ASSOCIATIVE SPACE-AND-TIME DOMAIN RECALL OF PICOSECOND LIGHT SIGNALS VIA PHOTOCHEMICAL HOLE BURNING HOLOGRAPHY

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A new version of space-and-time domain holography in media with photochemical hole burning is proposed where holographic recall is completed by partial space-time episodes of the ultrafast scene. Associative holographic storage and recall of picosecond light signals is experimentally demonstrated.

1. Introduction

Combining the method of persistent photochemical hole burning (PHB) in low-temperature impurity media [1–4] with the principles of optical holography makes possible to perform holographic recording and playback of space-and-time domain behaviour of ultra-short light signals [5–8]. The phenomenon of PHB provides the recording and long term storage of the intensity spectrum of incident object light field with an accuracy to 10^{-3}–10^{-4} cm^{-1}, while the introduction of an additional reference pulse provides the storage and playback of the phases of the quasimonochromatic components of the object light field as well.

For the sake of convenience it has earlier been assumed that the role of the reference signal in recording and playback of space-time holograms in PHB media should be performed by special δ-like reference pulses, i.e. pulses with the duration very short as compared to the duration of the object pulse [7,8]. At a first glance one may conclude that in an opposite case, i.e. when the duration of the reference pulse is comparable to or even longer than the duration of the object pulse, the signal recalled from the hologram should be temporally hopelessly distorted and dispersed.

The purpose of the present paper is to demonstrate that the role of the reference signals in recording and playback of space-and-time domain holograms can be accomplished in an associative manner by separate space-time fragments (episodes) of the object light field. Recall of such kind of associative holograms is performed, analogously to an associative recall of ordinary space-domain holograms, by feeding into the hologram one or several fragments of the stored-in signal. It is experimentally shown that by recording associative holograms in spectrally selective media not only the reproduction of the spatial image do occur but also the recall of the temporal features of the original signal takes place. In other words, one can reproduce from the hologram the whole event provided a single episode of this event is still available for the readout procedure.

Further prospects of this approach are also discussed.

2. Experimental

The experimental setup was similar to that described in refs. [4,5]: laser pulses with 2–3 ps duration and 6 cm^{-1} spectral width were generated with 82 MHz repetition rate by a picosecond dye laser synchronously pumped by an actively mode-locked argon ion laser. The sample was prepared from polystyrene activated with octaethylporphin molecules at concentrations 10^{-3}–10^{-4} and had the dimensions $15\times15\times5$ mm. The sample was contained at 2 K temperature in a liquid-He cryostat with pass-through optical windows. The inhomogeneously broadened

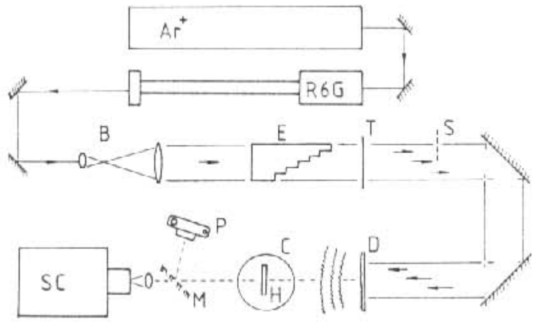

Fig. 1. Schematic of the experimental setup. B – beam expander; E – Michelson echelon; S – beamstop used to eliminate parts of the beam during readout of the hologram; D – mat glass beam disperser; C – cryostat; H – hologram; P – photographic camera; SC – synchroscan streak camera; M – semitransparent mirror; T – transparency.

absorption band used for PHB at 620 nm wavelength had a 200 cm^{-1} width. The starting value of the optical thickness of the sample (pre to PHB) was 2.0–2.5.

To record a hologram, exposures about 10 mJ cm^{-2} were needed, to perform the readout the exposures were 2–3 orders of magnitude less. The time interval required to write a hologram depended on the sample illumination conditions and varied from tens to several hundreds of seconds. During this long interval of time the PHB-action of 10^{10}–10^{11} identical light pulses was accumulated in the medium of the hologram.

Temporal resolution of the light signals with an accuracy to 20–15 ps was provided in the experiment by a synchroscan streak camera. To record temporally averaged spatial images a photographic camera was used.

