity dependence was investigated for a number of readout pulses (N in single-shot readout mode). The hologram was written by CPM laser pulse sequences and readout was performed by a single 150 fs pulse with energy of 0.3 μJ. The results are shown on Fig. 5 a.

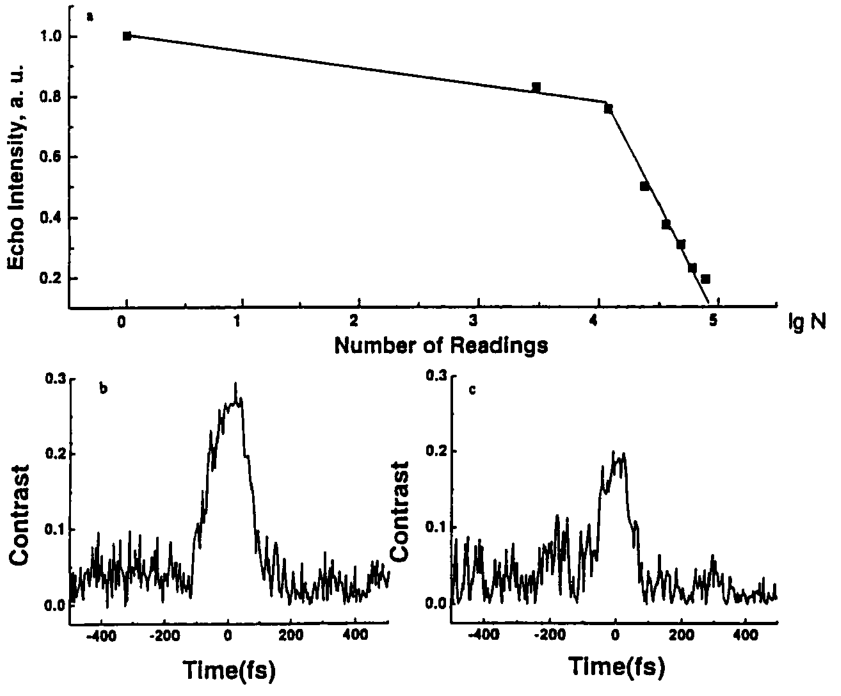

FIGURE 5 a) The decay of normalized single-shot echo intensity from the number N of the single-shot readout pulses (logarithmic scale) and b), c) crosscorrelation traces for N = 1 and N = 2.4×10^4.

The echo intensity demonstrates a very slow degradation with increase in the number of readout pulses up to $2x10^4$, and much faster after that. The corresponding crosscorrelation traces for N = 1 and N = $2.4x10^4$ are shown in Fig. 5, b and c. Despite a poorer signal to noise ratio the data pulse can be easily separated from a background, even after $7.2x10^4$ readouts. The "safe" number N = $2x10^4$ of readout pulses corresponds to a total reading exposure of 1.2 J/cm^2, which is close to a writing exposure of 1 J/cm^2. The interpretation is clear: the destructive readout gradually decreases the contrast of the hologram in the frequency domain. When accumulated reading exposure reaches the writing exposure, the hologram contrast became close to zero and the PE signal rapidly decreases. Thus, due to the high detection sensitivity, our single shot readout crosscorrelation technique allows for more than 10^4 readouts with reasonable signal to noise ratio.

CONCLUSION

These experiments demonstrate storage and multishot or single-shot retrieval of femtosecond echo signal without substantial spectral distortion for a OEP-sample. Upto 10^4 single-shot readout cycles with femtosecond pulses was observed without substantial echo signal degradation.

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