CWA45 **1:00 pm**

THG-based Third Order Autocorrelation for Direct Optical Pulse-shape Measurement on Mode-locked Ti:sapphire Lasers

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The temporal intensity of ultrashort optical pulses vary so fast that electronic devices (streak camera etc.) are too slow to measure the evolution. Therefore, many techniques were developed trying to characterize the temporal pulse shape. Most of them extract the temporal intensity either by assuming an analytic pulse shape (autocorrelation) or with the help of spectral measurements (including FROG[1] and SPIDER.[2]) However, in the later 1960, it was shown that without spectral measurement and pulse-shape assumption a triple-correlation is sufficient to determine the temporal intensity of a laser pulse with a direct mathematical calculation.[3] Direct third-harmonic-generation (THG) implementation of this proposal was first realized on a mode-locked Cr:forsterite laser with the method of Third Order Autocorrelation for Direct optical pulse-shape measurement (TOAD).[4] In this report, we went further to demonstrate this technique on commonly used Ti:sapphire mode-locked laser for the first time. By using THG process in a single GaN thin film or a thin BBO crystal, the intensity profile of the optical pulses was directly obtained with the background free third-order autocorrelation trace. In addition, we employed Gerchberg-Saxton algorithm to retrieve the corresponding phase by the obtained intensity and an additional spectral measurement. Complete information can then be obtained with improved O(n) complexity than O(n^2) in.[1] Its correctness was also investigated and will be presented in the conference.

An optical pulse with intensity I(t) can be expanded in frequency domain ν as

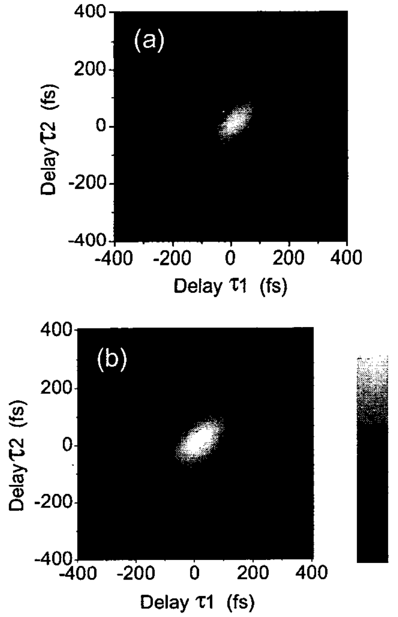
$$I(t) = \int \tilde{I}(\nu)\exp(-i2\pi\nu t)d\nu$$
$$= \int \left|\tilde{I}(\nu)\right| \exp(i\alpha(\nu) - i2\pi\nu t)\, d\nu \qquad (1)$$

where $|\tilde{I}(\nu)|$ and α(ν) are magnitude and phase of the optical pulse intensity I(t) in the spectral domain. After beam splitting, three mutual parallel and equal distance laser pulses were focused on the THG crystal. The THG crystal we employed was a GaN thin film, which was thin enough for phase-matching condition. Then the THG signal with three fundamental frequency photon contributed from three individual pulses was spatially selected with an iris according to momentum conservation law. By varying the time delay between pulses, τ_1 and τ_2, and recording the selected THG signals with the detector, the background-free TOAD trace

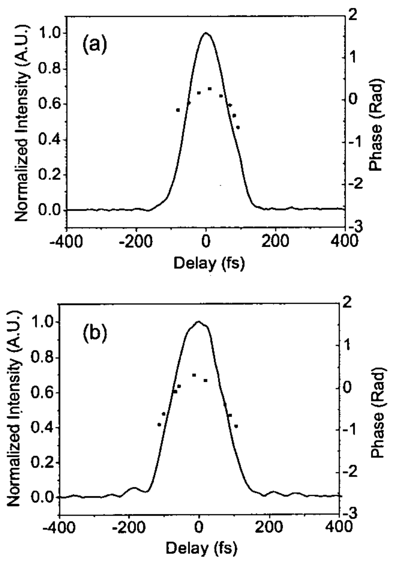
$$G^3(\tau_1, \tau_2) = \int I(t)I(t+\tau_1)I(t+\tau_2)dt \qquad (2)$$

was directly measured. Then we can use its bispectrum $\tilde{G}^3$ (ν_1, ν_2), the Fourier transform of triple correlation function, to analytically calculate $|\tilde{I}(\nu)|$ and α(ν,[3] and thus determine the I(t) using equation (1).

Figure 1(a) shows an example TOAD trace of femtosecond pulses from a mode-locked Ti:sapphire laser operating around 780 nm. Corresponding temporal intensity were calculated and it shows 130-fs pulse-width (See Fig. 2(a)(solid curve)). By Gerchberg-Saxton algorithm with the recovered pulse shape and an additional spectrum, the phase was retrieved (See Fig. 2(a) (dotted curve)) with 872-fs^2 dispersion. After placing 2-cm dispersive BK7 window halfway, the obtained TOAD (Fig. 1(b)) resulted in wider 162-fs pulse-width and larger 1800-fs^2 dispersion (See Fig. 2(b)). The increasing amount of dispersion agrees well with the expected 930-fs^2 for a 2-cm thick BK7 window at the wavelength of 780 nm. More detailed dispersion study and efficient THG generation on Ti:sapphire wavelength will be presented. We will also compare our technique with FROG and SPIDER.



CWA45 **Fig. 1.** TOAD traces of optical pulses from a mode-locked Ti:sapphire laser. (a) Without a BK7 window. (b) With a BK7 window.



CWA45 **Fig. 2.** Recovered temporal intensity (solid curves) and phase (dotted curves) profiles corresponding to the TOAD traces in Fig. 2.

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4. T.-M. Liu *et al.*, "Direct Temporal Intensity Measurement of Ultrashort Optical Pulses Using Third-Harmonic-Generation based Triple Correlation," in OSA *Trends in Optics and Photonics (TOPS) Vol. 56, Conference on Lasers and Electro-Optical (CLEO 2001)*, Technical Digest, Postconference Edition (Optical Society of America, Washington, D.C., 2001), pp. 74–75.
5. R.W. Gerchberg and W.O. Saxton, "Phase determination from image and diffraction plane pictures in the electron microscope," *Optik* 34, 275–284 (1971).

CWA46 **1:00 pm**

Linear Measurement of Space-time Coupling in Ultrashort Optical Pulses and Definition of a Degree of Spatio-temporal Uniformity

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1. Introduction

It is now routine to characterize the spatial or temporal electric field of light. The characterization of the field as a function of both variables was only recently demonstrated, [1–2], despite numerous applications since space-time coupling, a situation where the pulse shape is spatially dependent, is inherent to ultrafast optics. In general it is necessary to have both a short-duration temporal gate and spatially-resolved detection to undertake such characterization. For ultrashort pulses, non-stationary filters are most often synthesized using non-linear optics,[3] which limits the sensitivity. We demonstrate that space-time coupling can be characterized completely using very sensitive liner, time-stationary optics, without requiring complete characterization of the pulse. We also define and calculate a degree of spatio-temporal uniformity to quantify space-time coupling.

2. Space-time coupling and its linear measurement

In the absence of space-time coupling, the fields $E(x_1, \omega) = \sqrt{I(x_1, \omega)}\exp(i\varphi(x_1, \omega))$ and $E(x_2, \omega)$