Simultaneous Shaping and Shortening of Nanosecond Pulses

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ABSTRACT

Pump-induced probe beam deflection in an off-axis geometry is used to achieve simultaneous shaping and shortening of probe pulses. The first and the second harmonic of a Q-switched Nd:YAG laser served as a pump and probe wave respectively. Each pulse generated (super-Gaussian, sequences of two and three pulses) was of a reduced duration as compared to that of the incoming probe pulse.

1. INTRODUCTION

In many fields of modern optics specially shaped optical pulses are desired. One of the most precise techniques employs a manipulation of the spatially dispersed optical frequency components of the incoming ultrashort laser pulses [1]. As a result, the output pulses are shaped and broadened in time.

The aim of the present work is to provide evidences on the possibility [2] for a simultaneous shaping and shortening of laser pulses in the nanosecond time-scale.

2. PHYSICAL IDEA

The asymmetrical (self)induced refractive index correction along and across a nonlinear medium should lead to a far-field (self)induced beam deflection in space. Intensity-dependent beam self-deflection (in a two-beam interference configuration) and a subsequent spatial filtering of the beam could be used for laser-pulse shortening [3]. When a pump and probe wave copropagate in a nonlinear medium with an initial off-axial separation and/or with an initial angular deviation, an asymmetrical phase modulation (APM) of the probe beam is present. A simple far-field spatial filtering of the deflected probe wave can lead to the generation of optical pulses with a special shape and to the reduction of their duration [2]. The feasibility of this idea is proved in this work. The induced APM seems to offer additional possibilities [4,5] for generating and measuring the duration of short pulses in the shortwavelength spectral range.

3. EXPERIMENTAL SETUP

The experimental configuration used is presented in Fig. 1. The output of a Q-switched Nd:YAG laser ($\tau_{imp} = 20ns$) was frequency-doubled in a nonlinear crystal (SHG) and entered a tilted piece of optical glass. Due to the wavelength dispersion, at the

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exit of the element the pump and probe beams appeared with an off-axis offset of approximately 800 μm (0.6 times the pump beam radius). Both beams were focused with a lens (f=50 cm) in a 5 cm quivette filled with nitrobenzene. The APM of the probe beam resulted in its far-field spatial deflection. The temporally-averaged probe beam distribution was recorded with a CCD-camera and a frame-grabber. The time evolution of the deflected probe beam was recorded with a PIN-photodiode (response time of approximately 800 ps) and a 250 MHz storage oscilloscope. The spatial filtering of the deflected probe beam/pulse was a result of the small aperture of the photodiode (~1 mm^2). In order to scan across the probe beam cross-section, the diode was mounted on a translation stage.