3. Results and discussion

The output beam of the laser was expanded in a telescope and passed through a Michelson echelon (fig. 1). The optical path through the neighbouring segments of the echelon differed by 34 ps. At the output of the echelon the laser pulse appeared to be divided up in eight pulses. Each of the eight pulses corresponded to a fraction of the input pulse cross-section travelled through a certain segment of the echelon so that the relative delays of the segments were correspondingly 34 ps, 68 ps, 102 ps, etc.

The total duration of the pulse train did not exceed, as it is required in space-time holography, the phase relaxation time $T_2 \simeq 500$ ps of the excited electronic state of the impurity centers responsible for PHB.

By inserting into the laser beam various transparencies the spatial outlines of the light pulses could also be tailored, say, in the form of stripes, fragments of printed text etc.

In order to write a hologram, mutual interference of various parts of the incident object light field had to be arranged by making all the spatial parts of the object pulse meet each other all over the hologram. To do this a mat glass plate was inserted into the laser beam some 15 cm from the incident window of the cryostat. As a result the laser beam which at the output of the echelon comprised a train of co-propagating pulses with spatially non-overlapping wavefronts, turned at the incident plane of the hologram into a train of pulses with each pulse illuminating almost evenly the whole area of the sample.

In fig. 2a is presented a photograph of a spatial image produced by object pulses scattered from the mat glass disperser. This image was observed when looking through the sample and the windows of the cryostat during the writing exposure of the hologram. In fig. 2b the temporal structure of the same light signal recorded with a streak camera is presented. For the purpose of better visibility of the spatial image a transparency was used to shape the object pulse in such a way that only pulses with delays 0, 34, 68 and 170 ps of the whole echelon output train were present.

To perform the read-out of the hologram certain parts of the object beam were stopped so that they did not reach mat glass. At the time both spatial (averaged over the time interval of the photographic camera exposure) and temporal images of the light signal emerging from the hologram were recorded.

In figs. 3a, b a photograph of the spatial image and the streak camera record of the signal recalled from the hologram are presented. The readout of the hologram was carried out with a space-time fragment comprising first three pulses out of the four pulse sequence used to write the hologram. Comparing the data presented in fig. 2 and fig. 3 one can conclude that the hologram indeed had the ability to repro-

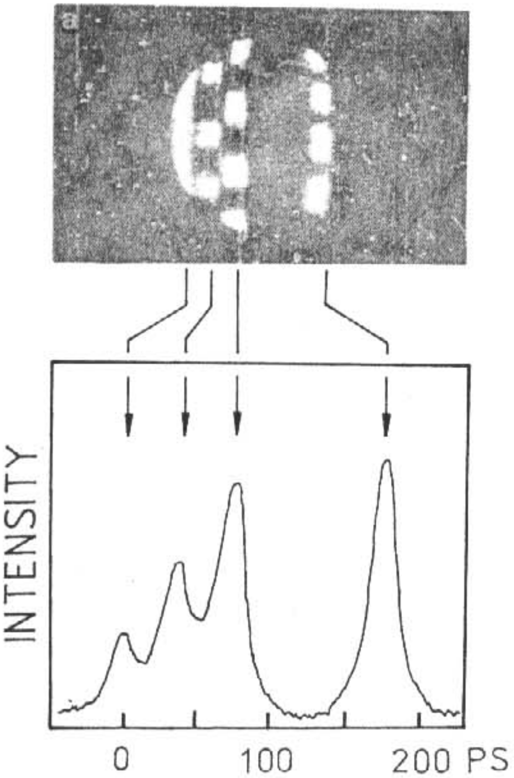

Fig. 2. Photograph of the spatial image (a) and corresponding streak camera record (b) of the object signal used to write the hologram. Correspondence between spatial and temporal fragments is indicated by arrows.

