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CONTROL OF LASER RADIATION PARAMETERS

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Temporal shaping of ultrashort laser pulses by volume Bragg gratings

N.S. Vorob'ev, A.A. Manenkov, A.A. Murav'ev, A.V. Smirnov, E.V. Shashkov

***Abstract*. We propose a new method of temporal shaping of picosecond laser pulses using interference of chirped beams reflected from chirped volume Bragg gratings. This method is numerically simulated and experimentally tested. Quasi-rectangular picosecond pulses are experimentally obtained.**

Keywords: *picosecond laser pulse, volume Bragg gratings, temporal shaping, optoelectronic camera.*

1. Introduction

The use of laser pulses with different temporal shape is of great interest for many applications, in particular, for investigation of nonlinear processes of interaction of laser radiation with matter. The character of this interaction is to a large extent determined by both the peak intensity and the temporal shape of laser pulses. These processes include, for example, self-focusing and self-phase modulation of high-power laser beams propagating in nonlinear optical media. The use of laser pulses with variable temporal shape allows one to realise stationary and nonstationary interaction mechanisms and to reveal their specific features.

In particular, the use of nanosecond rectangular, bell-shaped, and saw-like laser pulses to investigate self-focusing of laser beams in glasses allowed one to unambiguously interpret experimental results and prove the corresponding theoretical models of self-focusing (multi-focus structure and moving nonlinear foci models [1]). In these experiments, temporal shaping of laser pulses was performed by active methods based on the use of electrooptical Q-switches (Pockels cell) and was restricted by their characteristic switching time ($\sim$ 1 ns). Extension of this approach (i.e., the use of temporally shaped laser pulses) to the case of ultrashort pulses is of undoubted interest. In particular, this may lead to the development of new methods of investigation of filamentation and spectral variations in femtosecond pulses propagating in gaseous and condensed media [2]. However, ultrashort (pico- and femtosecond) high-power laser pulses of a given temporal shape are more difficult to obtain than nanosecond pulses.

At present, the temporal shape of ultrashort laser pulses is controlled using different principles and approaches [3 – 7]. The authors of [3] obtained rectangular picosecond laser pulses with a flat 10-ps top and $\sim$ 1-ps edges. This was achieved using an acousto-optic programmable dispersive filter. Formation of rectangular femtosecond pulses using programmable spatial light modulators (amplitude or phase) was demonstrated in [4 – 6]. Generation of transform-limited rectangular femtosecond laser pulses in a spectral compressor with a dispersive delay line and a single-mode fibre waveguide was experimentally studied in [7].

In [3 – 7], rectangular pulses were formed using special devices. These devices, on the one hand, were rather complicated and, on the other hand, were not equipped with detectors for direct measurement of the duration and shape of obtained pulses, even though such measurements are often performed today using pico- and subpicosecond streak cameras [8, 9].

In this work, we propose a new method for temporal shaping of ultrashort laser pulses by chirped-pulse interferometry (CPI) using reflection from chirped volume Bragg gratings (CVBGs) [10]. We describe the principle of the proposed method and present the computer simulation results, the optical scheme of the setup, and the experimental results in comparison with the calculated data.

2. Principle of the CPI method and computer simulation results

Figure 1 shows a scheme that explains the principle of the CPI method. An initial laser pulse falls on a CVBG stretcher and, reflecting from it, transforms into a temporally broadened chirped pulse. Then, this pulse falls on a CVBG compressor, which consists of two parts (red and blue) divided by a gap with a width ΔL. These parts were produced by cutting a grating along a plane that corresponds to the reflection of the central spectral component of the initial laser pulse. The red and blue parts of the compressor reflect radiation with wavelengths $\lambda > \lambda_0$ and $\lambda < \lambda_0$, respectively. At $\Delta L = 0$, the CVBG compressor is a replica of the CVBG stretcher rotated by an angle of 180° with respect to the incident beam. This scheme is similar to the conventional optical scheme of chirping, amplification, and compression of

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N.S. Vorob'ev, A.A. Manenkov, A.V. Smirnov, E.V. Shashkov
A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia;
e-mail: manenkov@kapella.gpi.ru;
A.A. Murav'ev Institute of Applied Physics, Russian Academy of Sciences, ul. Ul'yanova 46, 603950 Nizhnii Novgorod, Russia;
e-mail: sashamur@gmail.com

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ultrashort laser pulses. At $\Delta L > 0$, two beams reflected from both parts of the compressor interfere with each other thus forming an output pulse whose shape depends on the relative time delay Δt between the interfering beams. The delay Δt is determined both by the constant component $\Delta t_0 = 2\Delta L/c$, where c is the speed of light in the medium filling the gap between the two parts, and by the delay $\Delta t(\omega_i)$ between the interfering spectral components passed through the volume diffraction grating. The latter depends on the frequencies ω_i of the interfering spectral components and on the refractive index of the grating material; in our case, it is a constant value.

