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COMPRESSION AND RECOVERY OF TEMPORAL PROFILES OF PICOSECOND LIGHT SIGNALS BY PERSISTENT SPECTRAL HOLE-BURNING HOLOGRAMS

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Experiments are carried out to demonstrate the feasibility of chirped pulse compression and group velocity dispersion cancellation of picosecond signals by persistent spectral hole-burning holograms.

1. Introduction

Spectral holograms recorded in low-temperature persistent spectral hole-burning (PSHB) media provide unique means for storage and coherent processing of ultrashort optical time-and-space varying signals [1–6].

Recording of spectral holograms is carried out by irradiating the PSHB-media with a temporally (and spatially) modulated signal pulse and a reference pulse, both applied within a time interval less than the phase relaxation time (i.e. the inverse value of the homogeneous zero-phonon linewidth) of PSHB-active impurity molecules.

Holograms are produced as a result of interference between the signal pulse and the reference pulse which takes place via coherent excitation of narrow homogeneous zero-phonon resonances distributed over a broad inhomogeneous spectral band of the PSHB-media.

The interference pattern is fixed due to permanent spectrally selective bleaching of the inhomogeneously broadened zero-phonon absorption band and it preserves complete information about the amplitudes and relative phases of the spectral components of the signal.

Homogeneous linewidths of less than 10^{-2} cm^{-1} and inhomogeneous bandwidths of more than 100 cm^{-1} are typical for organic impurity systems at temperatures 5 K and lower. This makes PSHB-holograms well suited for recording ultrashort light signals on picosecond and subpicosecond timescales.

Recall of the stored signal is accomplished by irradiating the hologram with a short read-out reference pulse which excites a coherent optical response – photochemically accumulated stimulated photon echo (PASPE) [3,4]. It has been demonstrated that the PASPE signal emitted by the PSHB-media of the hologram faithfully reproduces both the spatial and the temporal profiles of the stored signal [2,4].

Spectral holograms can also be looked at as simple linear filters which transform input read-out pulses in accordance with the linear spatial–spectral transmittance characteristic of the PSHB-media [1,6]. As typical linear filters spectral holograms can be addressed at any moment of time and if the intensity of the reading signal is low enough the output pulse profile will not depend on the amplitude of the input signal.

A number of straightforward applications of spectral holograms acting as linear filtering elements have been suggested for the purposes of time-domain shaping of short laser pulses [2,4], time–space pattern recognition and correlation analysis [7,8], etc.

In this paper experiments are presented in which spectral holograms with frequency chirped transmittance characteristics were recorded. Afterwards these holograms were used as spectral filters fitted to perform compression and recovery of temporal profiles of frequency chirped picosecond signals.

2. Experimental

A schematic of the experimental setup is presented in fig. 1. The laser system comprised a synchronously pumped picosecond dye laser and a mode-locked Ar-ion laser. The duration of the pulses from the dye laser generated at a repetition rate of 82 MHz was 10 ps.

A picosecond temporal resolution of the optical signals was provided by a synchroscan streak camera coupled to an OMA system.

Holograms were recorded on small plates of polystyrene 4 mm thick and 4 cm^2 in cross-section, doped with octaethyporphine at a concentration of 10^{-3} mol/l. The hologram plate was immersed in liquid He and was kept at a temperature of 1.8 K by continuously pumping off He gas in the cryostat. As shown by previous experiments [2,4] the maximum duration of the signals that could be recorded under these experimental conditions was about 1 ns.

The maximum absorption wavelength of octaethyporphine zero-phonon transition of 619 nm coincided with the maximum intensity wavelength of the laser pulses both having a spectral fwhm of about 5 nm. Spectra of the laser pulses before and after passing through the recording medium measured with a low spectral resolution monochromator are presented in fig. 2.

Frequency chirped pulses were obtained by passing laser pulses through a dispersive delay line comprising two diffraction gratings (1800 grooves per mm) and a mirror (see elements D1, D2 and M6 in fig. 1). As a result of the dispersion introduced by the gratings the optical delay was smaller for shorter wavelength components then for the longer wavelength components of the input laser pulses [9]. At the output of the delay line laser pulses were negatively frequency chirped i.e. the optical carrier frequency decreases from the leading edge of the pulses towards the trailing edge. The dispersion of the delay line was 40 ps per nm which resulted in the increasing of the pulse duration from 10 ps at the input of the delay line to 180 ps at the output.