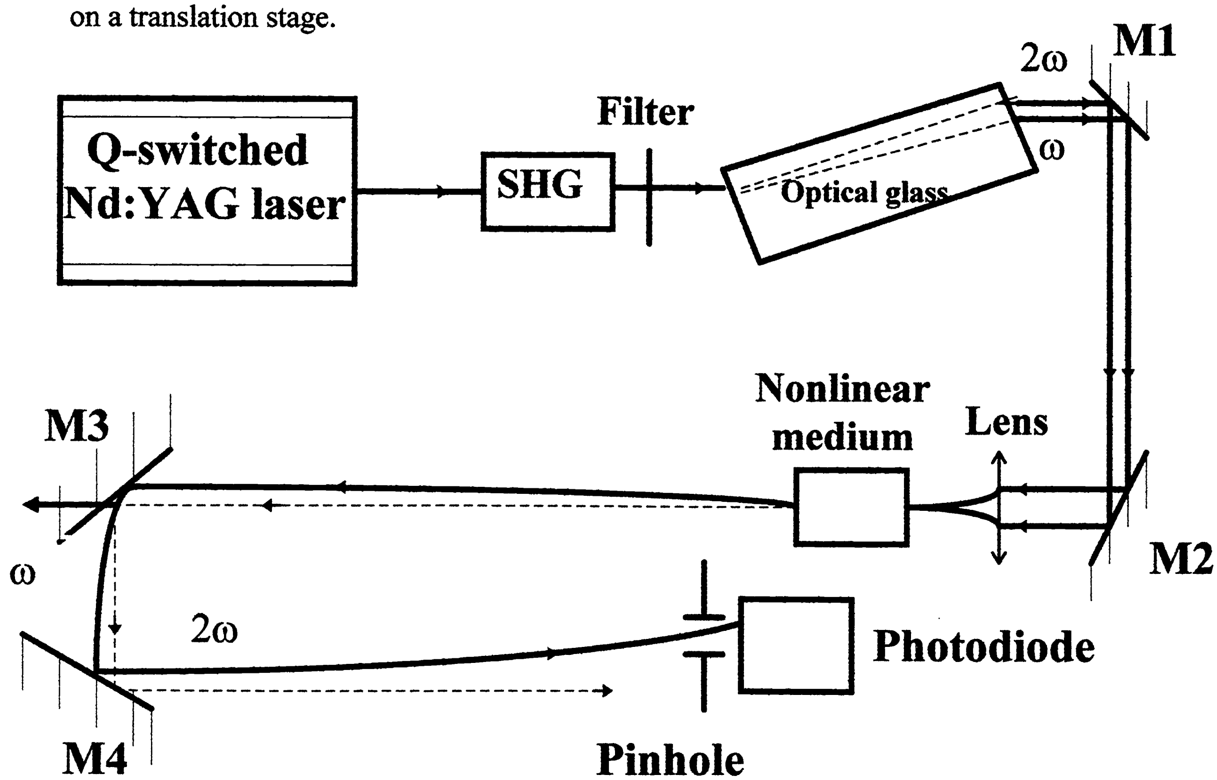


Fig.1. Experimental scheme

4. NUMERICAL SIMULATIONS

At the entrance face of the nonlinear medium the pump and probe beam/pulse are described as Gaussian beams/pulses with plane wavefronts

$$A_p = A_{p0} \exp\{-(x - x_0)^2 / a_p^2\} \exp\{-t^2\} \quad , \qquad (1a)$$

$$A_s = A_{s0} \exp(-x^2 / a_s^2) \exp\{-t^2\} \quad . \qquad (1b)$$

Within the nonlinear medium a nonlinear phase

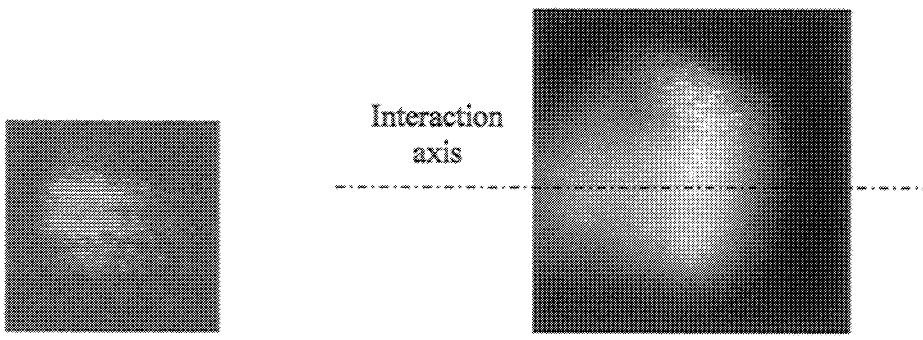
$$\phi^{NL}(x,t) = k_s l_{NL} n_2^{IPM} I_p(x - x_0, t) \tag{2}$$

is induced on the probe beam/pulse. The nonlinearity (i.e. the APM of the probe wave) is assumed to dominate strongly the diffraction. The free-space propagation from the exit face of the medium to the far-field was modeled by a fast Fourier transformation of the asymmetrically modulated probe beam/pulse

$$A_s = A_{s0} \exp(-x^2 / a_s^2) \exp\{-t^2\} \exp\{i\phi^{NL}(x,t)\} \tag{3}$$

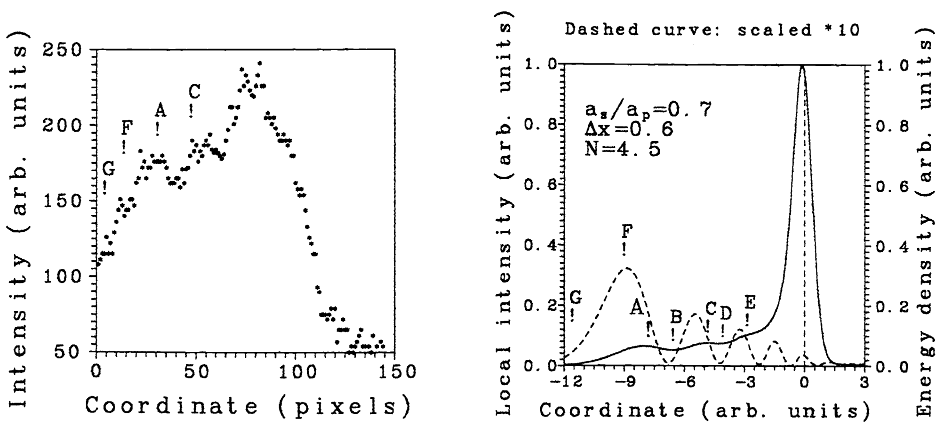
over a 256x1024 grid points.