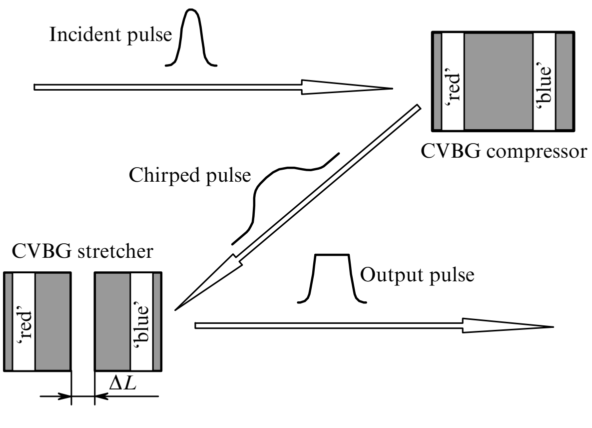

Figure 1. Schematic diagram of the CPI method of temporal shaping of laser pulses.

Computer simulation of the CPI method in the considered scheme shows that the temporal shape of the output (reflected from the CVBG compressor) pulse depends on Δt_0, i.e., on ΔL. At $\Delta t_0 = 0$, which corresponds to $\Delta L = 0$, the output pulse shape is identical to the shape of the initial pulse. The computer calculation results are presented in Fig. 2. For simulation, we used the initial data corresponding to the parameters of the experimental setup. The laser pulse temporal profiles are given for different phase shifts corresponding to changing ΔL with a step $\lambda/8$. The dependence shown in Fig. 2a corresponds to the case when the summation of two pulses reflected from the red and blue parts of the compressor leads to the formation of an output laser pulse with a flat top. The output pulse in Fig. 2c has a two-peak shape with a hole in the centre, while Figs 2b and 2d correspond to intermediate cases.

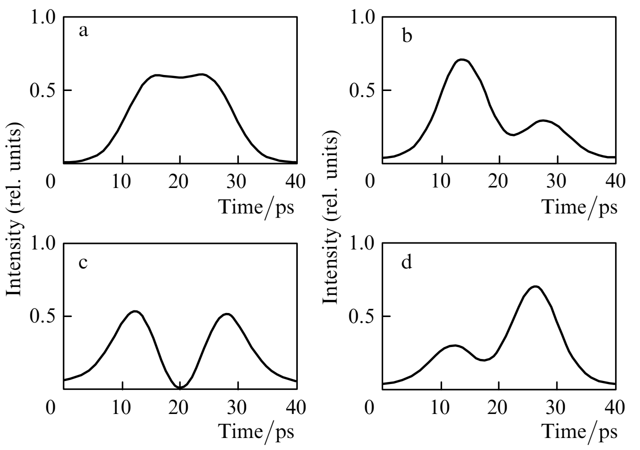

Figure 2. Computer simulation results: temporal profiles of laser pulses for different phase shifts formed by changing ΔL with a step $\lambda/8$.

3. Experimental results

Figure 3 shows the optical scheme of the experimental setup used to study the above-described CPI method of temporal shaping of laser pulses. As a source of pulses, we used a self-mode-locked Nd : YAP laser emitting a train of picosecond pulses [11]. Using an electro-optic Pockels cell, we separated a single pulse with a duration of ~ 8 ps and an energy of ~ 5 μJ. The spectral width of the pulse was ~ 0.3 nm with the central wavelength $\lambda_0 = 1079.5$ nm. The beams incident on the gratings and reflected from them were optically isolated by Glan prisms and $\lambda/4$ plates. The front (blue) part of the CVBG compressor was mounted on a table (Newport, Model 850A) driven by a step electric motor with an accuracy of ~ 16 nm. The CVBGs for the stretcher and compressor were developed and produced by Optigrate (US) [12]. The temporal profiles of output laser pulses were recorded by a streak camera (SC) operating in the linear scanning regime with the maximum rate 6.5 ps mm^{-1} and the maximum time resolution 0.7 ps [8]. The images on the exit screen of the streak camera were analysed with a C8484-05G (Hamamatsu, Japan) CCD camera. Figure 4 shows an image of the initial laser pulse and its microphotogram.

