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SIMPLE ULTRASHORT LIGHT PULSE CHIRP MEASUREMENT DEVICE *

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A simple device, Frequency Tracer (FT), for simultaneous measurement of ultrashort light pulse duration and chirp is presented. FT operation is based on the two-dimensional image analysis (time versus frequency) of the non-colinear second-harmonic autocorrelator beam, and FT enables one to evaluate the temporal phase variation over the femtosecond pulse duration. The spectral information of a fs pulse in FT originates from the angular divergence of a second-harmonic signal beam, and there is no need to use the spectral apparatus. Femtosecond pulses duration and chirp measurements of the Ti:sapphire laser system multi-pass amplifier (MPA) during adjustment of the compressor pair of gratings were made.

Keywords: ultrafast pulses, ultrafast measurements, nonlinear optics, temporal phase, optical device, correlators

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1. Introduction

Ultrashort light pulse characterization, which in general includes determination of the temporal dependence of the instantaneous frequency (chirp) or, equivalently, spectral phase, is a difficult and complicated task [1–13]. Our previous theoretical analysis has shown that the well-known nonlinear autocorrelator based on non-colinear second-harmonic generation (SHG) [13], in addition to pulse duration measurements, can provide measurements of the chirp of a fs pulse [2, 4, 13]. The SHG autocorrelation method has been verified experimentally with femtosecond pulses produced by the Ti:sapphire laser system based on the Colliding Pulse Amplification (CPA) scheme [7].

2. Theory

In this work we present a Frequency Tracer (FT) as a simple device for the ultrashort pulse duration and temporal phase measurement (Fig. 1(a, b)). The FT can work in two regimes: autocorrelator (AC) mode and FT mode. In AC mode the initial fs pulse light beam has to be divided into two beams, and the pulses in these beams are directed to the second-harmonic crystal to produce the second harmonic beam by the mechanism of sum-frequency generation. The width of the second-harmonic beam Δx is proportional to the pulse duration τ, provided the beam diameter d is large enough [2]:

$$d > \Delta x = \frac{c\tau}{2\sin(\varphi/2)}A\,, \qquad (1)$$

where c is the speed of light, φ is the angle between two beams of the initial pulse. The dimensionless factor A takes into account the increase of the autocorrelation function as compared to the initial function.

In FT mode the Frequency Tracer is designed to analyze the wavefront curvature of the second-harmonic beam which is proportional to the fs pulse chirp. To resolve the wavefront curvature of the second-harmonic beam the slit-diaphragm D and cylindrical lens CL are used (Fig. 1(a)). In the horizontal plane of setup the spherical lens SL displays the divergence of the second-harmonic beam in the charge coupled device (CCD) horizontal registration area, while in the vertical plane cylindrical and spherical lenses CL and SL project the autocorrelation function to the CCD. This means that the second-harmonic beam produced in the autocorrelator is converted by the optical setup into a two-dimensional image where the vertical coordinate y stands for time t and the horizontal one x –

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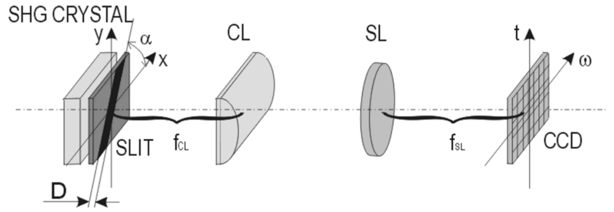
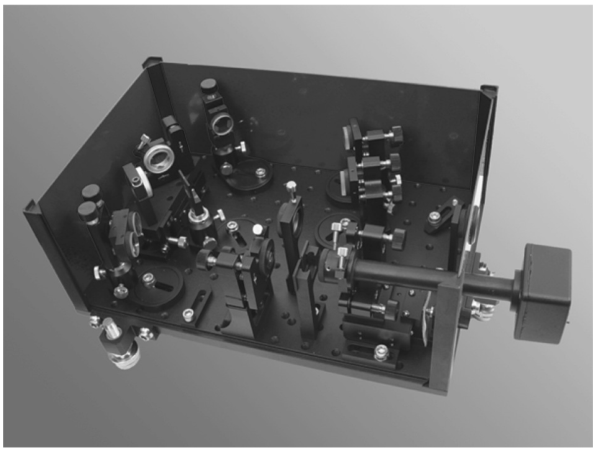


(a)



(b)

Fig. 1. (a) Design of optical setup of FT. SHG crystal is second harmonic generation crystal, D is slit-diaphragm, CL is cylindrical lens, SL is spherical lens, f_{CL} is focal length of cylindrical lens, f_{SL} is focal length of spherical lens, CCD is charge coupled device, α is the angle of slit-diaphragm orientation. (b) Photo of FT device.