5. EXPERIMENTAL RESULTS AND NUMERICAL SIMULATIONS



a) b)

Fig.2. Time-averaged grayscale images of the undistorted (a) and the deflected probe-beam (b).



a) b)

Fig.3a. Cross-section of the deflected probe beam along the interaction-axis

Fig.3b. Result obtained from the numerical simulations (solid line - temporally-averaged probe beam profile; dashed line - probe beam shape at a local time t=0).

It is naturally to expect a maximum probe beam deflection near the common pulse center (at a local time t=0). Due to their reduced local intensities, the leading and the trailing wing should be less deflected. For this reason the temporally-averaged energy-density distribution of the probe beam (Fig. 3b, solid line) differs significantly from the intensity distribution of the deflected probe-pulse peak (Fig. 3b, dashed line, scaled x10).

For comparison, Fig. 4 shows the shape of the probe pulse used in the experiment.

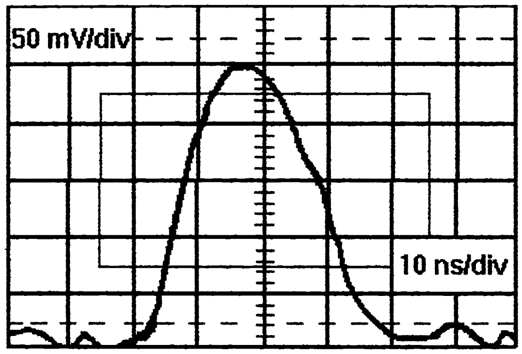


Fig.4. Typical shape of the probe pulses used in the experiment (λ=532nm)

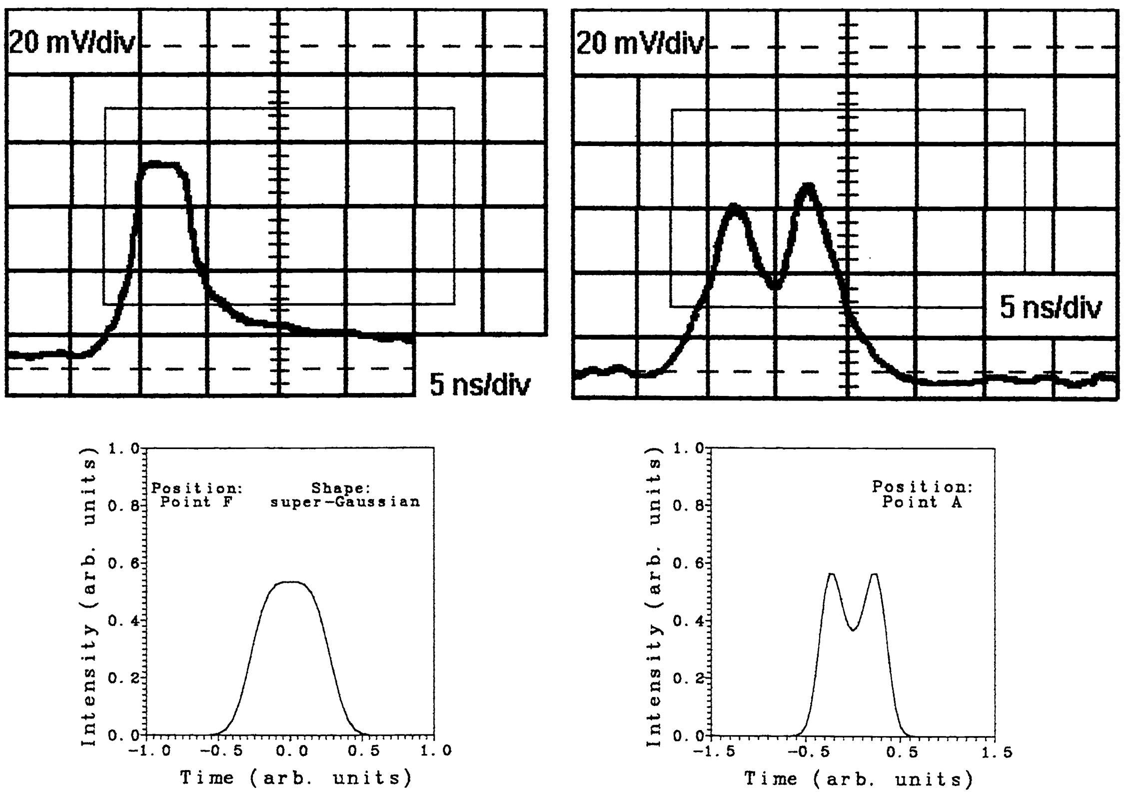


Fig. 5. Experimental (upper row) and numerical (lower row) results on the generation of super-Gaussian pulses (left column) and pairs of pulses (right column).