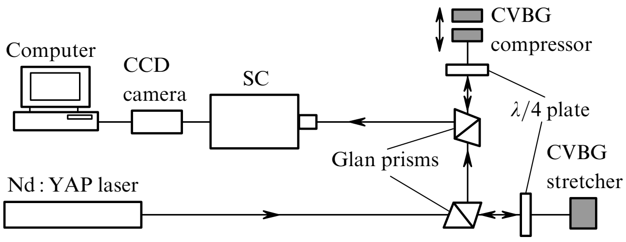

Figure 3. Optical scheme of the experimental setup.

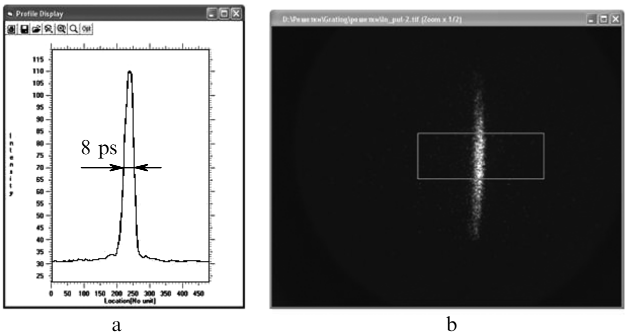

Figure 4. Microphotogram (a) and image (b) of the initial single laser pulse.

The microphotograms of the temporal profiles recorded by the streak camera for laser pulses reflected from the CVBG compressor at different ΔL are shown in Fig. 5. The temporal shapes of these pulses [quasi-rectangular with a flat top (Fig. 5a), two-peak (Fig. 5c), and intermediate (Figs 5b, d)] qualitatively agree with the computer simulation results (Fig. 2). Note that the high-frequency

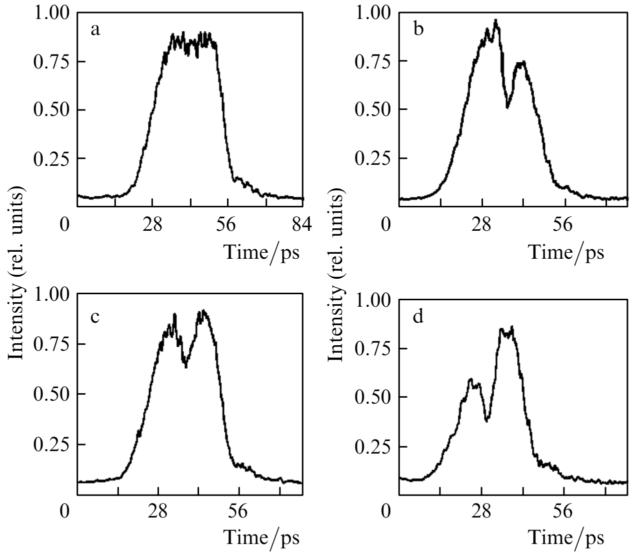

Figure 5. Microphotograms of the temporal profiles of laser pulses reflected from the CVBG compressor recorded by the streak camera at different ΔL.

fluctuations of the signal are caused by the SC noise rather than by the modulation of laser pulses.

4. Conclusions

As a result of computer simulation and experiments, we demonstrated a CPI method of shaping of picosecond laser pulses reflected from CVBGs. A laser pulse of a quasi-rectangular shape with a flat top is experimentally obtained. Our computer simulation and experimental results showed that the reproducibility of recorded temporal profiles of laser pulses considerably depends on arbitrary (uncontrolled) variations in ΔL. These variations can be caused by mechanical vibrations, temperature fluctuations, etc., which, in principle, can be prevented by conventional methods.

Thus, the results of the pilot experiments confirm the idea of the proposed CPI method of temporal shaping of ultrashort laser pulses and prove that this method is promising for obtaining pulses with different temporal shapes. Although this method was demonstrated for picosecond pulses, there are no fundamental limitations on its application for femtosecond pulses.

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