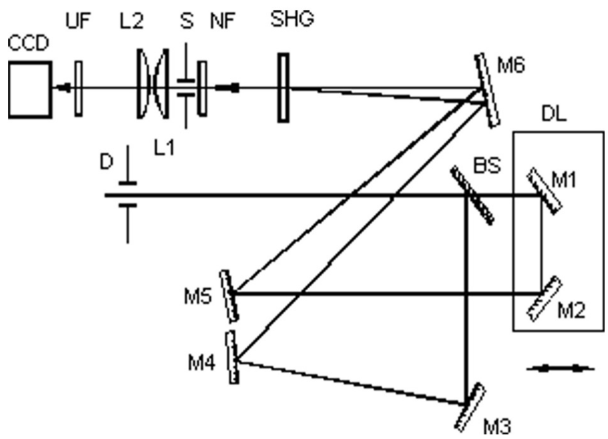
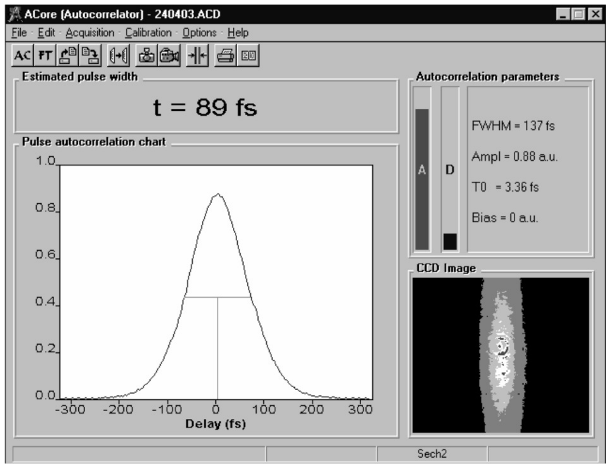
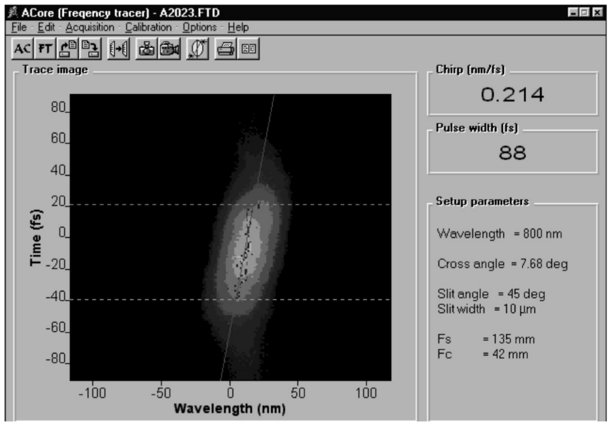


Fig. 2. Experimental setup of FT.



(a)



(b)

Fig. 3. (a) AC mode measurements of Ti:sapphire laser system fs pulse FWHM. (b) FT mode measurements of Ti:sapphire laser system fs light pulse instantaneous frequency (chirp) temporal dependence.

for instantaneous frequency Ω. The following relations give the scales [4]:

$$t = \frac{y f_{\mathrm{CL}}}{c f_{\mathrm{SL}}} \frac{\sin(\varphi/2)}{\tan\alpha}\,, \quad \Omega = \frac{x\omega_0}{f_{\mathrm{SL}}} \frac{1}{\sin(\varphi/2)}\,, \qquad (2)$$

where α is the angle of slit-diaphragm orientation, ω_0 is the central frequency of a fs pulse, f_{CL} is the focal length of cylindrical lens, f_{SL} is the focal length of spherical lens.

3. Experiment

The FT device was used to characterize the fs pulses produced by a Ti:sapphire laser system multi-pass amplifier (MPA). The FT input pulse has $P = 120$ mW, is as short as 40 fs, with the 1.66 kHz repetition rate of the 8-pass amplifier compressor (pair of gratings, 800 lines/mm) at 800 nm. The pulse to be measured is directed to the beam splitter BS (50/50%) through the input diaphragm D (Fig. 2). The transmitted part of a pulse is delayed in the delay line DL using mirrors M1 and M2 and then directed to the second-harmonic generation crystal SHG by mirrors M5 and M6. The second part of a pulse (reflected from the beam splitter) is directed to the second-harmonic crystal by mirrors M3, M4, and M6. Two different crystals phase-matched for the non-colinear SHG were used in the experiment: 1 mm thick BBO and 300 μm KDP. The second-harmonic beam passes neutral filters NF,