In order to obtain super-Gaussian pulses the detector was placed at point F (see Fig. 3a,b). Pairs of pulses are experimentally and numerically obtained with a pinhole (detector) positioned at point A on the same figures. The modulation depth of the two-pulse and of the four-pulse sequence could be improved at a moderate displacement of the detector (pinhole) with respect to the corresponding maximum in the time-averaged energy density distribution of the deflected probe beam

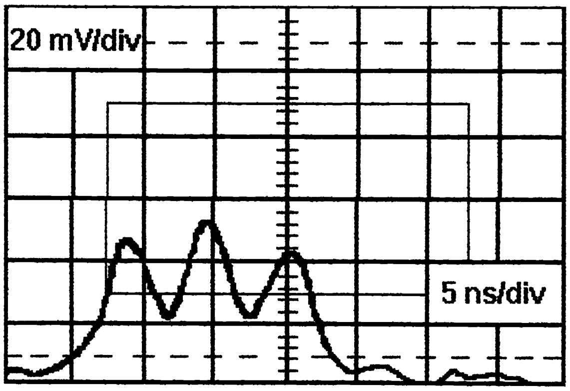


Fig.6a. Sequence of three pulses experimentally obtained with a detector positioned at point C on Fig. 3a.

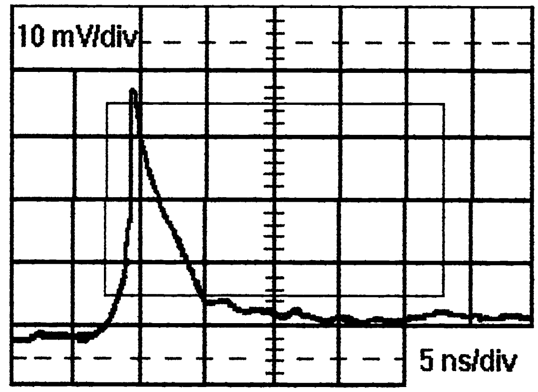


Fig.7a. Optimal pulse shortening (experimental result; detector position - point G on Fig. 3a)

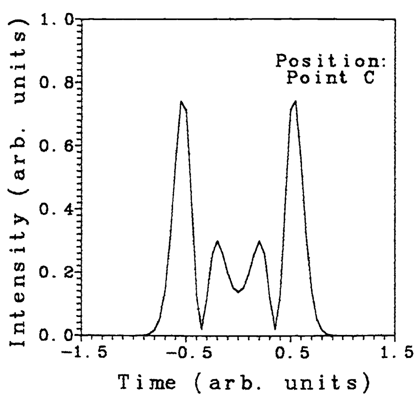


Fig. 6b Initial stage of the formation of a four-pulse sequence. The detector is less offset (Fig. 3b) from the linear probe beam axis than the second peak in the time-averaged pattern of the deflected beam.

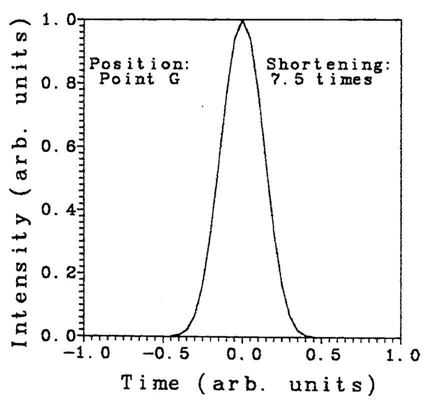


Fig. 7b The corresponding numerical result shows a temporal symmetry of the pulse transmitted (see point G on Fig. 3b)

Optimal probe pulse shortening (at the expense of a reduced energy efficiency) can be achieved by filtering the most deflected part of the probe beam (e.g. point G on Figs.3a,b). The accuracy of the experimental result presented in Fig. 7a is limited by the photodiode response-time and by the oscilloscope bandwidth.

6. Conclusion

Simultaneous shaping and shortening of probe pulses (deflected in space) seems relatively easy to be achieved. An advantage of the technique demonstrated is that no initial ultrashort pulses are needed. Shortening starting from longer pulses, an adjustable short pulse, or pulse train formation could be obtained in the picosecond and subpicosecond ranges. An initial time-delay between the incoming pump and probe pulses should offer an even wider possibility for probe pulse shaping.

7. References

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