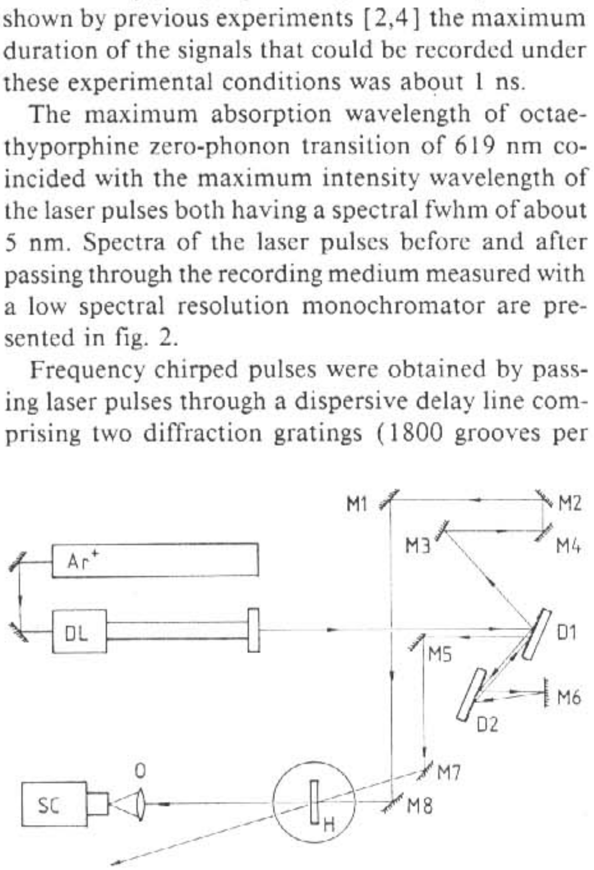

Fig. 1. Schematic of the experimental set-up. D1, D2, diffraction gratings with 1800 grooves per mm; M1, M2, ..., M8, metal coated mirrors; H, hologram plate; C, cryostat; SC, streak camera; DL, picosecond dye laser; O, focussing objective.

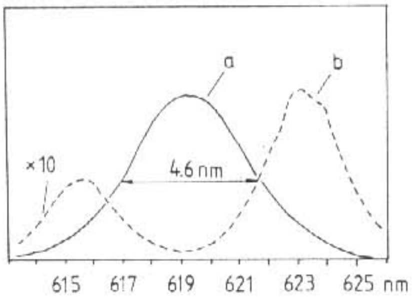

Fig. 2. Intensity spectrum of the picosecond laser pulses before (a) and after (b) passing through the PSHB hologram medium. Note strong absorption at 619 nm caused by the recording medium inhomogeneous absorption band.

Spectral holograms were recorded using the same frequency chirped laser pulses. Non-chirped reference pulses were obtained from the same dye laser by passing the zero order reflection from the diffraction grating D1 through an optical delay line comprised of ordinary metal-coated mirrors M1, M2, M3 and M4 (see fig. 1).

Spectral holograms were recorded by making use of the storage scheme applied in previous experiments to reproduce time-reversed replicas of stored signals [2,4]. Following this particular configuration the hologram was first illuminated by the frequency chirped pulse (in terms of [2] – signal pulse) and after that with a delay of 300 ps with the reference pulse which was applied relative to the signal pulse at an angle of 10°. The overall duration of the writing pulse sequence was about 500 ps i.e. less than the limit value determined in previous experiments.

Due to the low efficiency of the four-fold diffraction of the laser beam on the gratings the CW power of the writing frequency chirped beam was less than

0.1 mW. CW intensity of the reference beam was 10 mW. To record a hologram exposure times of several minutes were necessary so that exposures produced by a large number (10^{10}) of identical pairs of signal and reference pulses were accumulated.

3. Results and discussion

After the hologram was recorded the reference beam was blocked and only the frequency chirped pulses were passed through the hologram. The CW intensity of the frequency chirped read-out beam was low enough not to cause any additional undesired bleaching of the recording media during further read-out procedures.

As in previous experiments [2,4] two different beams were observed on the output side of the hologram: the passed-through frequency chirped read-out signal and the PASPE signal which was diffracted at an angle of 10° towards the direction of the reference beam.

The PASPE signal was then focussed on the entrance slit of the streak camera.

In fig. 3 streak camera images of the signals at the input and at the output of the hologram are presented. The duration of the input signal was 180 ps while the duration of the output PASPE signal was 30 ps. This compression effect was due to the spectral hologram acting as a dispersive optical element compensating for the frequency chirp of the input laser pulses.