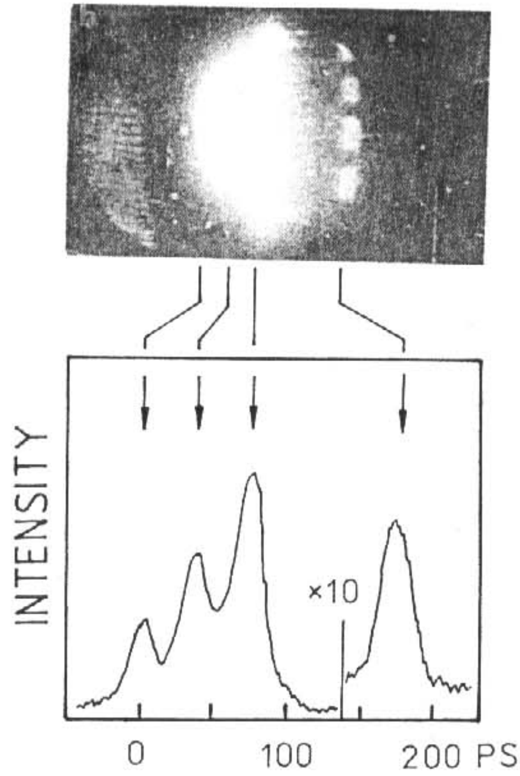

Fig. 3. Photograph of the spatial image (a) and the streak camera record (b) of the signal recalled from the hologram. For the readout fragment see the bright part at the left of the photograph (a) and the three pulses with delays 0, 34 and 68 ps (b).

duce both the spatial and the temporal structure of the missing part of the object signal. Note that the duration of the readout signal was some 70 ps while the temporal width of the recalled pulse was less than the streak camera 15 ps temporal resolution.

By utilizing combinations of various space-time readout fragments it was established that the missing part of the signal turned out only in case at least a fraction of the readout signal preceded in time during writing of the hologram the missing part of the signal. In the opposite case when the readout fragment belonged entirely to the retarded part of the signal no recall was observed. This feature is naturally understood if one accounts for the causality properties of space-time holography in PHB media [7,8].

During the readout of the hologram it was also observed that the more readout signals preceded the missing part of the scene, the more intense and detailed was the signal recalled from the hologram. This feature may be interpreted as a further property of an associative memory to reproduce the details of the stored-in scene depending on the amount of the preliminary information submitted for the readout.

Figs. 4a, b display the photographs of an associatively recorded and recalled picosecond space-time signal which had the form of a printed text each line of which had a duration in time 2 ps, the interval between the following lines was 34 ps. By illuminating the hologram with some of the first lines of the text it was possible to read from .he recalled image the rest of the text while the streak camera records showed that the temporal features of the signal were reproduced as well.

It should be noted that associative properties of the temporal recall observed in the described above

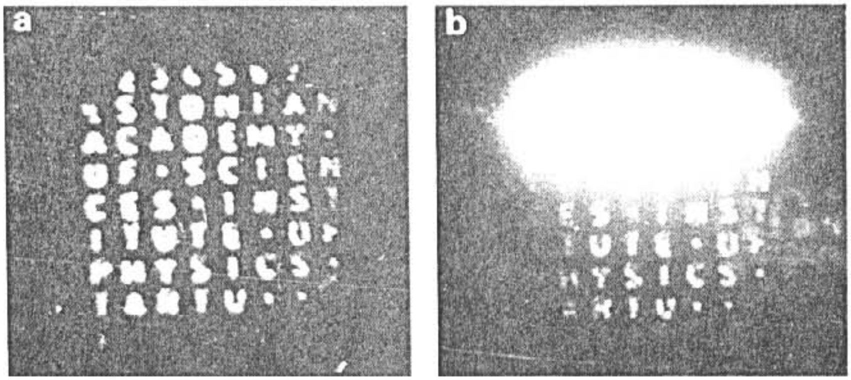

Fig. 4. Photographs of the image of a picosecond space-time signal applied to record a hologram (a) and the image recalled from the recorded hologram (see the text).

experiments manifested themselves to a considerable extent due to the fact that different temporal fragments of the recorded object scene had an irregular, different from one another spatial structure [9,10]. In this sense present experiments do remind the reproduction of a so-called phantom image observed in conventional holography.

Associative readout of space-time holograms can be performed also due only to the time-domain structure of the object signal provided the different fragments of the object scene do not correlate strongly with each another in time domain [10,11]. In this case to accomplish the readout of the hologram a fragment which possesses temporal structure coinciding with an episode belonging to the object scene is required.

It should be noted that the possibility of holographic temporal recall utilizing fragments of the recorded signal has been already indicated earlier by Gabor [12] and the analogy between holographic recall and some properties of human memory was also pointed out.

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