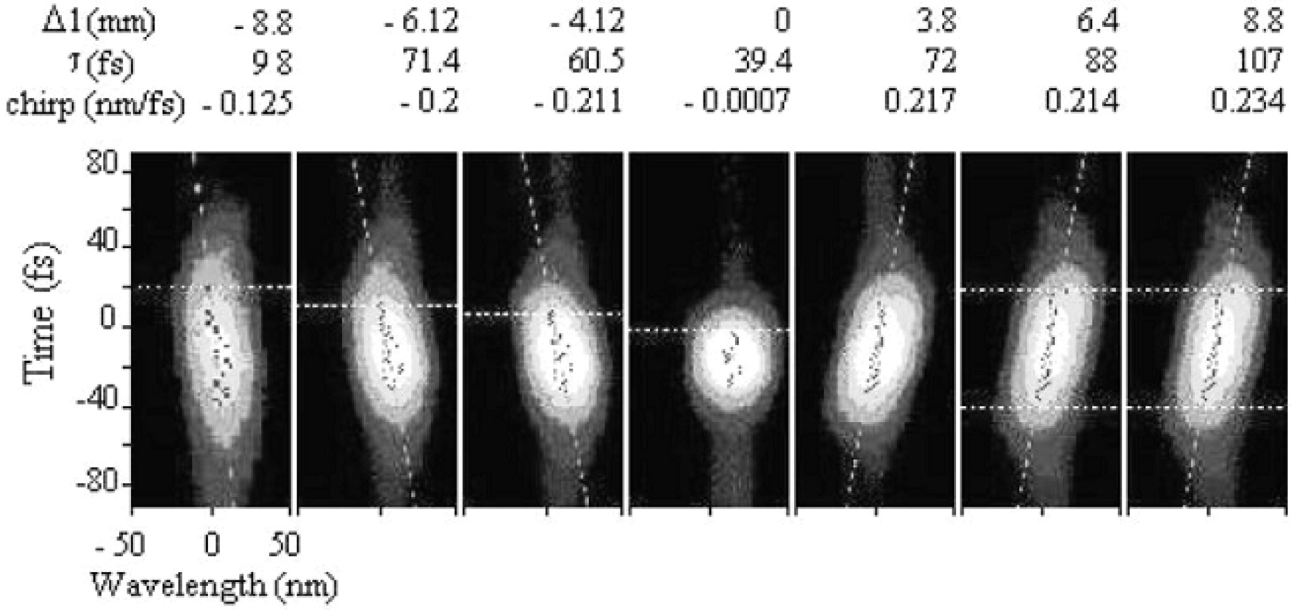


Fig. 4. FT mode visual images at the output of the multipass amplifier.

slit-diaphragm S (orientation angle $\alpha = 45°$, width 70 μm) and is projected to the CCD plane by cylindrical ($f_{\rm CL} = 40$ mm) and spherical ($f_{\rm SL} = 132$ mm) lenses; CCD sensitive elements are covered with a UV filter to cut initial pulses. The frequency versus time images were registered with the CCD (EDC–1000, 192×164 pixel, ELECTRIM Corp.) and transferred by a special interface board to the computer. The data acquired by the computer were processed by the original ACORE program (Avesta Project Ltd), which displays the pulse duration measurement using FWHW autocorrelation function (AC mode) or chirp versus time (FT mode) images on the computer display (Fig. 3(a, b)). Thus, observing the FT image one can estimate the pulse duration, chirp (and its sign), and temporal dependence of instantaneous frequency. This image reproduced by the CCD camera looks like a ridge and has simple intuitive meaning (Fig. 4): the maximum brightness at fixed time indicates the instantaneous frequency Ω of a pulse. The measurements have shown that the chirp and pulse duration reaches the minimal values at 0 mm adjustment point of the multi-pass amplifier compressor pair of gratings. The FT device does not require complicated mathematical calculation to estimate pulse characteristics. Nevertheless, accurate data on the chirp and pulse duration can easily be extracted from the image by using scaling formulas and well-known relation between the autocorrelation width and the pulse duration. In our work [7] the values of the linear chirp have been extracted from these images plotted against grating separation, and for each image the autocorrelator function has been calculated as an integral of the image intensity over the "frequency" coordinate.

4. Conclusions

The optical device, Frequency Tracer, which visualizes and quantifies the chirp of a single femtosecond light pulse is designed and manufactured. FT can work in single-shot and multi-pulse regimes. FT directly visualizes the chirp and its sign over the fs pulse duration as the two-dimensional image without any retrieval mathematical algorithm for creating the additional theoretical retrieved image. The main advantages of the FT are: simplicity of optical layout – no spectrometer, small amount of optical elements, operation in real time, direct mathematical calculation of measured results. As experiments have shown, FT is a robust and easy to use tool for adjustment of fs lasers and amplifiers. FT measures unambiguously, which allows determining the direction of time axis. The Ti:sapphire MPA laser system fs pulses have been experimentally characterized using the FT.

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PAPRASTAS ULTRATRUMPŲJŲ ŠVIESOS IMPULSŲ TRUKMĖS IR FAZINIŲ CHARAKTERISTIKŲ MATAVIMO ĮRENGINYS

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Santrauka

Pasiūlytas ir eksperimentiškai išbandytas ultratrumpųjų šviesos impulsų trukmės ir fazinių charakteristikų matavimo būdas ir įrenginys, pagrįstas nekolinearios antros harmonikos spinduliuotės generavimu. Siūlomas būdas ir įrenginys pasižymi paprastumu: fazinių charakteristikų registravimui nereikalingas spektrinis prietaisas ir laikinės fazės iškraipymai šviesos impulso trukmėje yra tiesiogiai nustatomi iš vieno lazerio spinduliuotės blyksnio, nenaudojant sudėtingo matematinio apdorojimo. Matavimų metu laikinės fazės iškraipymai yra tiesiogiai susieti su laikine koordinate (nėra matavimų neapibrėžtumo), kas leidžia nustatyti laiko ašies kryptį impulso atžvilgiu.