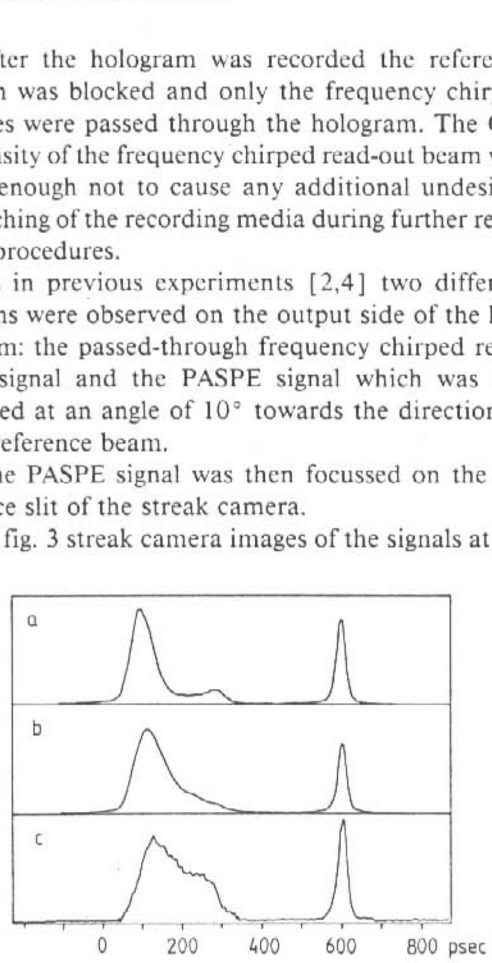

Fig. 3. (a) Time-resolved intensity profiles of the frequency chirped pulse (left) and the reference pulse (right) after passing the unexposed hologram plate. Note a "dip" in the centre of the chirped pulse profile due to stronger absorption of the central spectral components. (b) Intensity profile of the pulses after a 3 min exposure time (total exposition 200 mJ per cm^2). Note that the "dip" has decreased due to the increase of the transparency of the recording media. (c) PASPE signal (right) observed at the output of the hologram. A fraction of the frequency chirped input pulse (left) also penetrated the entrance slit of the streak camera due to scattering in the hologram media.

Let us note here that effective maximum geometrical pathlength difference compensated for by the hologram plate far exceeded the geometrical thickness of the hologram itself. This resulted from the obvious fact that in the case of spectral holograms the maximum input versus output pulse compression ratio is determined by the inhomogeneous versus homogeneous spectral width of the PSHB-active medium and not by any geometrical pathlength considerations crucial in compression schemes comprising combinations of dispersive optical elements [9] or three-dimensional spatial holograms [10].

Let us note also that spectral holograms represent a kind of adaptive elements which transmission characteristics can be upgraded to match any specific kind of signal linear amplitude and frequency distortions if the duration and the spectral width of the signal does not exceed the critical values set by the hologram media spectral parameters.

Further the same spectral hologram was used to restore the original temporal profiles of ultrashort optical signals distorted due to traversing the dispersive delay line.

To demonstrate the recovery effect a coated glass Fabry-Perot etalon was inserted into the picosecond laser beam at the input to the dispersive delay line. The etalon output comprised a series of pulses with an interval of 36 ps clearly resolved by the streak camera (see fig. 4a). At the output of the dispersive delay line the pulse series was completely smeared out and had a shape of a broad structureless pulse with a duration of approximately 300 ps. This distorted signal was passed through the spectral hologram and the resulting PASPE signal at the output of the hologram was recorded. Fig. 4b illustrates the experimental observation that the temporal structure of the PASPE signal almost completely recovered the original temporal intensity profile of the picosecond signal severely distorted by the group velocity dispersion.

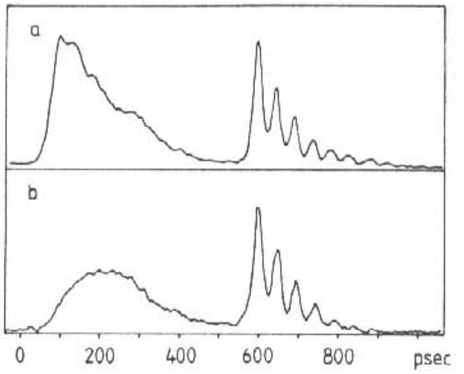

Fig. 4. (a) Time-resolved intensity profiles of the original picosecond signal pulsetrain (right) and of the same pulsetrain after passing through the dispersive delay line. (b) Totally distorted signal pulsetrain at the input of the hologram (left) and recovery of the signal intensity profile by the PASPE signal at the output of the hologram (right).

In conclusion experiments have been carried out demonstrating compression and recovery of temporal intensity profiles of frequency chirped picosecond light signals by spectral holograms in media with persistent spectral hole-burning.

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